EXPLORING PRIORITISATION EFFECTS ACROSS DIFFERENT FORMS OF BINDING AND MOTIVATIONAL TASK CONTEXTS IN WORKING MEMORY

Hatice Cinar

Submitted in accordance with the requirements for the degree of

Doctor of Philosophy

University of Leeds

School of Psychology

July 2024

INTELLECTUAL PROPERTY AND COPYRIGHT

I confirm that the work submitted is my own and that appropriate credit has been given where reference has been made to the work of others.

Only material produced by Hatice Cinar has been used in this thesis.

This copy has been supplied on the understanding that it is copyright material and that no quotation from the thesis may be published without proper acknowledgement.

The right of Hatice Cinar to be identified as Author of this work has been asserted by her in accordance with the Copyright, Designs and Patents Act 1988.

c) 2024 University of Leeds and Hatice Cinar.

ACKNOWLEDGEMENTS

Firstly, I would like to express my deepest gratitude to my supervisors, Richard Allen, Amanda Waterman, and Amy Atkinson. Thanks to Richard for providing support and guidance throughout this project and patiently answering all my questions. Amanda, thank you for your guidance in managing the process. Thanks to Amy for encouraging me and for all the brilliant ideas and suggestions. Thank you all for believing in me, I could not have imagined better supervisors.

I also extend my sincere thanks to the Republic of Turkey for funding my PhD and supporting my education in the UK.

To PhD friends Santi, Soumya, Max, George and Amy P. - thank you for making this journey beautiful, welcoming me, and helping me adapt to this country. Your encouragement and support have made me feel at home.

I would also like to thank my lab friends Amy M., Harry, Asiyah and Aeshah for supporting each other and enjoying the conferences together and all the good times we shared.

Finally, my biggest thanks goes to my parents, thank you always encouraging me in my pursuit, believing me and always being there to support me. I also want to big thanks to my non-PhD friends, Elif, Busra Y., Cansel, Tugrul and Busra O. thank you for always being there for me whenever I needed.

ABSTRACT

In the limited capacity system of working memory (WM), attention can be directed to specific items for prioritisation, based on allocated 'value'. This thesis investigated how allocated value affects memory performance in WM. Chapter 2 explored prioritisation effects in unitised (coloured shapes) and spatially separated (shape and colour as spatially proximate but separate stimuli) binding in online and lab-based experiments. Three online and one in-person experiments demonstrated that the prioritisation effect could be observed in unitised and spatially separated binding under at least controlled lab setting conditions. Additionally, there was better overall performance in unitised than spatially separated binding. Following that, Chapter 3 explored the prioritisation effect in unitised and cross-modal (shapes presented visually in synchrony with auditory colour names) binding in a lab-based study. A priority boost was observed in the higher-value items in unitised and cross-modal binding, and there were no differences in overall memory performance between binding types. As the online studies in Chapter 2 suggested that allocating attention could be challenging in the online experimental paradigm, Chapters 4 and 5 further explored the priority effect in the online experiments. In Chapter 4, monetary rewards were provided to participants in line with their performance, with a higher monetary reward for the high-value items. However, there was no clear sign of prioritisation. Consequently, to increase motivation in Chapter 5, prioritised items were tested in each trial by testing all items in the sequence. Results showed a clear priority boost. Taken together, this thesis demonstrated that prioritisation effects in WM were evident and equivalent across different binding types in lab

settings, whereas this effect was less clear in online experimental settings. However, it can be argued that in the online experimental context, participants can be motivated to show a clear effect by increasing the testing frequency of prioritised items.

TABLE OF CONTENT

LIST OF FIGURES

ABBREVIATIONS

ANOVA	Analysis of variance
BF	Bayes Factor
cm	Centimetres
d	Cohen’s d
FoA	Focus of attention
LTM	Long-term memory
M	Mean
ms	Milliseconds
SE	Standard error
SP	Serial Position
STM	Short-term memory
VWM	Visual working memory
WM	Working memory
η_p^2	Partial eta squared
η_G^2	Generalised eta square

CHAPTER 1

GENERAL INTRODUCTION

Working memory (WM) is a mechanism with a limited capacity for temporarily storing and processing information in support of cognition and action (Baddeley et al., 2021). WM is critical with regard to broader cognitive abilities such as reading and mathematics (Gathercole et al., 2006), expressive vocabulary and arithmetical reasoning (Henry & MacLean, 2003), comprehension ability (Marshall & Nation, 2003) and future academic success (Gathercole et al., 2003). WM storage capacity is critical since cognitive activities can only be achieved if the ability to retain information is sufficient. WM is assumed to have a limited capacity of around three to five meaningful items in young adults (Cowan, 2001; 2010).

The structure of working memory is evident at the age of six and possibly earlier and functional capacity grows from an early age through adolescence (Gathercole et al., 2004). However, the capacity is reduced in older adults (Naveh-Benjamin et al., 2007) as well as people who have been diagnosed with various neurological and developmental disorders (Martinussen et al., 2005; Chai et al., 2018).

Working memory plays a substantial role in the successful performance of a wide range of cognitive tasks, but its capacity can fluctuate depending on task demands. As various working memory tasks can create different levels of load, this can impact the amount of resources remaining in working memory.

Therefore, an investigation into potential enhancements to WM has been initiated. This thesis will investigate a method that involves encouraging people to prioritise information that is especially important or valuable for their goals. If participants can successfully direct their attention to specific information or objects, such findings can also be used to generate real-life strategies and procedures that might be designed to motivate people to direct their attention to enhancing the efficiency of working memory.

In this general introduction, the review of the historical background of WM will be followed by an examination of the most notable theoretical models of WM in conjunction with domain-specific (Baddeley & Hitch, 1974) and domain-general approaches (Cowan, 1999; Oberauer, 2002). Subsequently, the link between WM and attention will be addressed by investigating whether individuals can allocate their attention to goal-relevant or valuable information in WM. Following that, it will be examined whether this ability is influenced by different binding types (unitised, spatially separated and cross-modal binding) and under different motivation conditions. Lastly, the objectives and structure of this thesis will be explained.

1.1 History of Working Memory

The concept of WM was initially referenced in the writings of philosopher John Locke (1690). In this writing, Locke clearly distinguished between temporary and permanent storage (Logie, 1996). Later, in 1890, William James introduced a temporary, primary memory, which he defined as "the trailing edge of consciousness" and a more long-lasting secondary memory. Then, Waugh and Norman (1965) specified the characteristic of primary memory as a system that can hold information temporarily, and this information can be removed by new materials if it is not rehearsed verbally. With rehearsal, it can be moved to secondary memory.

To propose the separation between short-term memory (STM) and long-term memory (LTM), the case of HM was influential (Scoville & Milner, 1957). HM had a bilateral hippocampal surgery. Following the surgery, he became severely amnestic, yet with normal performance on STM tasks. This case is one of the most influential examples that reveal an apparent dissociation between STM and LTM. Moreover, further studies showed that patients who have impairment in the left temporoparietal cortex with intact hippocampus reported normal performance on LTM but impaired STM (Baddeley, 2010), which supports revealing the distinction between STM and LTM. Therefore, along with the theoretical characterisation, notable neuropsychological discoveries support the distinction between STM and LTM.

Furthermore, Broadbent (1958) proposed short-term storage as a limited-capacity system that directs attention and controls sensory input and longer-term memory (Logie & Cowan, 2015). Atkinson and Shiffrin (1968) built upon these concepts by introducing the multi-store model of memory. Atkinson and Shiffrin (1968) developed Broadbent's proposal and described control processes consisting of encoding, rehearsing, manipulating and retrieving and temporarily holding information. The proposed components of STM are a sensory store, a short-term store, and a long-term store. Within this system, information is first received by the sensory store and subsequently transferred to the short-term storage. This functions as an interface by interacting with the long-term component and is responsible for strategically managing and retrieving memory information.

This model is known as "the Modal Model", and it was highly influential; however, there were some shortcomings in this model. For example, Atkinson and Shiffrin (1968) framed STM as holding and manipulating information and transferring it into a more permanent LTM. Learning requires holding information in STM, and the longer information is held in STM, the more likely it is to transform into LTM. This conceptualisation assumes that information needs to go through STM in order to hold in LTM. However, Shallice and Warrington (1970) revealed that neuropsychological patients with an impaired STM should have shown LTM deficit, but they did not. These shortcomings motivated the work of Baddeley and Hitch (1974).

In order to provide a more elaborate understanding of short-term storage, Baddeley and Hitch (1974) proposed a WM structure and this represents the initial version of the multicomponent model of WM, where the main principle was a system with a limited-capacity that could adaptively store and manipulate information according to the requirements of the task. The first version of the concept (Baddeley & Hitch, 1974) emerged from a series of experiments. While participants needed to retain a series of digits, they also conducted verbal reasoning, LTM-free recall and comprehension tasks. The assumption was that retaining digits would load on an STM system, which would affect participants' performance in the cognitive tasks if those tasks relied on identical resources (Baddeley & Hitch, 1974). Response times in the verbal reasoning test considerably increased on the condition that participants were instructed to simultaneously memorise six-digit sequences. This led to the conclusion that information processing and short-term storage are handled by a single system, and there is a trade-off between the two.

The theoretical framework of the model was further expanded in the following years, and the initially proposed version of the model was a three-component form of the multicomponent model (Baddeley,1986; see Figure 1. A). The primary component of this model was a central executive, which is a system responsible for controlling attention the processing and formation of information transferred from subsystems, identified as the phonological loop and visuospatial sketchpad. The phonological loop is responsible for holding verbal information. The visuospatial sketchpad serves as a retaining mechanism for visuospatial data.

The visuospatial sketchpad was also suggested to be divided into subsystems by Logie (1995); these two subsystems include an inner scribe that maintains spatial representations and a visual cache that is in charge of retaining visual information (Logie, 1995; 2011).

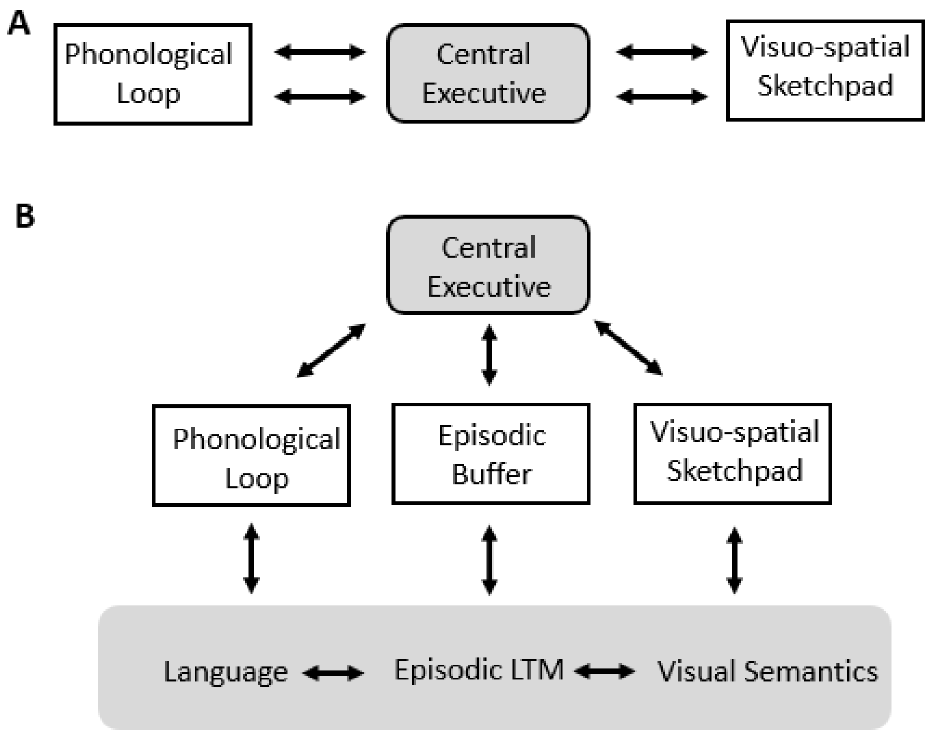

Figure 1.1 A) The three-component version of the multicomponent model (Baddeley, 1986). B) The four-component version of the multicomponent working memory model (Baddeley, 2000). Figure adapted from "Working memory: Theories, models, and controversies" by A. D. Baddeley, 2012, Annual Review of Psychology, 63, 1-29. Copyright 2012 by Annual Reviews.

However, it subsequently emerged that this model is not in itself sufficient to explain the way different kinds of information are bound or integrated into the same representations (Allen et al., 2006). To overcome this shortcoming, Baddeley (2000) suggested the episodic buffer, which is the fourth component of WM (see Figure 1. B). The episodic buffer is a limited-capacity, temporary storage system which serves as an interface between different subsystems to bind various basic forms of memory information (Baddeley et al., 2010). It is thought to be episodic since it can store episodes, which are integrated chunks of data (Baddeley et al., 2010). The multicomponent model is thought to serve as a crucial link between a variety of cognitive processing systems, including perception and episodic and semantic LTM (Baddeley et al., 2021). Furthermore, Logie (2011) summarised the core claims of the multicomponent model, which is that on-line cognition consists of the combined limited capabilities of a variety of specialised systems functioning cooperatively to answer task demands rather than just capacity-limited attention.

Another notable WM framework is Cowan's embedded processes model (Cowan, 1999). The substantial distinctness from the multicomponent model is that Cowan's embedded processes model proposes that WM is described more competently as a domain-general structure as opposed to a combination of distinct parts (Cowan, 1999; Oberauer, 2002). According to Cowan, WM is a combination of embedded processes from both attention and LTM (Cowan, 1999). The model suggests that WM is comprised of the activated part of LTM. According to this view, the information in WM is part of a hierarchical structure; the broadest component is LTM, followed by the currently activated subset of LTM, and the narrowest component is activated memory in the FoA. The focus of attention (FoA) can store a limited amount of information in a more integrated form (Cowan, 1999). The model suggests different components have different limitations. While the FoA is capacity-limited, activation in LTM is time-limited. Information can reach the systems via two different paths. Firstly, the central executive manages voluntary processes and directs attention toward specific objects to hold these objects in the FoA (Cowan, 1999; 2016).

Secondly, information may also automatically enter the FoA via involuntary processes through the attentional orienting system. This involuntary information can enter the system owing to environmental change (e.g. a bright light) or alterations to the physical characteristics of surrounding stimuli (Cowan, 1999).

Another influential WM approach is Oberauer's three-embedded-components model (Oberauer, 2002; 2013), which bears some similarity to Cowan's embedded processes framework. Oberauer's approach defines WM in three stages; "activated long-term memory, a capacity-limited region of direct access, and a focus of attention" (Oberauer, 2002, p. 411). According to the model, information that could be related to the present task is held available by the activated LTM. For example, during an arithmetic calculation activity, activated LTM might retain digits and mathematical operators that are available.

The region of direct access contains some of the representations in activated LTM and is responsible for holding and binding this information into new structures. This region also approximately corresponds to Cowan's focus of attention. However, as a novel approach, Oberauer suggests that this region of direct access has a limited capacity to keep and bind around four items (Oberauer & Hein, 2012). Additionally, Oberauer (2013) argues that capacity limits emerge as a result of interference between temporary bindings.

The third component is FoA, which is responsible for selecting one chunk as the target of the next cognitive process, being the FoA at any particular time from the region of direct access (Oberauer, 2002). The FoA is not limited to a single object by a capacity limit. Usually, the FoA restricts itself to one item or chunk because more would interfere with its function (Oberauer, 2013).

Another novel approach Oberauer suggests is distinguishing between declarative and procedural WM. Representations must be made available for processing by the declarative part, while processing is the responsibility of the procedural part. In a manner, the declarative system is the memory part, while the procedural system is the operative part of working memory (Oberauer, 2009). The defined three stages belong to declarative working memory. The procedural working memory represents procedures. Procedures can be cognitive or motor actions linked to conditions in which they can be used and expected outcomes. Procedures form the LTM networks and connect them sequentially and hierarchically to action plans (Oberauer, 2009).

There are further WM theories, one of them being the time-based resource-sharing model (Barrouillet et al., 2004). According to this model, processing and storage compete for attention, and both of them constitute limited resources. Because of this limited resource, attention alternates between processing and maintenance, therefore leading to a trade-off between these two activities. Additionally, this alteration is time-constrained due to the time-related decay of memory traces (Barrouillet et al., 2004). When processing time increases, recall performance decreases (Portrat et al., 2009).

In conclusion, throughout this section, the prevailing theoretical perspectives on WM were presented as an overview in conjunction with domain-specific (Baddeley, 2000; Baddeley & Hitch, 1974) and domain-general frameworks (Cowan, 1999; Oberauer, 2002). Although these different WM approaches may have varying viewpoints, there is also research that demonstrates commonalities among theories. For example, Gray et al. (2017) established a study with school-age children to identify which WM model – Cowan (2001) or Baddeley (2000) - better explained their findings, which suggested that both models fit their findings and came together on shared ground. This demonstrates that despite the definitions being distinct across different models of WM, they can be comparable to explain findings.

Despite the presence of commonalities, since this thesis mainly aimed to discover the underlying structure of processing the information from various domains in WM, Baddeley's Multicomponent Model of WM framework might provide a more pertinent approach to reveal the connections across different domains in WM. Additionally, while the theoretical perspective varies across different approaches, the crucial role of attention on WM is widely established. Therefore, as WM is closely related to attention, the subsequent section will examine the term of attention and its association with WM.

1.2 Working Memory and Attention

Attention can be described as the cognitive process by which certain information is selected or processed while disregarding others (Pashler, 1994). One taxonomy is defined by Posner and Petersen (1990) in which there are three attention networks that are responsible for different roles: alerting, orienting, and executive attention. The alerting network is responsible for regulating the overall level of responsiveness to sensory stimuli. The orienting network is responsible for the selection of a certain subset of sensory input that is given priority for processing. The executive attention network is responsible for processing post-sensory representations and is essential in situations when there is competition for access to a central, limited-capacity system (Fan et al., 2002).

It has been the subject of discussion when attentional selection occurs during the processing stage. Empirical data suggests that attention has an impact on early perceptual processing (Mangun & Hillyard, 1991), while others suggest later processing stages (Osman & Moore, 1993). The existence of strong endorsement for both early and late selection theories has prompted the suggestion that there might be many types of attentional selection (Fougnie, 2008).

Investigations have suggested the existence of distinct attentional systems by differentiating between perceptual and central attention (Johnston et al., 1995; Luck & Vecera, 2002; Vogel et al., 2005). Perceptual attention is the process of selectively attending to a certain subset of sensory information. The concept of central or executive attention pertains to the representation of a central processing capability that is widely shared in post-perceptual cognition (Fougnie, 2008).

In terms of the relationship between attention and WM, Fougnie (2008) suggested that attention has an important role in the processes of encoding and manipulating information within WM while having a limited role in WM maintenance. Additionally, Fougnie suggested the possibility of substantial co-dependence between attention and WM. One source of evidence for this co-dependence between attention and WM can be identified by the contents of WM affecting whether data in the surrounding environment is attended to (Awh & Jonides, 2001), with attended data being more likely to enter WM (Vogel et al., 2005). Additionally, Baddeley et al. (2021) suggested that in attempts to understand working memory, attention is considered to have a crucial function. Indeed, it has been clearly demonstrated that there is a close link between WM and attention (Yantis, 2000).

Attention can be described as top-down (goal-directed) and bottom-up (stimulus-driven). Top-down attention corresponds to the processing of sensory data that can be influenced by current behavioural goals, while bottom-up attention refers to the process by which attention is captured by stimuli in the external environment (Yantis, 2000). Top-down control is frequently perceived as intentional and dependent on executive resources, whereas bottom-up capturing is regarded as naturally automatic (Katsuki & Constantinidis, 2014; Pinto et al., 2013; Theeuwes, 2018). Consistent with this definition, attention, as used in this thesis, will refer to resources that implement either top-down control or bottom-up capture to select information to process (Fougnie, 2008; Yantis, 2000).

Moreover, Chun et al. (2011) described a taxonomy of external and internal attention. In this taxonomy, attention is described as a non-unitary concept. Instead, attention is identified in relation to several perceptual and cognitive processes. This taxonomy clarifies a fundamental difference between external and internal attention. External attention is described as a process of regulating and selecting sensory information as it enters the consciousness. The sensory input can be systematically categorised based on its distinctive qualities or grouped together to form coherent objects, which can then serve as focal points for external attention. An alternative term for external attention can be conceptualised as perceptual attention. Internal attention is the process of selecting and regulating information that is generated internally. This includes the information stored in working memory, long-term memory, task sets, and response selection. Internal attention encompasses cognitive control and is also known as central attention (Chun et al., 2011). In this taxonomy, working memory is accepted as the interface between external and internal attention. The placement has been supported by research indicating that the maintenance of information in working memory influences attention towards similar types of information and, parallel with this, influences eye movements (Hollingworth et al., 2008).

1.3 The Focus of Attention in Working Memory

As there are a great number of studies showing that there is a limit for individuals to simultaneously perceive and recall input channels in an effective manner (Cowan, 2010; Hartshorne, 2008), Cowan (2001) indicated that it has been necessary to define a capacity-limited sub-region of functions of attention in WM, which is the FoA. The function of the FoA is believed to involve storing a limited amount of information in a highly accessible condition in order to improve the speed and accuracy of its retrieval. As previously stated in this chapter, the FoA is essential to various prominent theories of WM, such as Oberauer's embedded component theory (Oberauer, 2002; 2013) and Cowan's embedded processes model (Cowan, 1999; 2016). Although FoA is fundamental for both theories, the formalisation is distinct across different WM models.

According to Cowan (2001), the FoA can store a limited amount of information in a more integrated form with a capacity that is typically restricted to processing approximately four chunks of information. Under certain circumstances, FoA can zoom in to focus intensively on a specific objective while encountering obstacles, and maybe limit the inclusion of extraneous information to only the essential components and zoom out to extend the capacity when there is no interference (Cowan, 2005). However, Oberauer (2002) described FoA as a function which is responsible for selecting one chunk as the target of the next cognitive process, being the focus of attention at any particular time from the region of direct access.

Moreover, recently, it has been proposed that the FoA can be integrated into the episodic buffer in Baddeley's multicomponent model (Baddeley, 2000) (Hu et al., 2014). Hitch et al. (2020) and Hu et al. (2014) defined FoA as a structure incorporated within WM in which items are retained in a privileged condition where objects are easily accessed but are subject to overwriting. This definition will be used to refer to the FoA in this thesis.

Within this conceptualisation, it was suggested that the capacity of the focus of attention is two or three items (Hu et al., 2014) in parallel with

Oberauer and Hein (2012). This conceptualisation was further supported by recent studies which explore the value effect in WM also (e.g. Allen & Ueno, 2018; Berry et al., 2018; Hitch et al., 2018; Hu et al., 2014; Hu et al., 2016).

Particularly, Hu et al. (2014) proposed that in the serial presentation of items, two items can be held in the privileged state at a given time. The most recently encountered item is in the focus, and that can be broadened to include one other item. The theoretical view suggested that when memorising items presented serially, there is a constant shift in the contents of the focus of attention. This phenomenon occurs because each item momentarily benefits from automated storage in the focus but is subsequently displaced by succeeding items (Hu et al., 2014).

Hu et al. (2014) proposed that each encoded item is initially directed to the FoA, but that the following items then replace it. Consequently, this leads to a recency boost, in which the last encountered item is automatically given an advantage over the previous items (Berry et al., 2018; Hitch et al., 2018; Hu et al., 2014; 2016). Hu et al. (2016) suggest that the FoA can selectively retain beneficial or goal-relevant information (which will be further described in the next section). Strategically retaining an item in the FoA might improve memory for that information (Atkinson et al., 2018; 2019; 2021; Hitch et al., 2018; Hu et al, 2014; 2016). This procedure appears to rely on executive resources, as indicated by Hu et al. (2016). The important item is consciously held in the focus of attention and given more frequent or longer times of refreshing by reactivating the representation of the item in the FoA during the maintenance phase (Hitch et al., 2018; Hu et al., 2016; Sandry et al., 2014). The theoretical assumptions mentioned above, which explain the broad conceptualisation of the FoA, are mostly derived from the research conducted by Baddeley and colleagues (e.g. Atkinson et al., 2018; 2019; 2021; Hitch et al., 2018; Hu et al., 2014; 2016) and are parallel with Cowan (1999; 2016) 's embedded processes model which is proposed that the FoA can be reached through both automatic and purposeful pathways. Therefore, it can be concluded that the FoA can obtain information in two ways: automatically, via bottom-up capturing, or intentionally, via top-down management.

As it is possible to control attention within WM by these two methods, the following section will review the literature investigating how individuals have the ability to allocate their attention within WM.

1.4 Prioritisation

Since WM has a limited capacity system, specific methods, such as cueing and value-directed prioritisation, can be used to improve the recall of a specific item. Cueing methods are typically based on the use of spatial location to inform participants which stimuli will be tested with either the presentation of a cue before (pre-cue) or following (retro-cue) the visual array (Astle et al., 2012). Participants are provided with a visual signal that indicates which item will be tested or is very probable to be tested during retrieval. Both pre-cues and retro-cues greatly improve performance accuracy and reaction time.

These effects are illustrated in numerous tasks, including recognition, change detection and cued recall (Souza & Oberauer, 2016). All of these procedures share a basic characteristic: Participants are shown a memory array that contains visual items. Subsequently, in retro-cues, the retro cue is introduced, followed by a short pause, and then memory is assessed by the presentation of a test display. Conversely, in the pre-cue paradigm, participants are first presented with a cue, followed by a memory array and then participants are subjected to memory assessment (Vogel et al., 2005)

Prioritisation is a broad term that can be related to a wide range of methods by which participants' motivation is manipulated to direct their attention (Myers et al., 2017). Differentiating from retro-cue and other methods, in this thesis, the term "prioritisation" will refer to value-directed prioritisation (Atkinson et al., 2021; Hitch et al., 2018; Hu et al., 2016). This prioritisation method is also referred to as probe value in some previous literature (Atkinson et al., 2018; 2019). In the prioritisation method, participants are usually presented with three or four different coloured shapes in sequence. The stimuli are linked to varying amounts of 'points' that participants can earn for correctly recalling them when tested on one of the shape-colour bindings. Recalling performance for items connected with high point values is found to be better than items associated with low point values (Hu et al., 2014; 2016; Sandry & Ricker, 2020).

In the manipulation proposed by Hu et al. (2014), four coloured shapes were presented serially, and following a short pause, the test cue appeared. The test cue in this study was the specific item that was probed from the four stimuli in the study array. Participants were instructed to recall either the name of the colour or the shape. When the test cue was the shape, participants were instructed to recall the name of the colour it was paired with and when the test cue was colour, they were required to remember the shape it was paired with. It used sequential presentation to produce serial position (SP) curves, which is an advantage as these curves facilitate a detailed display of retention, which helps in differentiating the impacts of internally motivated, goal-directed control versus external stimulus-driven selection.

Participants were instructed that correct remembering of the first item was associated with four points, with one point for each subsequent item. This is identified as a primacy strategy. The converse is the recency strategy; participants were instructed that the last item would be worth four points and one point for the other items. The aim was to investigate if two strategies result in a trade-off between primacy and recency. Additionally, participants were instructed to ignore a further coloured "suffix" item that appeared after a brief interval after the study array. Two types of suffixes are described; in the implausible suffix condition, the suffix had no overlap with the proposed memory set, while in the plausible suffix condition, the suffix drew from the same memory set of items. The results indicated that there was a recency effect, which is the last item performed better than the other items in the study array, regardless of the point values assigned. Furthermore, a prioritisation effect was noticed, whereby memory at that SP was better than the others when the first or the last item was linked with more points. However, these effects come with a cost, which is that the memory performance of less valuable objects is decreased. This indicates that the worth of a given item does not result in an overall enhancement of performance; instead, it motivates individuals to allocate a greater portion of their focus towards that particular item. The additional observation from this series of experiments was that suffixes disrupted both the value and recency effect; namely, in the condition that suffixes presented, the memory of the last and higher value item was reduced even though those items were maintained in FoA as a privileged condition in WM. These findings suggest that the most recently encountered and high-value items are in a more accessible state in FoA but are also more vulnerable to perceptual interference.

Hitch et al. (2018) broadened these findings. In this study, the same design and methodology as Hu et al. (2014) was adopted. Participants were instructed to prioritise middle items (SP2 or SP3), with or without the posting of a post-sequence suffix distractor, in order to observe the suffix effect on middle items. Findings showed that the priority boost on SP1 and SP4 can generalise to middle items. The results supported the implication of the previous study: items in the FoA are accessible but vulnerable to interference. Prioritising the item at SP2 or SP3 increased its retention but simultaneously made it more susceptible to disruption caused by a suffix distractor. As a result, the traits of elevated accessibility and susceptibility to perceptual overwriting are shared by prioritised and recent items in the FoA.

The effect of prioritisation and recency boosts may arise from different underlying mechanisms in terms of attention type. Hu et al. (2016) showed that by investigating whether executive resources are required for the effects. The cued recall was utilised as used in Hu et al. (2014); following the presentation of four coloured shapes, a test cue appeared, which was randomly selected from the four stimuli in the study array, and participants were asked to recall either the colour or the shape of the stimuli. Participants were instructed to prioritise higher-value items, either the first or the last position in the sequence, rather than suffix presentation, concurrent tasks utilised by participants needed to be engaged during retaining and encoding. There were two different conditions depending on the load: high load and low load concurrent task. Low load conditions required repeating two-digit numbers. In high load conditions, participants were required to count upwards in 2s from a two-digit number. Reduced prioritisation and recency boosts in the presence of a high load would indicate that executive control is required to observe those effects. On the other hand, evidence that these boosts remain constant would imply that they are mainly automatic and cost-free. The results suggested that there was a prioritisation effect; moreover, when participants performed a demanding concurrent task, prioritisation effects at both the first and last sequence were significantly diminished, indicating that executive control plays a crucial role. In addition, the boost on the final item was identified in both concurrent task conditions. Based on the findings, it can be concluded that the underlying mechanisms vary. Specifically, recency effects happen in a relatively automatic and cost-free manner, whereas probe value boosts appear to be dependent on executive resources. However, it is important to note that both prioritisation and recency effects contribute to an increased likelihood of an item being retained in the FoA, thereby improving the performance of that item.

This was extended by Allen and Ueno (2018), who investigated whether people can also direct their attention when multiple items are presented simultaneously. In this study, four items were presented simultaneously, and participants were required to recollect a feature of one item that was investigated after a brief delay. The results indicated the same overall priority and suffix effects as observed in prior studies (Hitch et al., 2018; Hu et al., 2014; 2016); even further, the effects became clearer when multiple items were of higher value, indicating some differences between simultaneous and sequential presentation.

Moreover, as already noted in the retro-cue paradigm, the effect of cues seems to depend on their validity (testing the cued item) on the test phase (Berryhill et al., 2012; Gunseli et al., 2015). To test the validity effect in the prioritisation study, Atkinson et al. (2018) investigated the relationship between prioritisation and frequency of cued item testing at retrieval. The magnitude of prioritisation increases may also vary in accordance with the frequency of testing the higher-valued item. Similar to other probe value studies (Hitch et al., 2018; Hu et al., 2014; 2016), four items were presented sequentially and one of them was asked in the test phase. The initial SP was assessed at the same ratio as the remaining items (25% of the time) under the equal probe frequency condition. In the differential probe frequency condition, the first SP was assessed 70% of the time, whereas the other items were probed 10% of the time. The findings specified that both prioritisation and probe frequency boosts were observed, but there was no interaction between them. Therefore, the effect of prioritisation and frequency on performance were additive, suggesting they reflect independent underlying forms of attentional control.

Furthermore, studies with older adults (Allen et al., 2021) and children (Atkinson et al., 2019) showed that the prioritisation effect can be observed across different age groups. Recently, it was observed that the priority effect extended beyond visual WM. For example, Atkinson et al. (2021) showed that value-directed prioritisation could be observed in an auditory-verbal WM. Additionally, Johnson and Allen (2023) explored binding between colour-olfactory information to explore the prioritisation effect in cross-modal binding. The results revealed only a weak effect of prioritisation with a slight increase in accuracy at the prioritised SP compared to the control condition. Finally, the priority boost also has been observed in tactile memory (Roe et al., 2024).

In order to understand the value-directed prioritisation effect, it is also important to understand at what stage of attention-directing within working memory tasks this effect might emerge. In the visual retro-cue paradigm, as cues are presented following the encoding phase, this shows that WM representations require attentional direction during maintenance or retrieval (Souza et al., 2015; 2018). On the contrary, research investigating value-directed prioritisation has generally presented value information in advance of encoding (Atkinson et al., 2018; Hitch et al., 2018; Hu et al., 2014; 2016). Consequently, any effects may emerge during encoding, maintenance, or retrieval. Therefore, Allen and Atkinson (2021) investigated whether the value-directed prioritisation effect can be applied retrospectively to explore the underlying mechanism of the prioritisation effect. Findings suggested that while value-directed prioritisation can be implemented retroactively, its effectiveness is not as great as when it is implemented during encoding. One possible interpretation might be that the prioritisation effect is partially attributable to processes occurring during the encoding phase. Another possibility is that the accessibility or availability of items for retrospective prioritisation may be diminished (Allen & Atkinson, 2021).

In summary, it is observed that high-value items can be prioritised in WM, and this effect is seemingly contingent upon executive resources. Additionally, there was a relatively automatic recency effect (higher performance on the last item). This could be caused by prioritised and recent items being held in the FoA. Research to date investigated how priority effect works from various different perspectives, including different age groups (Allen et al., 2021; Atkinson et al., 2019), prospective versus retrospective (Allen & Atkinson, 2021), and visual, verbal-auditory, visual-olfactory and tactile domains (Atkinson et al., 2021; Hu et al., 2014; 2016; Johnson & Allen, 2023; Roe et al., 2024). However, the extent to which the effect of prioritisation emerges in and is affected by different task contexts still needs exploration. Therefore, in this thesis, the prioritisation effect will be investigated when items are presented in different binding conditions (unitised, spatially separated, and cross-modal binding), when experiments are conducted online, and when the motivation of participants is manipulated (monetarily and in different test paradigms). These dimensions will be briefly considered in the following sections.

1.5 Binding

Comprehending the world requires simultaneous processing of a wide variety of information and distinct characteristics; to accomplish this, these characteristics must be bound into objects. "Binding" refers to the process by which visual characteristics are combined; it has also been suggested that this process requires visual attention in the context of perception (Treisman & Gelade, 1980).

In visual working memory (VWM), binding is the process of grouping different features (such as colour and shape) of an object together and maintaining them. Several studies have investigated the mechanisms of binding in VWM. Luck and Vogel (1997) showed that objects about only four colours or orientations can be simultaneously stored in VWM; however, VWM maintains these features as integrated objects rather than isolated elements. Furthermore, Luck and Vogel (1997) demonstrated that objects that have a combination of four features, such as colour and orientation, can be preserved in WM just as effectively as single-feature objects, allowing for the retention of sixteen distinct features when spread across four objects. However, it should be noted that these findings have not been generally replicated (Delvenne & Bruyer, 2004; Wheeler & Treisman, 2002). For example, Wheeler and Treisman (2002) utilised the same paradigm to determine the consistency of the obtained results. There was a display of simple coloured shapes. Following that, a test display was presented, which was either the same as the initial display or varied by one to two features, depending on the binding of those features. When doing a whole-display test, the complete display was presented once again in the test phase. In the single probe test, a single randomly selected object was displayed during the test. Findings indicated that binding between separate dimensions requires attention; in contrast, features from distinct dimensions might be stored in parallel. Although binding can occur between these features, it needs focused attention for it to form and maintain, and this integrated format is susceptible to interference. Additionally, Wheeler and Treisman (2002) proposed a model that indicated that WM storage is limited both by simple feature capacity and by unified objects consisting of complex and distributed data, which requires attention. From the findings of Wheeler and Treisman (2002), it can be concluded that focused attention is necessary to retain integrated representations.

Moreover, Allen et al. (2006, Experiment 5) provided additional evidence of the greater susceptibility to interference of bound features. In this experiment, items (colours, shapes, or coloured shapes) were presented sequentially rather than as a simultaneous array, and retention was assessed by probing one item from the sequence. In these conditions, feature binding and individual feature memory performance were only comparable in the final item, with the retention of the binding being especially low for the early items. According to Allen et al. (2006) bound object representations are not forgotten due to a reduction in attentional support but rather are rewritten by the encoding of further feature combinations. To further investigate, Ueno et al. (2011) utilised a suffix paradigm, in which the presentation of the array was followed by the presentation of to-be ignored stimulus (plausible, semi-plausible and implausible suffixes). It was found that when suffixes were plausible and semi-plausible, they disrupted bound features of subsequent stimuli equally. From these findings, it can be concluded that initially, there is a feature-based attentional filter and all stimuli that cross this filter can effectively replace existing items in the VWM.

In consideration of how the binding function serves in a multicomponent model of WM, it is proposed that the episodic buffer serves as an interface between different subsystems to bind different basic forms of memory information as integrated chunks of data. While the capacity of chunks is limited, the amount of information it contains can be expanded through binding additional information into each chunk (Baddeley, 2000). In the first proposed definition of the episodic buffer, the binding process was thought to be intentional rather than automatic. This assumption was tested in a subsequent research series.

Firstly, Allen et al. (2006) defined a provisional distinction between two types of binding processes on the basis of attentional demand: automatic and active binding. In active binding, executive processes will be involved, while they are not critical in automatic binding. Allen et al. (2006) investigated the nature of binding within visual short-term memory utilising dual-task techniques to explore whether it relies on executive processes. If the binding condition deteriorates more than the feature condition due to increased executive load, this would imply that bindings require executive processes. The findings showed that concurrent tasks impact encoding and retention performance for both single features and bindings, but there was no difference in this impact between feature and binding conditions. Thus, although general attentional ability is required for visual WM, binding features do not require more attention than encoding them independently. Even though these results were further confirmed by Allen et al. (2012), Brown and Brockmole (2010) reported conflicting results in the study with a similar paradigm; performance in binding was specifically impacted by a demanding concurrent activity. Therefore, there was mixed evidence, albeit mostly indicating automaticity.

These results contradicted with the previous hypothesis that feature binding is an active and effortful process that occurs in a multimodal episodic buffer (Baddeley, 2000). Instead, they provide support for an explanation that suggests automatic feature binding occurs before information enters the episodic buffer, as irrelevant concurrent tasks did not disturb binding more (Baddeley et al., 2011).

Furthermore, to have a greater understanding, Baddeley et al. (2011) reviewed the hypothesis that the episodic buffer serves as an interface between different subsystems to bind information to each other and controlled by the central executive through examining how various attentionally demanding concurrent tasks affected the ability to encode and hold bound objects as well as individual aspects. There was no differential impact of the concurrent task, regardless of whether the binding process was complicated spatially, temporally, visually, or auditory by separating the shape and colour features (Allen et al., 2006; 2009; 2012; Karlsen et al., 2010). Also, results were consistent when the study sample of coloured shapes was presented both simultaneously and sequentially (Allen et al., 2014). It was concluded that the episodic buffer might not itself have a binding function in simple visual binding tasks; instead, it is a passive mechanism for integrating data from various dimensions and sources and making it available to conscious awareness (Hitch et al., 2020). Nevertheless, the complete description of this passive mechanism remains unclear.

The typical approach in research examining binding in VWM was simple unitised feature binding (Allen et al., 2006; Luck & Vogel, 1997; Morey & Bieler, 2013; Wheeler & Treisman, 2002). However, it is important to extend beyond that to different binding types in WM.

In earlier studies, the distinction between unitised and non-unitised objects has been defined and examined (Ceraso, 1985; Delvenne & Bruyer, 2006; Walker & Cuthbert, 1998; Walker & Moylan, 1994; Wilton, 1989). Generally, research has found that when features of objects are unitised into one representation, these unitised stimuli are recalled more easily than the features of non-unitised stimuli (Walker & Cuthbert, 1998; Walker & Moylan, 1994; Wilton, 1989). Numerous hypotheses have been proposed regarding the origin of this unitisation effect (Walker & Cuthbert, 1998). For example, Treisman's feature integration theory suggests that focused attention on an object helps bind its distinct features through their shared spatial location (Treisman & Gelade, 1980).

Recently, Cecchini et al. (2023) conducted a systematic review and meta-analysis on different types of binding describing that the binding of individual features in memory can be achieved through two distinct mechanisms: conjunctive and relational. Relational binding refers to the process by which stimuli are associated with memory (Mayes et al., 2007). In this form of binding, the individual elements maintain their original identity; colours and shapes are presented simultaneously but visually separated. Conjunctive memory binding, conversely, refers to having the ability to combine features of stimuli into one unitised representation like coloured shapes.

Parra et al. (2015) also utilised conjunctive and relational binding to investigate whether these two different types of binding differed in a patient affected by a stroke, which caused damage to brain areas known to be important to memory, such as the hippocampus. The results showed that there was no performance decline in STM conjunctive binding, whereas there was a significant impairment in STM performance for relational binding. Thus, it can be inferred that different parts of the brain may be responsible for different types of binding, and this emphasises the importance of investigating different binding types.

Geldorp et al. (2015) also examined different types of binding (conjunctive and relational) and whether they decrease with age in young, middle-aged, and older adults. Findings demonstrated that participants showed better performance on conjunctive binding overall, but there was no significant interaction between binding types (relational and conjunctive binding) and age. Based on these findings, it can be concluded that ageing has comparable effects on conjunctive and relational binding. However, findings also showed that compared to conjunctive binding, relational binding was more vulnerable to interruption, which implies that relational binding would need more attentional resources.

As binding is thought to be a cognitive marker of Alzheimer's disease, a meta-analysis conducted by Cecchini et al. (2023) revealed that the ability of feature binding in STM impacts a variety of stages in Alzheimer's disease. Although it is controversial whether there is a different effect between conjunctive and relational binding, impairment in feature binding is considered a cognitive marker for Alzheimer's disease. Similarly, investigations on whether the ability to bind unitised and cross-modal objects differs in healthy ageing and Alzheimer's disease patients indicate that there is no age-related difference between cross-modal (one feature present visually and other auditory) and unitised (coloured shape) binding but Alzheimer's disease patients showed impaired performance, independent of the binding types (Guazzo et al., 2020).

Moreover, Xu (2002b) aimed to explore the binding mechanism when features of items are not unitised by comparing the memory of features from different and same dimensions. Also, they aimed to indicate whether there is an object-based benefit in visual STM for encoding two distinctive features within the same dimension that belong to distinct parts of the same object. Additionally, the aim was to explore whether object-based benefits for two features from the same dimension of the same object, as found in Luck and Vogel (1997) and Vogel et al. (2001), can be replicated. However, Xu (2002b) failed to replicate those findings, and results showed that two colour features of one single object provided no object-based benefit. However, an object-based advantage was observed when identical stimuli were employed, but the two features of each object (colour and orientation) were applied from separate dimensions. This demonstrates that object-based encoding is advantageous only for features belonging to separate dimensions.

Moreover, Xu (2002a) used the change detection paradigm to explore encoding differences when features (colour and shape) are presented as a part of the same object or features from spatially separated objects. In the change detection paradigm, participants are typically tasked with determining whether the test display has changed when compared to the memory array (Rensink, 2002). Results showed that feature retention is greatly enhanced when the shape and colour characteristics to be remembered are present on the same component of an object than features from spatially separated objects. The findings of Delvenne and Bruyer (2004) were also similar: integration of features that are presented separately are not stored as well as unitised objects in visual short-term memory.

Parallel with Xu (2002a) and Delvenne and Bruyer (2004), Karlsen et al. (2010) investigated whether the effect differs when the task is required to bind objects actively. The recognition performance was tested when items (colour and shape) were separated either spatially or temporally with concurrent task manipulation. Findings showed impairment in the performance when features separated. Although there was a disrupting effect of concurrent tasks, the effect was no greater for the separated features. This also showed that even if it requires more attention to bind separated features, it does not require an executive process as it did not interact. It is conceivable that while the binding of distinct features does not heavily depend on executive attention, it also does not happen automatically via perceptual processes in the same manner as unitised binding (Karlsen et al., 2010). It can be explained that participants need to strategically bind separated features without the requirement of an executive process. However, the nature of this strategic binding needs further investigation.

To further investigate the role of attention on binding across different domains, Allen et al. (2009) investigated how concurrent tasks affect recall performance in unitised (coloured shape), spatially separated (colours and shapes presented visually separate) and cross-modal binding (one feature present visually and other auditory) conditions. In this study, participants were shown items in different modalities with concurrent tasks (repeatedly tapping with one hand, repeating four numbers and backward counting) and asked to recall if they had seen a shape-colour combination before. Although there was a slightly better memory performance in the unitised binding condition, this difference was not significant. Additionally, concurrent tasks did not have larger effect on cross-modal binding compared to unitised binding. This result was interpreted as suggesting that cross-modal binding does not require additional attention load.

To summarise, Luck and Vogel (1997) illustrated that items described by the conjunction of four characteristics can be remembered just as well as single-feature objects in WM and that binding of features would have become the topic of the feature binding in WM studies. However, their findings have not been generally replicated (Wheeler & Treisman, 2002; Delvenne & Bruyer, 2004; Xu, 2002b). Moreover, different types of binding have been defined (active and automatic; unitised, separated and cross-modal; relational and conjunctive), and a variety of research revealed that mechanisms and brain regions are likely to differ in different forms of binding (Cecchini et al., 2023; Geldorp et al., 2015; Parra et al., 2015). Nevertheless, it is still not clear how the attentional control mechanism interacts with different binding types.

As revealing the mechanisms of binding can provide vital information about WM, this thesis aimed to make a more in-depth investigation of how directing attention affects different binding types by giving high value to specific items by using the prioritisation method.

1.6 The effect of Motivation

According to Kane and Engle (2002), the role of WM is to maintain goals and direct attention to specific information or objects in accordance with the current goals of the organism. This conception of WM is relevant to strategic prioritisation; participants need to direct their attention to a specific item to increase recall performance on that specific item (Allen et al., 2021; Atkinson et al., 2018; 2019; 2021; Hitch et al., 2018; Hu et al., 2014; 2016). As prioritisation involves the manipulation of strategic attentional selection, this concept requires sufficient motivation for the participant. For instance, previous findings indicated motivation as a critical dimension when looking at the effect on children. Initially, Berry et al. (2018) observed that the 7 to 10-year-old age group was not capable of allocating their attention to high-value items with prioritisation. However, a subsequent study by Atkinson et al. (2019)

demonstrated that they were capable of prioritising effectively when provided with suitable assessments. In addition to this, monetary reward studies further showed that motivation is an outstanding factor for prioritising items in WM (Grogan et al., 2022; Zheng et al., 2022)

As motivation is an important factor in prioritisation studies, within this thesis, different types of motivation will be investigated using an online experimental paradigm. Online testing methods have become much more common recently owing to the widespread use of internet-based technology and, in some ways, mandatory changes with the COVID-19 pandemic (Gagné & Franzen, 2023). Prior to the recent shift towards online research, investigations in the psychology field conventionally relied on in-person assessments conducted with accessible individuals, such as students. However, there were some common drawbacks, such as limited sample sizes and the fact that student samples are frequently comprised of individuals who are Westernised, Educated, Industrialised, Wealthy, and Democratic (i.e., WEIRD, Henrich et al., 2010), their profiles might differ significantly from those of the general population. Online experiments have become increasingly popular in recent years due to their potential to address the shortcomings of conventional laboratory research, achieved through the accumulation of data in parallel and at a rapid pace from a significantly larger sample size than was previously feasible (Gagné & Franzen, 2023). However, one of the most important potential consequences of conducting online research is the diminished ability to control the testing environment and the rise in lack of motivation and attention (Gagné & Franzen, 2023).

Due to these reasons, the engagement of participants in online experiments may remain a question. Uittenhove et al. (2022) explored the differences between the impact of the participant pool and testing modality (online – in-person) on data quality. Initially, the test was conducted on a sample of undergraduate students, and the various testing modalities were compared. More specifically, it compared student data in person versus online with the working memory experiment. When administering tasks to students online as opposed to in person, some data quality is lost. 17 % loss of data quality was reported in the online experiment compared to in-person data.

Moreover, Jun et al. (2017) described five motivator categories for participation in online experiments: self-learning, science, enjoyment, comparison, and boredom. It is indicated that the focus of participants in the study is impacted by those motivational factors. Additionally, Yetano and Royo (2017) indicated that participants drop out more online compared to in-person tests, even though the efforts to improve participants' motivation through various positive incentives. Therefore, it is evident that motivation plays a crucial role in an online experiment paradigm, specifically in the prioritisation task, where adequate motivation is necessary for the appearance of the effect. (Atkinson et al., 2019; Grogan et al., 2022; Zheng et al., 2022).

Within the context of this thesis, two approaches were used to prevent data loss and ensure the same data quality as in-person experiments and online experiments. The initial approach entails implementing a performance-based monetary incentive system for the participants. The second approach is modifying the testing methodology. These two approaches will allow for a more in-depth discovery of the motivational basis to understand the insights of strategic attentional control in WM. In addition, it helps to build a methodological perspective to establish how to maximise participant motivation to follow instructions across task contexts.

1.6.1. Monetary motivation

Most research on value-directed prioritisation has used notional rewards in the context of in-person studies. It was repeatedly seen from the results that participants performed better on VWM on high-reward items as compared to equal-reward or no-value items (Allen & Ueno, 2018; Atkinson et al., 2018; Berry et al., 2018; Hitch et al., 2018; Hu et al., 2014; 2016).

In order to see the effectiveness of notional reward, it can be enlightening to compare it with monetary reward. A number of studies have investigated whether monetary rewards could be used to manipulate attention and prioritisation. For example, Morey et al. (2011) used monetary incentives to influence the attention of participants in working memory tasks. Participants were informed that giving correct answers could win them money, that points represented money, and that gathering as many points as possible would get them more money. The findings suggested that offering a reward had a positive effect on overall motivation (Morey et al., 2011). Furthermore, Klyszejko et al. (2014) demonstrated that the precision of an item in WM could be increased by prioritisation with monetary reward. Similarly, Brissenden et al. (2021) showed that such rewards influence the allocation of attention to determine the content of WM. Additionally, higher reward was associated with a higher ability to prioritise cued items in VWM.

One of the few studies to directly address this question, Zheng et al. (2022) evaluated whether the nature of the reward determines reward boosts in VWM. In this study, the reward type (monetary and notional) and the item type (high, low and equal reward) were manipulated to examine whether reward type increases recall performance. The reward boosts were greater in the monetary reward condition as opposed to the notional reward condition. However, there was no interaction between the reward and item type. According to these results, participants can be motivated to direct their attention to high-value items through the use of both monetary and notional reward manipulations.

Similarly, van den Berg et al. (2023) investigated whether individuals have control over the VWM resources when some items are more important than others. In other words, they explored whether increasing the monetary value will enlarge the overall WM capacity. However, no evidence was found of greater monetary reward to manipulate motivation to increase the general VWM capacity.

To sum up, it is unclear how well monetary rewards function as incentives in working memory tasks. Examining the impact of monetary reward is useful in discovering which motivational factors might influence the presence of size of strategic prioritisation effects in WM.

1.6.2. Test Types Effect

A number of different test types are commonly used to evaluate working memory. This includes recognition, cued recall and serial recall. In the recognition test, after the presentation of items, one item is shown to the participants (half of these items are shown before and half not), and then participants are asked whether these items were presented before or not (e.g. Allen et al., 2006; 2009; Karlsen et al., 2010). In the cued recall test, after the presentation of paired shape-colour items, the test cue is presented on the screen, which can be shape or colour. If the test cue is presented as a shape, it is required to recall the colour paired with that shape and vice versa. Precisely, it is required to remember the relevant shape–colour binding in order to answer correctly (Atkinson et al., 2018; Hitch et al., 2018; Ueno et al., 2011). In studies adapting the cued test paradigm, four items are shown in order; one of them is prioritised and one of them will be asked in the test part, with the probability of all of them being asked is the same (Hitch et al., 2018; Hu et al., 2014; 2016).

Different test paradigms can affect the performance of participants. In the old/new recognition test, a guess typically has a chance probability of .5 since participants are only required to answer whether the item is shown before or not. In the cued recall test paradigm, the guessing probability is the number of items used in this experiment. If eight colours and eight shapes are utilised, the guessing probability is 1/8. Therefore, it can be argued that the cued recall test will provide a more reliable result since the probability of reaching the correct result with guessing is lower. However, since three or four items were presented and only one of the items tested in cued binding (Allen et al., 2014), this may affect motivation in the prioritisation method. In the condition that four items are presented in the study array, participants are asked to prioritise a particular item, but it is only tested in 25% of the trials. Instead, testing all items presented in the study array can increase motivation along with test reliability.

Test reliability is commonly investigated with the retro-cue paradigm in which spatial cues are presented following an array of objects to be remembered that highlight a specific memory item, thereby increasing the likelihood that it will be tested. It is widely shown that recall performance of the cued item improved by retro-cues (Astle et al., 2012; Griffin & Nobre, 2003; Gunseli et al., 2015; Pertzov et al., 2013). Additionally, Gunseli et al. (2015) showed that the size of improvement depends on the reliability of the cue. In the retro-cued paradigm, Gunseli et al. (2015) tested the cue reliability through manipulation of the retro-cue's validity. Participants were presented with four bars in different spatial locations. Following that, they were required to remember the orientation of the probed one. In some trials, cued items were tested 80% of the time, 50% in some trials and in others cued items were not tested. A larger benefit was found for cued items being tested in 80% of trials compared with the condition of cued items being tested in half of the trials.

Moreover, Atkinson et al. (2018) explored this effect in the probe value (prioritisation) paradigm as the relationship between prove value and frequency of cued item testing at retrieval. Similar to other prioritisation studies (Hitch et al., 2018; Hu et al., 2014; 2016), four items were presented sequentially, and one of them was tested in the test phase. The initial SP was assessed at the same ratio as the remaining items (25 per cent of the time) under the equal probe frequency condition. In the differential probe frequency condition, the first SP was assessed 70% of the time, whereas the other items were probed 10% of the time. Results showed both probe value and probe frequency boosts. Although the effects were independent of each other, it was observed that testing prioritised items increased the recall performance of that item more.

Therefore, in the prioritisation paradigm, it has been shown that raising the frequency of testing highly valued items increases recall performance (Atkinson et al., 2018). Additionally, the priority boost observed in verbal WM utilised serial recall of all items in the study array even under additional simple and high concurrent task conditions (Atkinson et al., 2021).

Based on this finding, testing all the items presented in the study array in an online experiment, where the participant's engagement in the experiment is likely to be lower, can increase the participant's motivation and increase the chance of obtaining larger impacts of strategic task manipulations such as prioritisation.

1.7 Thesis Outline and Aims

This thesis will initially examine whether different binding types (unitised, spatially separated and cross-modal binding) can influence directing attention to a more valuable object in WM (termed as prioritisation effects). This will be examined within in-person lab experiments (Experiments 4-5-6) and automated online task settings (Experiments 1-2-3). When examining value-directed prioritisation, participants need to direct their attention to higher-value items, and motivation is crucial in this process. Given the uncertain nature of motivation in online assessment, the motivation of participants will be manipulated in further experiments through the utilisation of monetary rewards (Experiment 7) and various test types (Experiment 8).

Despite the growing interest, value-directed prioritisation manipulation has not been studied to the same extent as visual cueing. It might be viewed as prioritisation manipulation has a higher compatibility to real-world situations than cueing, as information presented in daily life activities could naturally vary in value or task importance. For example, in real-life situations, if a certain stimulus or object is more valuable to a person and will result in earning more rewards, the possibility of the person directing their attention more towards that item is higher. Therefore, interventions can be developed from value-based prioritisation methods in real-life situations, such as improving working memory ability in schoolchildren or older adults. Although it does not seem possible to increase the general working memory capacity, it is possible to increase motivation by giving a higher value to some objects and ensuring working memory capacity is at an optimal level. This thesis will, therefore, aim to explore how prioritisation might be affected by a range of task contexts, with a view to testing its broader generalisability.

CHAPTER 2

PRIORITISATION EFFECTS IN UNITISED AND SPATIALLY SEPARATED BINDING IN WORKING MEMORY

2.1 Introduction

As indicated in Chapter 1, individuals can direct their attention in visual (Hu et al., 2014), verbal (Atkinson et al., 2021) and tactile (Roe et al., 2024) domains in WM. The current chapter examined whether individuals can allocate their attention to high-value items in different binding types in WM and whether this effect is consistent in online and in-person testing paradigms.

Prioritisation is a general term that can be applied to various techniques involving the manipulation of participants' motivation in order to direct their attention (Myers et al., 2017). As mentioned earlier, in this thesis, the term "prioritisation" refers to value-directed prioritisation (Allen & Ueno, 2018; Atkinson et al., 2018; 2019; 2020; Hitch et al., 2018; Hu et al., 2016; Roe et al., 2024). Usually, the prioritisation method involves the sequential presentation of three to four distinct coloured shapes. Individuals might earn different amounts of "points" for accurately recalling the stimuli. It has been observed that recall performance is enhanced for items that are linked with high point value as opposed to those that are linked with low point value. Additionally, performance for high-value items was also better than performance when all items were of equal value (Allen & Ueno, 2018; Atkinson et al., 2018; 2019; 2020; Berry et al., 2018; Hitch et al., 2018; Hu et al., 2014; 2016; Roe et al., 2024).

This approach was first adopted by Hu et al. (2014); in the prioritisation manipulation, participants successfully directed their attention to higher-value objects in the prioritisation condition. However, it came with a cost to other items, which indicates that the overall capacity of WM did not increase, but participants' recall performance of some items was enhanced by directing attention to those items. Additionally, results showed a recency effect, which showed higher performance in the last item regardless of point values.

However, how the prioritisation mechanism functions, such as the requirement of the executive process, needed to be clarified. The dependence of prioritisation effects on executive resources was examined by Hu et al. (2016). A series of coloured shapes was presented to participants, and following that, participants were required to recall the colour of one of the shapes. Participants were instructed to recall that either the first or the final item would earn them more points than the other items. Additionally, participants needed to engage in relatively high (count upwards in twos from a two-digit number) or low (repeat two-digit numbers) load concurrent tasks to test the role of executive processes. There was a prioritisation boost in the high-value items in relation to low-value ones, but it was reduced in the presence of a high-load concurrent task. This indicates that executive control is required to observe prioritisation effects. However, the recency effect was constant regardless of the concurrent task condition, indicating that recency effects may occur automatically and without any associated costs, whereas probe value boosts appear to be dependent on executive resources.

Baddeley's multicomponent model describes an episodic buffer as a mechanism that is responsible for binding and maintaining memory information in the integrated form (Baddeley, 2000). In this initial conceptualisation, the episodic buffer is required to direct attention to high-value items to prioritise them in addition to binding and maintaining items. If this were the case, requiring an episodic buffer to perform both binding and prioritising high-value items simultaneously may result in a decline in performance. However, further investigations indicated that the episodic buffer functions as passive storage rather than actively binding memory information (Allen et al., 2012; Baddeley et al., 2011). Furthermore, recently it has been suggested that the FoA can be incorporated within the episodic buffer as a function responsible for holding items in a privileged state (Hitch et al., 2020; Hu et al., 2014). To build a more comprehensive understanding, it is crucial to examine how FoA functions within the episodic buffer in different types of binding with the manipulation of the item values.

Several studies have investigated the relationship between binding and attention in WM (Allen et al., 2012; Brown & Brockmole, 2010; Delvenne et al., 2010; Elsley & Parmentier, 2009; Morey & Bieler, 2013; Yeh et al., 2005). Notably, Wheeler and Treisman (2002) suggested that although features from distinct dimensions might be stored in parallel, binding from the same dimensions requires attention. They further proposed that forming and maintaining the features of objects needs focused attention.

Furthermore, as discussed in Chapter 1, Allen et al. (2006) suggested a preliminary differentiation between automatic and active binding processes according to attentional demand, with the executive resources involved in active binding processes but not in automatic binding. Similar to Hu et al. (2014, 2016), dual-task methods were employed to examine whether binding is dependent on executive processes under dual-task conditions. It was found that concurrent tasks impact memory for single features and bindings, but there was no difference between them. Thus, although the general attentional ability is required for VWM, binding features do not require more attention than encoding a single item. These results were confirmed and expanded with further investigations with numerous concurrent tasks (Allen et al., 2012; Delvenne et al., 2010; Morey & Bieler, 2013; Vergauwe et al., 2014; Yeh et al., 2005). Therefore, these findings suggest a relatively automatic but fragile visual feature binding structure in WM.

However, with a similar paradigm, Brown and Brockmole (2010) indicated contradictory findings; binding was affected explicitly by a concurrently demanding task rather than single features. This finding was further supported by Fougnie and Marois (2009) and Zokaei et al. (2014), who had similar findings in visual search tasks. Additionally, Elsley and Parmentier (2009) also suggested that (visually presented) verbal and spatial binding recruits attentional resources. Expanding on this, Brown et al. (2017) examined feature binding in working memory across younger and older adults. Their results showed consistently small but significant effects of binding compared to single-feature memory, with memory for individual features being better than for bindings. This effect was of medium size in older adults but was still observable in younger participants as well. Thus, there has yet to be a clear consensus about the relationship between binding in WM and attention.

The typically utilised method in research examining binding in VWM was a shape with a pattern (Wheeler & Treisman, 2002) or coloured object (Allen et al., 2006; Luck & Vogel, 1997; Morey & Bieler, 2013), and generally, these were unitised objects. However, it is also informative to examine the mechanisms of different binding types in WM. For instance, Karlsen et al. (2010) used features of items separated either spatially (shape outlines and coloured blobs were presented in close proximity but not as a unitised object) or temporally (shape outlines and coloured blobs were displayed in the same locations, but with a brief delay in between) with concurrent task manipulation. It was found that performance was lower when features were separated. Yet, in line with Allen et al. (2006), the disrupting effect of concurrent tasks was no greater for the separated features. It can be concluded that, even though binding separated features requires more capacity in WM, it does not require executive resources as there was no greater impairment in the presence of disrupting concurrent tasks. Based on the finding that concurrent task has no more disruptive effect on spatially separated than unitised items, whereas the overall lower memory in spatially separated compared to unitised binding, Karlsen et al. (2010) suggested that although the binding of distinct features does not rely significantly on executive attention, it is also unlikely to occur automatically through perceptual processes as unitised binding does. Participants might be strategically binding distinct features which does not necessitate conducting an executive process. Nevertheless, further work is necessary to understand the nature of this strategic binding.

Furthermore, studies with Alzheimer's disease also indicated that remembering single features and bound features of objects might have different mechanisms, as Alzheimer's disease patients specifically show impaired performance in binding features (Cecchini et al., 2023; Guazzo et al., 2020). Moreover, Parra et al. (2015) specified a similar effect with patients affected by stroke, which damaged regions of the brain known to be critical for memory. Patients showed no performance decline in conjunctive binding (coloured shape), whereas there was a significant impairment in STM performance when items presented spatially separated. Therefore, results showed that the nature of binding still needs further investigation.

Previous literature indicated, even though it is not completely accepted (Brown & Brockmole, 2010; Elsley & Parmentier, 2009; Fougnie & Marois, 2009; Zokaei et al., 2014), that maintaining unitised object in WM seem to be not more attentionally demanding than single feature objects (Allen et al., 2006; 2012; Delvenne et al., 2010; Hu et al., 2014; 2016; Morey & Bieler, 2013; Vergauwe et al., 2014; Yeh et al., 2005). Nevertheless, most research investigating the association between WM and attention has used unitised objects, whereas the process of binding spatially separated objects seems to require more examination. This will give novel insights into feature binding and prioritisation in working memory and attention. The binding types investigated in this study were unitised (coloured shapes) and spatially separated (shapes and colours presented simultaneously in separate, vertically adjacent locations).

Furthermore, another critical aspect of this section was that most of the experiments were conducted online (Experiment 1-2-3) due to restrictions during the COVID-19 pandemic. The prevalence of online testing methods has increased significantly in recent years owing to the extensive adoption of internet-based technology and, to some extent, mandatory reforms prompted by the COVID-19 pandemic. Therefore, there is a common tendency to adapt researchers to the online version (Gagné & Franzen, 2023; Uittenhove et al., 2022; Van de Weijer-Bergsma et al., 2014).

However, in the online experiment, it is not clear whether individuals' performance is comparable with in-person assessment. Various differences between online and in-person experiments may have caused this issue such as increased variability in sample demographics relative to lab-based study (Greene et al., 2021). Another issue could be that of controlling motivation. Ensuring that participants are motivated enough to complete experiments can be more challenging online than in lab-based experiments (a more detailed discussion about the potential differences between in-person and online experiments can be found in Chapters 4 and 5). As performing strategic prioritisation tasks in WM rely on motivation to prioritise high-value information (Atkinson et al., 2018; 2019; 2021; Hitch et al., 2018; Hu et al., 2014; 2016; Roe et al., 2024), motivation may be an essential variable in the WM test. As an example of the critical effect of motivation in prioritisation, Berry et al. (2018) conducted a study with children between the ages of 7 and 10 years, and the findings showed no evidence that they are capable of focusing their attention on high-value items. However, Atkinson et al. (2019) indicated that children are capable of prioritising high-reward items when sufficiently motivated. This demonstrates the importance of motivation in assessing an individual's capacity to direct attention while utilising executive resources.

Therefore, motivation is likely to be an important factor in prioritisation, but in online experiments, it can be more challenging to ensure participants are motivated. This chapter of the thesis examined whether the prioritisation effect can be observed in unitised and spatially separated binding within online (Experiments 1-3) and lab (Experiment 4) settings.

2.2 Experiment 1

The aim of this experiment was to test whether individuals can prioritise high-value items in different binding types in WM through an online experiment. In this experiment, participants were presented with four visual items serially and attempted to recall the colour of one of the shapes in each trial as a test cue. Test cue was randomly selected from one of the objects in the study array in each trial, and the testing of each SP was counterbalanced across trials. Cued recall paradigm was utilised in this study in line with prior studies on prioritisation in visual WM (Allen et al., 2014; Allen & Atkinson, 2021; Atkinson et al., 2018; Hu et al., 2014; 2018; Hitch et al., 2018). Participants were required to remember the relevant shape–colour binding to answer correctly (Atkinson et al., 2018; Hitch et al., 2018; Ueno et al., 2011).

In this experiment, binding types and priority conditions were manipulated. There were two binding types (unitised and spatially separated). In the unitised condition, colours and shapes were presented as single-coloured shapes. In the spatially separated binding condition, a colour and a shape were presented simultaneously but at vertically adjacent locations. The presentation of separated and unitised items was similar to previous studies (Karlsen et al., 2010).

The prioritisation manipulation involved either the first item being assigned a higher point value than the others (priority condition) or all items having an equal point value (no priority condition). The point value system utilised in this study was notional, consistent with earlier investigations (Allen et al., 2021; Atkinson et al., 2018; 2019; 2021; Hitch et al., 2018; Hu et al., 2014; 2016). Additionally, the prioritisation manipulation targeted only the first item, with consistent effects being found in previous research (Atkinson et al., 2018; Hu et al., 2014; 2016). Based on previous findings (Atkinson et al., 2018; Hitch et al., 2018; Hu et al., 2014; 2016), it was expected that participants would show better recall performance at the prioritised SP in the priority condition than at the same SP in the no priority condition; this was expected as a significant interaction between prioritisation and SP.

It was also predicted that participants would show better overall memory performance in unitised conditions when compared to spatially separated, which is in line with previous findings (Karlsen et al., 2010). However, previous research has investigated the memory of unitised and spatially separated binding under concurrent tasks (Karlsen et al., 2010) or different patient groups (Cecchini et al., 2023; Guazzo et al., 2020; Parra et al., 2015) rather than with prioritisation. The prioritisation effect has mostly been observed in unitised objects in visual WM (Allen & Atkinson, 2021; Atkinson et al., 2018; Hu et al., 2014; 2016; Hitch et al., 2018). However, it is also essential to generalise priority exploration beyond unitised binding since individuals are highly likely to be exposed to many forms of binding in everyday life. In the current study, assuming the results emerged as separated binding is not more attention-demanding aligned with Karlsen et al. (2010), no interaction between prioritisation and binding type would be predicted. Alternatively, actively holding and prioritising separated features might be more difficult or error-prone or take up more episodic buffer/FoA capacity, which would then predict an interaction between prioritisation and binding type. Hence, this experiment addressed these possibilities to provide further exploration of the nature of separated feature binding.

Furthermore, although participants could show better overall memory performance in the unitised conditions, their ability to prioritise the higher-value SP may not differ across binding types. Supporting this, dual-task studies showed that attentional demanding concurrent task has no more disrupting impact when items were presented spatially separated rather than unitised (Allen et al., 2006; 2009; Karlsen et al., 2010), these findings indicated that binding does not require executive resources and this process occurs automatically in the episodic buffer (Baddeley et al., 2011). Although there is research concerning the effect of dual tasks on binding (Allen et al., 2012; Delvenne et al., 2010; Morey & Bieler, 2013; Vergauwe et al., 2014; Yeh et al., 2005), to the best of our knowledge the effect of value directed prioritisation in unitised and spatially separated bindings is still unexplored.

Therefore, the current study would broaden the findings by exploring whether attention can be directed to high-value SP when features of items are separated spatially as well as unitised feature items.

2.2.1 Method

2.2.1.1 Participants

G*Power 3.1 (Faul et al., 2009) analysis was conducted to determine required sample size. The primary comparison in this study was between higher value and equal value conditions at the prioritised serial position (SP1). Based on a large effect size of d=.8, power analysis indicated a required sample size of N = 23 to achieve .95 power with alpha of .05. This sample size calculation has been applied to all subsequent studies in this thesis since each experiment is focused on the same comparison.

Twenty-seven students (aged 19-23 years; M = 21.10; SD = 1.14; 19 females) recruited from the University of Leeds participated in this experiment. Most participants were reimbursed for their time with course credits. They were all native English speakers, and none reported a history of neurological disorders. The participants reported normal or corrected-to-normal vision and no colour blindness. Informed consent was acquired in accordance with the guidelines set by the University of Leeds Psychology Ethics Committee (Ethics reference number: PSC-325). This study and the subsequent studies in this thesis were not pre-registered.

2.2.1.2 Material

Six colours (black, red, blue, green, yellow, and purple) and six shapes (circle, cross, diamond, star, flag, and triangle) were used as visual stimuli, as taken from Allen et al. (2006). A neutral formless shape ("a blob") and shape the outline of the same six shapes were utilised to display colours in spatially separated conditions and present as a test cue, while coloured shapes were utilised to display in unitised binding conditions (Allen et al., 2009). Shapes and colours were not repeated within the same trial. All stimuli were presented in the size of 3.3 x 3.3 cm (124.72 x 124.72 pixels) based on a standard small monitor screen (1280x1024 pixels), (33.5cmx27cm) on a white background.

2.2.1.3 Design and Procedure

A 2x2x4 repeated measures design was implemented, with two types of binding conditions (unitised and spatially separated), two priority conditions (priority and no priority) and four probed serial positions (SP 1:4).

The Gorilla Experiment Builder (www.gorilla.sc) was used to collect data (Anwyl-Irvine et al., 2020) and the experiment was conducted online. Participants needed to complete 4 blocks (one per condition), and each block included 40 test trials. The order of condition blocks was counterbalanced across participants. Each serial position was tested an equal number of times (10 times) in a random order for each block. There were two practice trials at the beginning of each block to familiarise participants with the condition.

At the beginning of all conditions, participants were informed of task details via written instructions. In the prioritisation condition, they were instructed that the first stimulus would be paired with 10 points while the other three stimuli were worth 1 point. In the no-priority condition, participants were informed that all stimuli were paired with 5 points. Thus, in the no priority condition, none of the items were explicitly to be prioritised, whereas, in the priority condition, only the first stimulus was to be prioritised. Point values were notional and were not predictive of which item would be tested.

There were two different binding conditions. In the unitised condition, colours and shapes were presented as single-coloured shapes (e.g., a circle outline with red infill). In the spatially separated condition, colours and shapes were presented simultaneously but visually separated as pairs of coloured blobs and unfilled shapes (e.g., a red-coloured blob and the outline of a circle). In this condition, colours and shapes were displayed as vertically adjacent, with colours always presented directly above the shapes, separated by 0.6cm (see Figure 2).

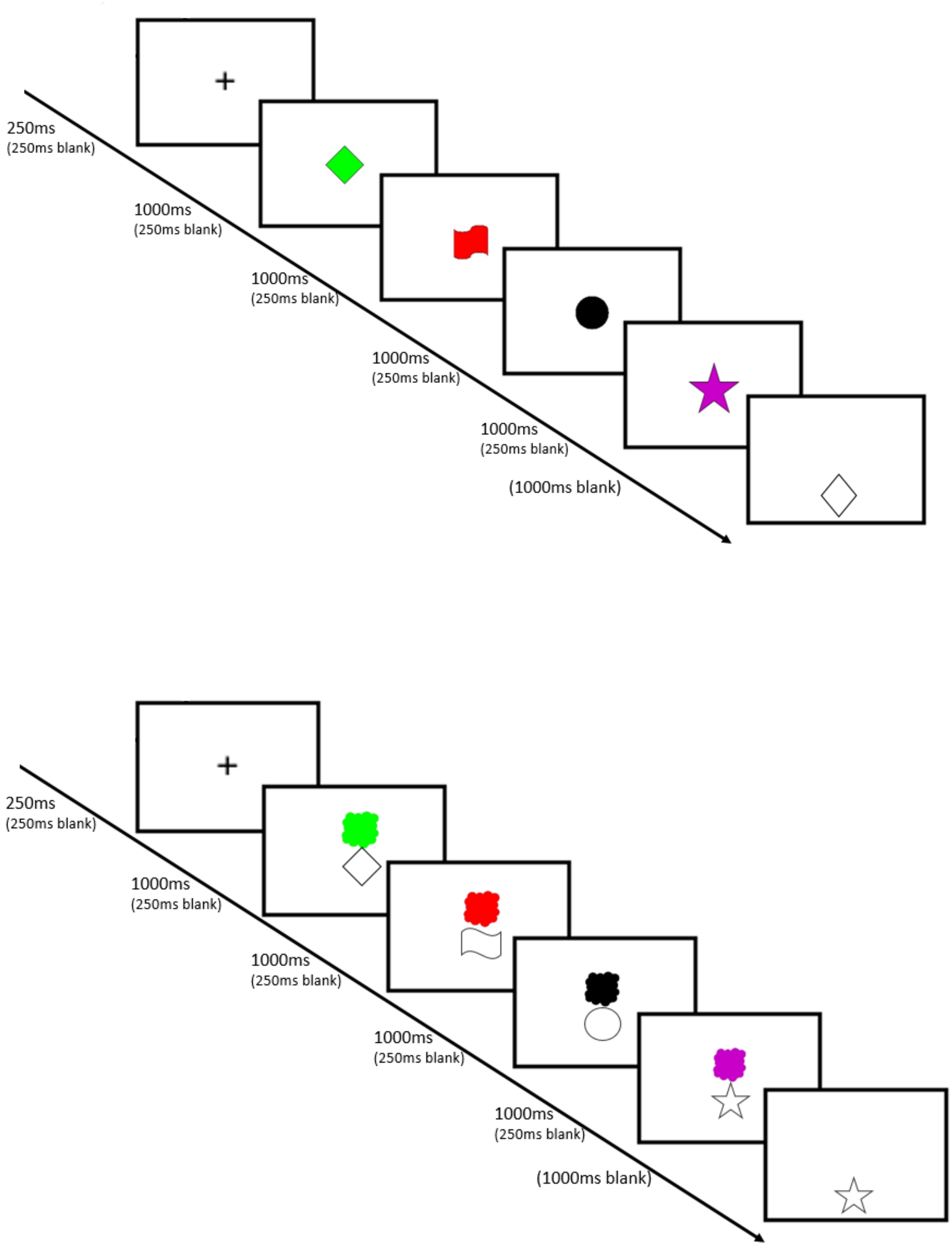

Figure 2.1. The experimental paradigm used in Experiment 1. The top panel shows an example of a unitised trial, whilst the bottom panel shows an example of a spatially separated trial. Figure not to scale.

Figure 2.1. shows the experimental paradigm. To-be-remembered stimuli were presented in the middle of the screen. Each trial began with the 250ms presentation of a fixation cross, followed by a 250ms blank screen. Each of the four visual stimuli was presented on a white background directly above the screen centre for 1000 ms with an inter-stimulus interval of 250ms. A 1000ms blank screen delay followed the presentation of the four stimuli, and then the test cue was presented. The test cue, a shape outline, was randomly selected from the four stimuli in the study array with the restriction that each of these stimuli would be selected with equal probability as well as each SP tested an equal number of times per participant. The test cue was presented below the screen centre so as not to spatially overlap with the target. Participants were asked to recall the name of the colour that was presented with that shape and type their response via keyboard and then pressed the “next” button to progress to the next trial. Reminders about the item values were presented to participants after every 20 trials. Participants were given feedback on their ongoing points score halfway through each block and their total points score at the end of each block. The experiment took approximately 35-40 minutes to complete.

2.2.1.4 Data analysis

In this experiment, the outcome variable is the accuracy of recalling the correct colour, which is determined by the proportion of trial participants who responded correctly. The independent variables were binding types (unitised and spatially separated), prioritisation (priority and no priority) and serial position (SP) (1-2-3-4). Thus, the data were subjected to 2 (binding types) x 2 (prioritisation) x 4(SP) repeated measures ANOVA.

Results were initially reported as a function of SP. Additional planned analysis was then conducted at SP1 since the priority manipulations were aimed at this SP. Data analysis was conducted using frequentist and Bayes Factor (BF) methods. The analysis was performed using JASP (Version 0.16) and R.

2.2.2 Results

2.2.2.1 Across serial positions

The 2 (binding type) x 2 (priority) x 4 (SP) repeated measures ANOVA indicated no main effect of binding type (Unitised *M* = 0.63, SE = 0.03; Separated *M* = 0.62, SE = 0.03; ($F(1,26) = 0.11$, $p = .740$, $\eta_p^2 < .01$, $\eta_G^2 < .001$; $BF_{10} = 0.11$) or prioritisation (Priority *M* = 0.62, SE = 0.03; No Priority *M* = 0.63, SE = 0.03; ($F(1,26) = 0.30$, $p = .589$, $\eta_p^2 = .01$, $\eta_G^2 < .001$; $BF_{10} = 0.13$). A main effect of serial position emerged ($F(3,78) = 18.63$, $p < .001$, $\eta_p^2 = 0.42$, $\eta_G^2 = 0.15$; $BF_{10} > 10{,}000$). Pairwise comparisons (corrected using Bonferroni – Holm) revealed significant differences between SP1 (*M* = 0.59, SE = 0.03) and

SP4 (M = 0.78, SE = 0.03; p < .001), between SP2 (M = 0.54, SE = 0.03) and SP4 (p < .001) and between SP3 (M = 0.58, SE = 0.03) and SP4 (p < .001).

There was a significant interaction between SP and priority (Greenhouse- Geisser corrected $F(2.37,61.60) = 3.01$, p = .048, η_p^2 = 0.10, η_G^2 = 0.01; BF_{10}= 0.87), albeit the BF slightly favours the null hypothesis. There was no significant interaction between SP and binding ($F(3,78) = 0.97$, p =.411, η_p^2 = 0.4, η_G^2 = 0.002; BF_{10}= 0.07) (see Figure 2.3.(B)); or between binding and priority ($F(1,26) = 0.02$, p = .892, η_p^2 < .001, η_G^2 < .001; BF_{10}= 0.14); or a three-way interaction between SP and binding and priority ($F(3,78) = 0.32$, p =.809, η_p^2 = 0.01, η_G^2 = 0.001; BF_{10}= 0.06).

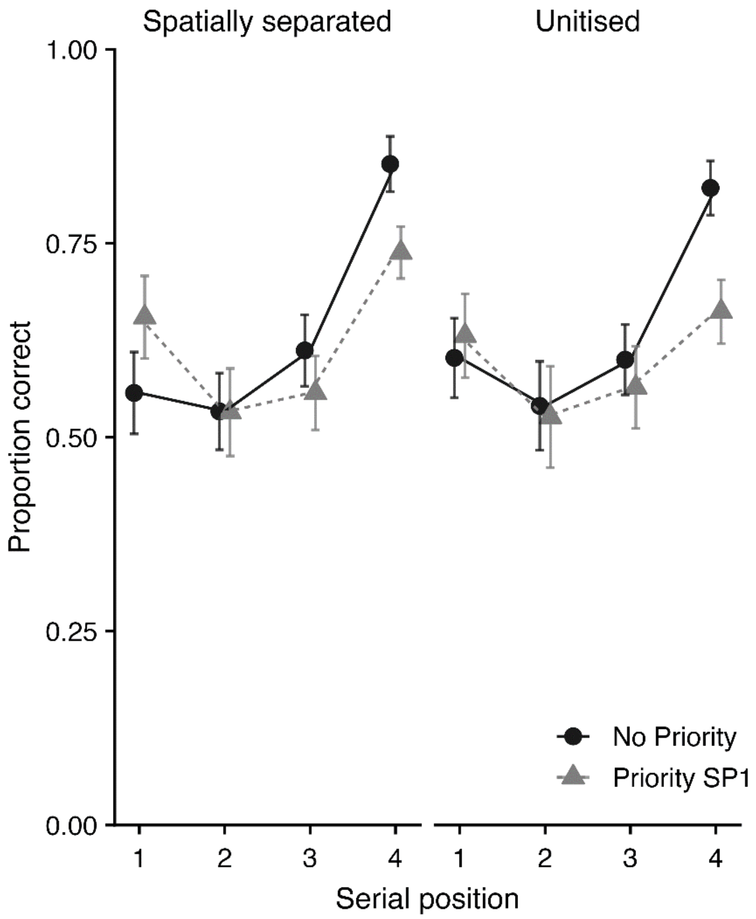

Figure 2.2. Mean proportion correct (and SE) as a function of binding type, prioritisation, and SP from Experiment 1. Data are presented by serial position.

To investigate the interaction between SP and priority, a series of paired sample t-tests were conducted. The mean proportion correct as a function of the priority value and SP is displayed in Figure 2.3.(A). A significant difference emerged only at SP4 (last SP), the performance of participants was significantly better in the no priority condition in SP4 relative to priority ($t(20) = 3.98$, $p < 0.001$, $BF_{10} = 47.19$, $d = 0.87$). No significant differences emerged between the priority and no priority conditions in SP1 ($t(20) = -1.07$, $p = 0.297$, $BF_{10} = 0.38$, $d = -0.23$), SP2 ($t(20) = 0.16$, $p = 0.873$, $BF_{10} = 0.23$, $d = 0.03$) or

SP3 ($t(20) = 1.43$, $p = 0.168$, $BF_{10} = 0.55$, $d = -0.31$). To sum up, the results showed that directing participants to prioritise the first item did not have a significant effect on the performance of this item (SP1) but decreased performance at the last item (SP4). It additionally had no significant effect on performance at SP2 and SP3.

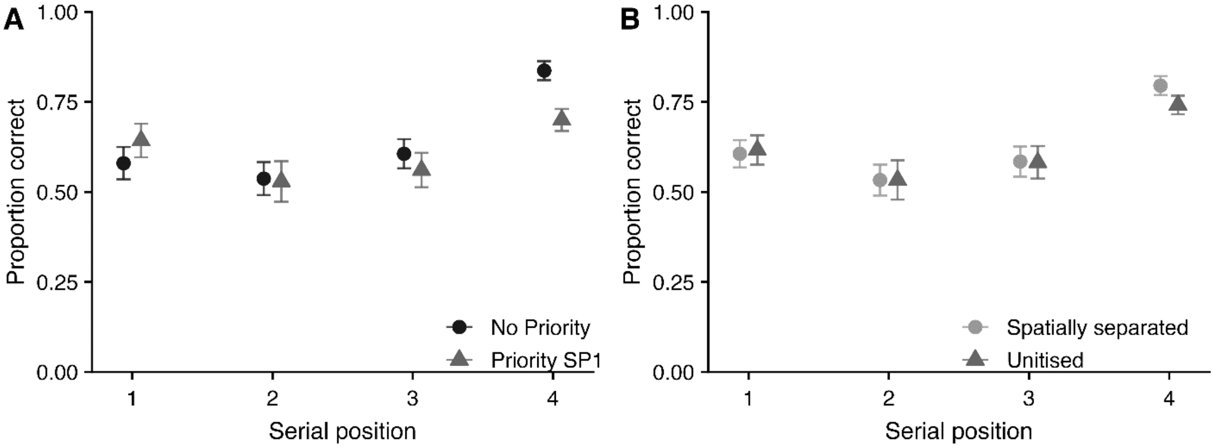

*Figure 2.3***.** A) Mean accuracy (with SE) in experiment 1 as a function of priority and SP, collapsed across binding conditions; B) Mean accuracy (with SE) as a function of the binding type and SP, collapsed across priority conditions. Data are presented by serial position.

2.2.2.2 Serial Position 1

Further analysis was conducted at SP1 as the priority manipulation was targeted at this SP. To investigate the interaction between priority condition and binding type, a 2 (Priority condition) × 2 (Binding type) repeated-measures ANOVA was conducted. There was no significant main effect of priority ($F(1,20) = 1.15$, p =.297, η_p^2 = 0.05, η_G^2 = 0.02; BF_{10} = 0.54) and no significant main effect of binding ($F(1,20) = 0.10$, p =.759, η_p^2 = 0.01, η_G^2 < 0.001; BF_{10} = 0.23). Additionally, there was no significant interaction between priority condition and binding type ($F(1,20) = 0.78$, p = .389, η_p^2 = 0.04, η_G^2 = 0.01; BF_{10}= 0.39).

2.2.3 Discussion

This experiment found a significant recency effect, which is consistent with previous findings (Atkinson et al., 2018; Hay et al., 2007; Hitch et al., 2018; Hu et al., 2014; 2016). There was an interaction between serial position and priority. Whilst there was no increase in the recall of the prioritised item, there was a significant decrease in the recall of the final item when the first item was prioritised. These findings indicated that although the priority condition did not do what was intended, it reduced the recency effect. Therefore, although there was no substantial increase in the prioritised item, there was a significant reduction in the priority condition SP4 when compared to its no priority condition, which is consistent with previous studies showing that prioritising one item results in lower performance for others (Astle et al., 2012; Atkinson et al., 2018; Chun et al., 2011; Hitch et al., 2018; Hu et al., 2014; 2016). These findings indicated that participants may have tried to prioritise the first item, yet because of the trade-off effect, their ability to recall the last item decreased significantly.

Even though the results of the current study showed that there was no priority effect when the first item in the sequence was prioritised, recent studies suggest that instructing participants to prioritise the first item resulted in improved recall for these items (Allen & Atkinson, 2021; Atkinson et al., 2018; Hu et al., 2014; 2016; Hitch et al., 2018). In these studies, which showed a significant priority effect, stimuli were presented to the participant in different spatial locations on the screen. However, in the current experiment, all stimuli were displayed at the same place on the screen. Thus, one reason for prioritisation not being effective in this experiment may be the overwriting effect. Overwriting can occur when two items share a feature; they compete for the representation, which might result in that characteristic being lost in one of the representations (Oberauer & Kliegl, 2006). In this experiment, it can be thought that the shared feature across different items is location. Since stimuli share the exact location, this could result in overwriting, thereby reducing the prioritisation effect in the first item.

Additionally, although some studies suggested that spatial separation lowered recognition accuracy when compared with unitised object-colour binding (Karlsen et al., 2010), the results of this experiment indicated no differences in recall between unitised and separated binding types. The absence of differences in overall memory performance between unitised and spatially separated binding may also be related to location overwriting. In previous investigations, such as Karlsen et al. (2010), items were displayed at various locations on the screen. In contrast, Allen et al. (2009) explored unitised, spatially separated and cross-modal binding and used screen-centre presentation. The results indicated no difference in memory performance between the binding types. Thus, the presentation of items in different locations may facilitate the emergence of the distinctions between the different binding forms. To investigate this, in Experiment 2, items were presented in different locations. This could potentially help the unitisation effect (better performance in the unitised compared to spatially separated binding) emerge.

Furthermore, since the priority effect was not observed, which could have resulted from possible overwriting effects, conducting a second experiment with the display of items in various locations on the screen can provide a further understanding of the mechanism of the prioritisation effect and how prioritisation possibly interacts with binding.

2.3 Experiment 2

Experiment 2 examined whether the prioritisation effect can emerge when items are presented in different spatial locations in different binding types. In the first experiment, there was no increase in the recall of the prioritised item, but there was a significant decrease in the recall of the final item when the first item was prioritised. This finding suggested that participants attempt to allocate their attention to the first item, which subsequently impairs their ability to recall the final item. Considering that all of the stimuli were presented in the exact same location on the screen, an overwriting effect may have occurred as items compete for the location, and this can result in missing that characteristic in one of the representations (Oberauer & Kliegl, 2006).

Moreover, in the previous prioritisation studies that utilised serial order, stimuli generally tended to be present in different locations (Allen et al., 2020; Atkinson et al., 2018; Baddeley et al., 2011; Hu et al., 2014; 2016). However, there was some research that presented all items at the screen centre (Allen et al., 2009; Sandry et al., 2014; Sandry & Ricker, 2020). Some of these studies demonstrated a notable prioritisation effect when the first item was prioritised in three-item sequence trials (Sandry & Ricker, 2020; Sandry et al., 2014). However, Sandry et al. (2014) demonstrated a ceiling effect in the priority condition, whilst Sandry and Ricker (2020) showed that accuracy for prioritised positions did not differ from the control positions. One distinctive aspect is that Sandry et al. (2014) and Sandry and Ricker (2020) utilised the presentation of three items in the study array, while four items were presented in the present study. The observation of priority boost in Sandry et al. (2014) and Sandry and Ricker (2020) may be attributed to the 3-item sequence trial, as it was not observed in experiments utilising the 4-item sequence (Atkinson et al., 2018; Hu et al., 2014; 2016). Utilising three-item sequences can make the experiment easier than expected, and this may result in participants being able to prioritise each item easily despite the overwriting effect. Consistent with this argument, Pertzov and Husain (2014) and Schneegans et al. (2021) illustrated that recall of visual items declined when sequences of four items were presented at the same location when compared to a different location. Additionally, Pertzov and

Husain (2014) showed that participants had a stronger tendency to report features from the incorrect object in memory when numerous objects shared the same spatial location in the trial; that is, they were confused by features from objects that appeared in a trial but not investigated at retrieval. It has been suggested that even when the position is unrelated to the activity, the spatial location may play an important role in retaining accurate visual memories across time and showing objects in various positions helps to distinguish between them in WM (Pertzov & Husain, 2014).

Furthermore, the results of the first experiment demonstrated that there is no difference observed in the overall memory performance between unitised and spatially separated binding, whereas previous findings showed that spatial separation lowered the accuracy of the recall (Karlsen et al., 2010). One main difference between the current and previous studies (Karlsen et al., 2010) is the location of the item display. While Karlsen et al. (2010) presented items in different locations by utilising simultaneous presentation, in the current study, all items were presented in the same location with sequential presentation. Showing all items in the same location may have eliminated the difference between binding types by causing location overwriting. Therefore, there is a strong argument about the effectiveness of showing items in different locations in sequential presentation (Pertzov & Husain, 2014; Schneegans et al., 2021). In this experiment, with the presentation of the stimuli in different locations, it was expected that this would overcome the overwriting effect, and that participants would successfully allocate their attention to higher-value items, and that the unitisation effect would emerge.

2.3.1 Method

2.3.1.1 Participants

Twenty-seven students (aged 19-27 years; M = 21.41; SD = 1.42; 15 females) recruited from the University of Leeds participated in this experiment. Most participants were reimbursed for their time with course credits. They were all native English speakers, and none reported a history of neurological disorders. The participants had correct or corrected-to-normal vision and no colour blindness. Informed consent was acquired in accordance with the guidelines set by the University of Leeds Psychology Ethics Committee (Ethics reference number: PSC-325).

2.3.1.2 Design and Procedure

The method was closely based on Experiment 1, with the same material set, design, and trial procedure. The only exception is that to-be-remembered stimuli were presented in the four corner quadrants of an imaginary rectangle (26.8x17.26) cm in a standard small monitor screen (1280x1024 pixels), pseudo-randomising position with the constraint that each location was only occupied once per trial and counterbalanced order. For example, the first shape colour pairing was shown in the upper-right corner, the second in the lower-left corner, and so on. At each trial, only one item was presented within each quadrant (see Figure 2.4).

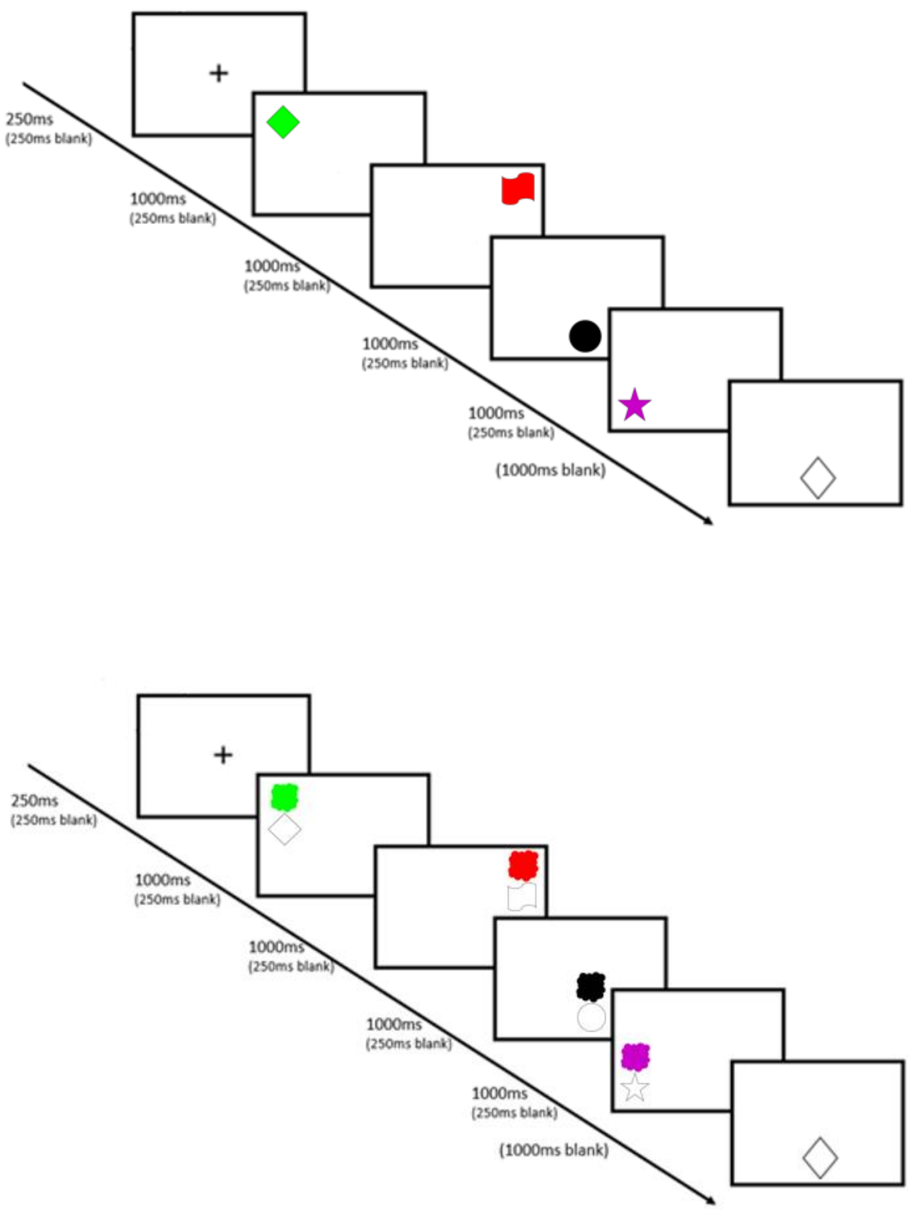

Figure 2.4. The experimental paradigm used in Experiment 2. The top panel shows an example of a unitised trial, whilst the bottom panel shows an example of a spatially separated trial. Figure not to scale.

Same as with Experiment 1, a 2x2x4 repeated measures design was implemented in each experiment, with two types of binding condition (unitised and spatially separated) and priority condition (priority and no-priority) and probed serial position (SP 1:4). Prioritisation condition, trial, and test procedure was identical to Experiment 1.

2.3.1.3 Data analysis

In this experiment, the outcome variable is the accuracy (proportion of trials participants recalled the correct colour). The independent variables were binding types (unitised and spatially separated), prioritisation (priority and no priority) and serial position (SP) (1-2-3-4). Thus, the data were subjected to 2 (binding types) x 2 (priority) x 4 (SP) repeated measures ANOVA. Additional planned analysis was then conducted at SP1 since the priority manipulations were aimed at this SP. Data analysis was conducted using frequentist and Bayes Factor (BF) methods. The analysis was performed using JASP (Version 0.16) and R.

2.3.2 Results

2.3.2.1 Across serial positions

The mean proportion correct as a function of priority, binding type and SP is displayed in Figure 2.5. The 2 (binding type) x 2 (priority) x 4 (SP) repeated measures ANOVA indicated no main effect of priority (Priority *M* = 0.64, SE = 0.03; No Priority *M* = 0.62, SE = 0.03; (F(1,26) = 1.16, p =.291, η_p^2 < .04, η_G^2 = 0.003; BF_{10} = 0.29). A main effect of serial position emerged (F(3,78) = 32.55, p < .001, η_p^2 = 0.56, η_G^2 =0.23; BF_{10} > 10,000). Pairwise comparisons revealed significant differences between SP1 (*M* = 0.55, SE = 0.03) and SP3 (*M* = 0.66, SE = 0.03; p = .005) and SP4 (*M* = 0.82, SE = 0.03; p < .001), between SP2 (M = 0.50, SE = 0.03) and SP3 (p < .001) and SP4 (p < .001) and between SP3 and SP4 (p < .001). A main effect of binding emerged (Unitised *M* = 0.66, SE = 0.03; Separated *M* = 0.61, SE = 0.03; (F(1,26) = 10.05, p = .004, η_p^2 < .28, η_G^2 = 0.01; BF_{10} = 2.85).

There was no significant interaction between SP and priority (F(3,78) = 0.29, p =.834, η_p^2 = 0.01, η_G^2 = 0.001; BF_{10}= 0.03) (see Figure 2.6.(A)); or between SP and binding (F(3,78) = 0.35 , p = .787, η_p^2 = 0.01, η_G^2 = 0.001; BF_{10}= 0.03) (see Figure 2.6.(B)); or between binding and priority (F(1,26) = 1.18, p = .288, η_p^2 = .04, η_G^2 = 0.001; BF_{10}= 0.20);or for the three-way interaction between SP and binding and priority (F(3,78) = 0.77, p =.515, η_p^2 = 0.03, η_G^2 = 0.002 ; BF_{10}= 0.12).

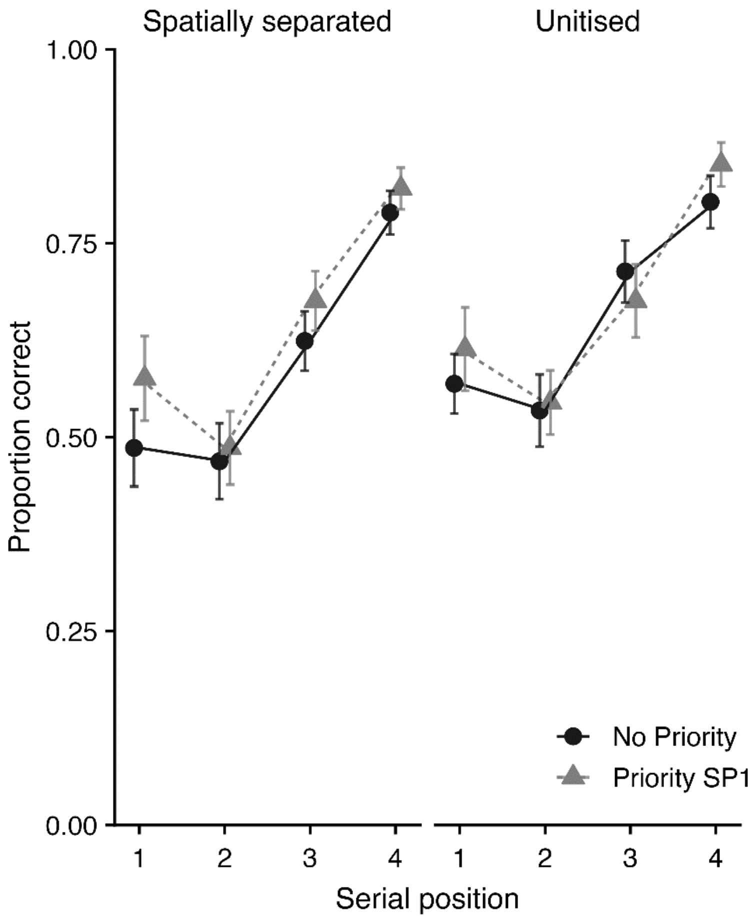

Figure 2.5. Mean proportion correct (with SE) in each binding types condition, priority condition contrasted with the control (no priority) condition from Experiment 2. Data are presented by serial position.

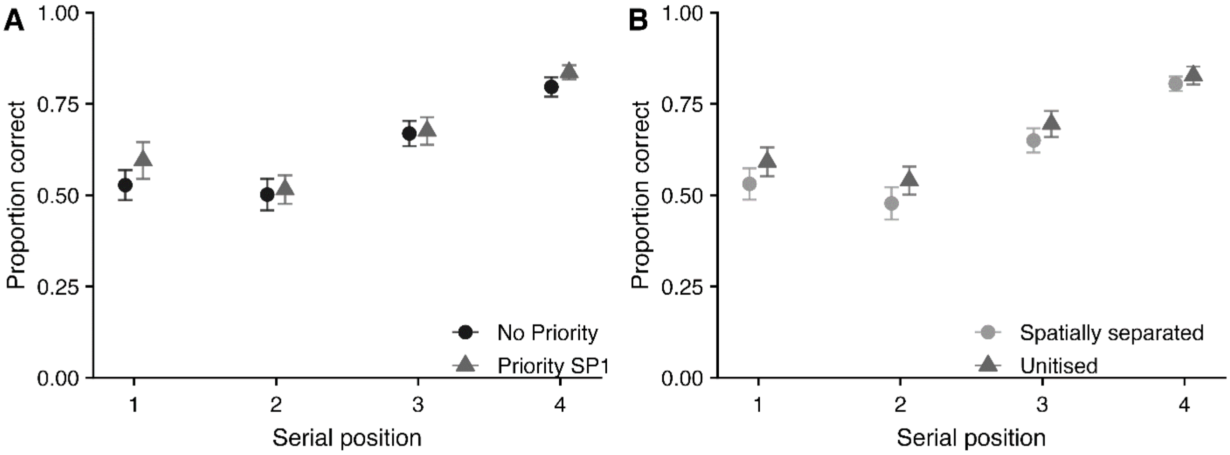

Figure 2.6. A) Mean accuracy (with SE) in experiment 2 as a function of priority and SP, collapsed across binding conditions; B) Mean accuracy (with SE) as a function of the binding type and SP, collapsed across priority conditions. Data are presented by serial position.

2.3.2.2 Serial Position 1

Further analysis was conducted at SP1 as the priority manipulation was targeted at this SP. To investigate the interaction between priority condition and binding type, a 2 (Priority condition) × 2 (Binding type) repeated-measures ANOVA was conducted. There was no significant main effect of priority ($F(1,26) = 0.98$, $p = .331$, $\eta_p^2 = 0.04$, $\eta_G^2 = 0.01$; $BF_{10} = 0.49$), with no increase in the performance in prioritised item. There was a significant main effect of binding ($F(1,20) = 5.53$, $p = .027$, $\eta_p^2 = 0.18$, $\eta_G^2 = 0.01$; $BF_{10} = 0.74$), with participants' performance higher in unitised binding. Additionally, there was no significant interaction between priority condition and binding type ($F(1,26) = 0.59$, $p = .449$, $\eta_p^2 = 0.02$, $\eta_G^2 = 0.002$; $BF_{10} = 0.31$).

2.3.3 Discussion

Replicating the findings of Experiment 1 and previous research (Atkinson et al., 2018; Hay et al., 2007; Hitch et al., 2018; Hu et al., 2014, 2016), there was a recency effect. Although, once again, this experiment failed to find significantly higher memory performance at SP1 (high-value SP) in the priority condition, yet the binding effect emerged, with higher overall performance in unitised than spatially separated. However, there were no interactions between SP, binding, and priority, nor were there three-way interactions.

Therefore, the results suggested that when items were presented in different spatial locations, participants showed better performance in unitised binding compared to spatially separated. This is consistent with previous findings by Karlsen et al. (2010), in which it was found that when features of items separated spatially or temporarily, the memory of those items decreased. Therefore, while the findings of the first experiment indicated no difference in overall recall of memory items, the current experiment revealed a significant difference. Thus, when items were presented in different locations, participants demonstrated increased performance in unitised binding. This finding further supported Pertzov and Husain (2014) and Schneegans et al. (2021), who found decreased memory when items shared the same location. One possibility for the decreased memory performance when features of items are separated is that it is more attentional demanding to bind, as some previous studies suggested (Brown & Brockmole, 2010; Elsley & Parmentier, 2009; Fougnie & Marois, 2009; Zokaei et al., 2014). However, the absence of three-way interaction shows that it is not harder to allocate attention in unitised than spatially separated. Therefore, it might not be accurate to draw a conclusion that binding requires more attention from this finding.

Another possibility is that according to Karlsen et al. (2010), compared to unitised binding, which occurs automatically through perceptual processes, binding separated features can be more difficult. In order to accomplish the task, participants were expected to strategically bind features; however, this did not require executive resources. This conclusion was reached by Karlsen et al. as separated feature binding was not adversely affected by an additional concurrent task. There might also be other possible explanations to describe decreased memory in spatially separated binding, such as spatially separated objects being more vulnerable to error or memory decay or requiring more capacity of the episodic buffer or FoA.

Notably, although presenting the items in different locations revealed better performance in unitised binding compared to spatially separated, no difference was found in the overall performance between Experiments 1 and 2. Previous findings indicated that presenting the items in different locations would increase performance (Pertzov & Husain, 2014; Schneegans et al., 2021).

Based on these findings, an overall increase in performance could be expected in Experiment 2, as the items were presented in a different location compared to the same location presentation in Experiment 1. However, no such effect was observed. Therefore, it is important to state that only the difference emerged between the two binding types; their overall performance remained consistent between the two experiments.

Importantly, in numerous previous studies, the prioritisation effect emerged when people were instructed to direct their attention to higher-value items (Atkinson et al., 2018; 2019; 2021; Hitch et al., 2018; Hu et al., 2014, 2016; Roe et al., 2024). However, it was not observed in this experiment, which requires further research. One possible issue that may be important could be the participants' maintenance strategies. Even though this was a visual WM task, verbal recoding is a potentially important maintenance strategy (Gonthier, 2021), which occurs with verbal repetition of to-be-memorised items (Camos et al., 2009). It can be a strategy to hold higher-value items in WM when they are allowed and required for the task.

One possible reason for the absence of a prioritisation effect is if participants relied on a verbal rehearsal to remember each item on a visual prioritisation test. As memory items were presented sequentially for 1000ms, timing would enable verbal rehearsal, which can enhance the likelihood of verbal encoding. Participants might have already rehearsed the first few items in the control (no-priority) condition, so there is not as much scope to detect a priority boost. Thus, to increase the likelihood that participants are persistent on a visual-based strategy, articulatory suppression would be helpful.

Articulatory suppression is required to repeat a simple verbal item, such as one syllable or one sound that is not relevant to the task while completing the experiment (Baddeley & Hitch, 1994; Baddeley et al., 1984; Camos et al., 2009). As suggested in previous studies, utilising articulatory suppression increases the dependence on visual memory (Hanley & Bakopoulou, 2003; Salamé & Baddeley, 1986) due to its effectiveness in reducing verbal subvocal rehearsal (Salamé & Baddeley, 1982). The majority of research on value-directed prioritisation employs articulatory suppression in order to reduce the impact of verbal rehearsal (Atkinson et al., 2018; 2021; Hu et al., 2014; Sandry et al., 2014). Another potential effect concerning the no priority effect observed might be rehearsing order; it is suggested that individuals often verbally rehearse in sequential order (from first to last presented item) (Hitch et al., 2005). If participants verbally rehearse in sequential order in both priority and no priority conditions, it is possible that this could lead to the disappearance of the priority effect. Similarly, this effect again predicts that participants are verbally rehearsing. Utilising articulatory suppression can be advantageous in order to minimise the potential verbal rehearsing effect.

However, in Experiments 1 and 2, no articulatory suppression was utilised. This might result in participants rehearsing verbally in visual WM tasks, and thus, the value effect might be reduced as potentially they already rehearsed verbally the initial items in the control condition. Therefore, in order to reduce the possible effects of rehearsing, Experiment 3 explored the prioritisation effect in a task with articulatory suppression.

2.4 Experiment 3

Experiment 3 assessed whether individuals can allocate their attention to high-value items in different binding types in WM when items are presented in different locations, and participants engage with articulatory suppression.

In the second experiment, when the items were presented in different locations, the effect of different binding types emerged, whereas no priority effect was found. Thus, one possibility is that the priority effect might disappear in visual WM when participants are able to engage in verbal rehearsal, which is known to be an effective strategy for maintaining items in WM (Camos et al., 2009).

Sandry et al. (2014) examined the durability of the value-directed prioritisation effect with articulatory suppression. Memory performance was better for high-value items compared to low-value ones during articulatory suppression, indicating that individuals are capable of focusing their attention on more valuable information with articulatory suppression. A further indication of the efficacy of value-directed prioritisation in the presence of articulatory suppression was identified by Atkinson et al. (2021) and Roe et al. (2024).

Furthermore, it was shown that articulatory suppression increases dependence on visual memory (Hanley & Bakopoulou, 2003; Salamé & Baddeley, 1986) by preventing verbal recording (Baddeley & Hitch, 1994; Camos et al., 2009). Articulatory suppression was utilised in the majority of studies investigating value-directed prioritisation to eliminate the influence of verbal rehearsal and value effects are generally not negatively affected by articulatory suppression (Atkinson et al., 2018; Hu et al., 2014; Sandry et al., 2014; Roe et al., 2024). Moreover, according to Atkinson et al. (2021), the prioritisation effect was larger under articulatory suppression.

No implementation of articulatory suppression in Experiments 1 and 2 could facilitate verbal rehearsal during the visual WM task. Participants may be unable to show benefits of directing their attention to the prioritised item if they rely on a verbal rehearsal to remember each item on a visual prioritisation test. Participants may have already been verbally rehearsing the initial items in the no-priority condition; thereby, this can limit the emergence of the difference between the prioritised and non-prioritised first item. This is particularly critical in the present experiment since the first item was prioritised in the priority condition. Therefore, in order to ensure that participants remain committed to a visual-based strategy, the application of articulatory suppression might be beneficial. Consequently, considering that the value-directed prioritisation effect can be observed when the ability to engage in verbal rehearsal is reduced, it was decided to use AS in experiment 3.

2.4.1 Method

2.4.1.1 Participants

Twenty-seven students (aged 18-29 years; M = 19.56; SD = 2.10; 20 females) recruited from the University of Leeds participated in this experiment. Most participants were reimbursed for their time with course credits. They were all native English speakers, and none reported a history of neurological disorders. The participants had a correct or corrected-to-normal vision and no colour blindness. Informed consent was acquired in accordance with the guidelines set by the University of Leeds Psychology Ethics Committee (Ethics reference number: PSC-325).

2.4.1.2 Design and Procedure

The method was closely based on Experiment 2, with the same material set, design, and trial procedure. The only exception is that articulatory suppression was used, which involves repeating one syllable continuously throughout the experiment to prevent verbal rehearsal. Each trial began with the 1000ms presentation of the word "la," which participants were required to repeat until the recall stage. Participants were instructed to produce this sound at a rate of one syllable per second. In addition, an audio recording was included during encoding to determine whether the subject engaged in articulatory suppression. The rest of the trial continued the same as Experiment 2.

Same as with Experiment 2, a 2x2x4 repeated measures design was implemented in each experiment, with two types of binding condition (unitised and spatially separated) and priority condition (priority and no-priority) and probed serial position (SP 1:4). Prioritisation condition, trial, and test procedure was identical with Experiment 2.

2.4.1.3 Data analysis

In this experiment, the outcome variable is the accuracy of recalling the correct colour. The independent variables were binding types (unitised and spatially separated), serial position (SP) (1-2-3-4) and prioritisation (priority and no priority). Thus, the data were subjected to 2 (binding types) x 2 (prioritisation) x 4(SP) repeated measures ANOVA.

Results were initially reported in terms of SP function. The additional planned analysis was conducted at SP1 since the priority manipulations were aimed at this SP. Data analysis was conducted using frequentist and Bayes Factor (BF) methods. The analysis was performed using JASP (Version 0.16) and R.

2.4.2 Results

2.4.2.1 Across Serial Positions

The mean proportion correct in each binding types as a function of priority condition contrasted with the no priority in each SP is displayed in Figure 2.7. The 2 (binding type) x 2 (priority) x 4(SP) repeated measures ANOVA indicated no main effect of priority (Priority *M* = 0.53, SE = 0.02; No Priority *M* = 0.52, SE = 0.02; (F(1,24) = 0.83, p =.371, η_p^2 = .03, η_G^2 = 0.001; BF_{10} = 0.18). A main effect of serial position emerged (F(3,72) = 67.37, $p <$ .001, η_p^2 = 0.74, η_G^2 =0.36; BF_{10} >10,000). Pairwise comparisons revealed significant differences between SP1 (*M* = 0.39, SE = 0.03) and SP3 (*M* = 0.56, SE = 0.03; $p < .001$) and SP4 (*M* = 0.75, SE = 0.03; $p < .001$), between SP2 (M = 0.40, SE = 0.03) and SP3 ($p < .001$) and SP4 ($p < .001$) and between SP3 and SP4 ($p < .001$). A main effect of binding emerged (Unitised *M* = 0.55, SE = 0.02; Separated *M* = 0.49, SE = 0.02; (F(1,24) = 10.77, p = .003, η_p^2 = .31, η_G^2 = 0.02; BF_{10} >10,000) with higher memory in unitised binding relative to spatially separated.

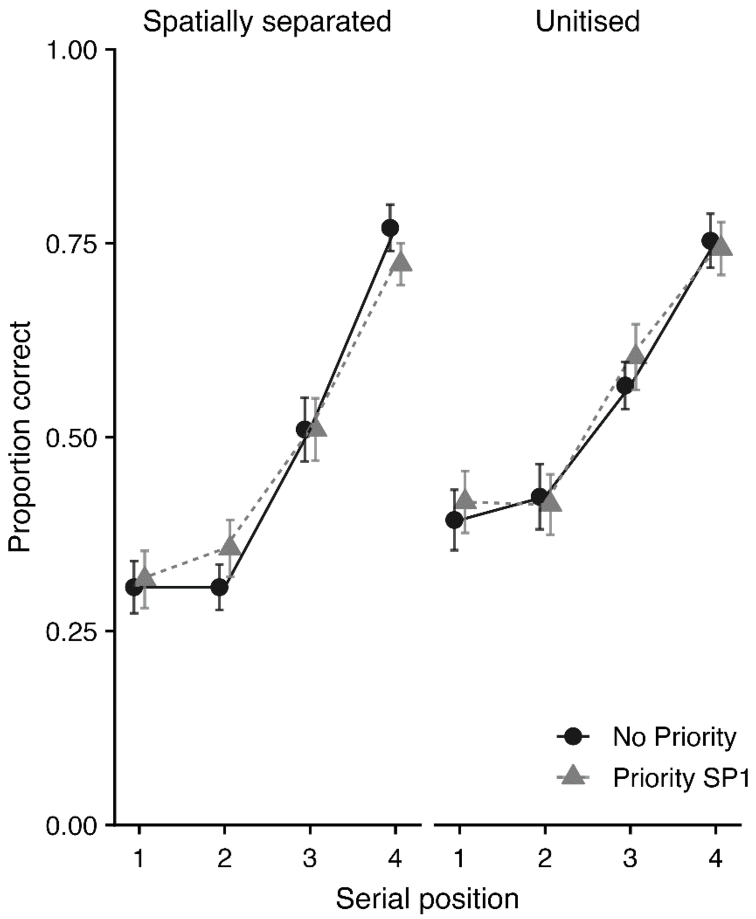

Figure 2.7. Mean proportion correct (with SE) in each binding types condition, priority condition contrasted with the control (no priority) condition from Experiment 3. Data are presented by serial position.

There was no significant interaction between SP and priority (F(3,72) = 0.26, p = .852, η_p^2 = 0.01, η_G^2 = 0.001; BF_{10} = 0.03) (see Figure 2.8.(A)); or between SP and binding (F(3,72) = 2.31, p = .083, η_p^2 = 0.09, η_G^2 = 0.01; BF_{10} = 0.37) (see Figure 2.8.(B)); or between binding and priority (F(1,24) = 0.09, p = .766, η_p^2 = .004, η_G^2 < .001; BF_{10}= 0.13);or for the three-way interaction between

SP and binding and priority (F(3,72) = 1.25, p =.300, η_p^2 = 0.05, η_G^2 = 0.006 ; BF_{10}= 0.18).

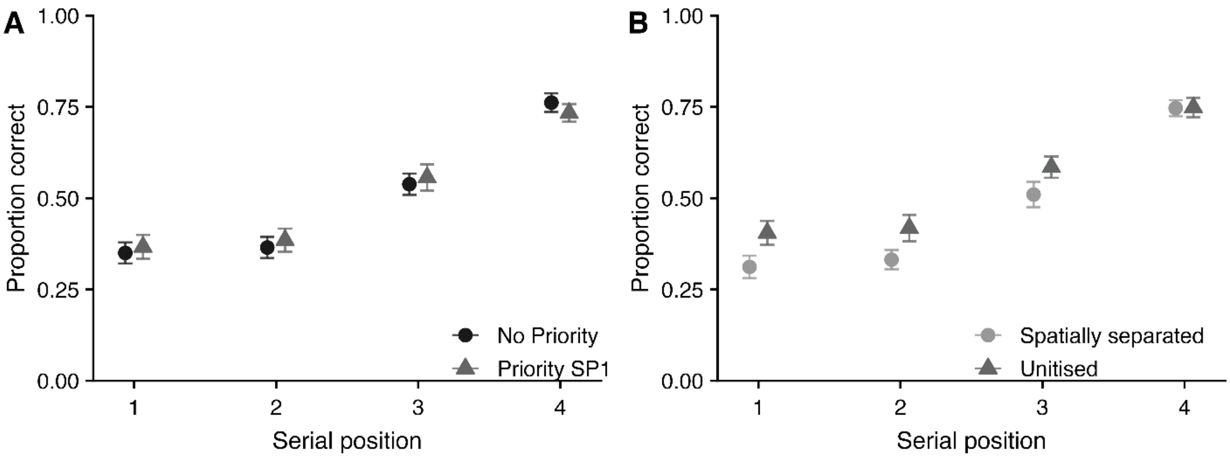

Figure 2.8. A) Mean accuracy (with SE) in experiment 3 as a function of priority and SP, collapsed across binding conditions; B) Mean accuracy (with SE) as a function of the binding type and SP, collapsed across priority conditions. Data are presented by serial position.

2.4.2.2 Serial Position 1

Further analysis was conducted at SP1 as the priority manipulation was targeted at this SP. To investigate the interaction between priority condition and binding type, a 2 (Priority condition) × 2 (Binding type) repeated-measures ANOVA was conducted. There was no significant main effect of priority (Priority M = 0.40, SE = 0.03; No Priority M = 0.37, SE = 0.03; F(1,24) = 0.69, p = 0.413,

η_p^2 = 0.03, η_G^2 = 0.004; BF_{10} = 0.27), with no increase in the performance for the prioritised item. There was a significant main effect of binding (Unitised SP1 *M* = 0.43, SE = 0.03; Separated SP1 *M* = 0.34, SE = 0.03; $F(1,24) = 6.45$, *p* =.018, η_p^2 = 0.21, η_G^2 = 0.04; BF_{10} = 5.07); participant's performance was higher in unitised binding. There was no significant interaction between priority condition and binding type ($F(1,24) = 0.34$, $p = 0.563$, η_p^2 = 0.01, η_G^2 = 0.002; BF_{10}= 0.33).

2.4.3 Discussion

Similar to the first two experiments, the results of Experiment 3 showed that while there was a higher performance on the last item (recency effect), no priority effect emerged. As in Experiment 2, there was a binding effect, with higher memory performance in unitised binding than spatially separated. Additionally, there was no interaction between SP, binding, and priority, nor was there any three-way interaction.

The findings when utilising articulatory suppression did not considerably differ from the previous experiment. Therefore, although articulatory suppression minimised the potential verbal encoding in a visual task to increase reliance on visual memory (Baddeley & Hitch, 1994; Camos et al., 2009; Hanley & Bakopoulou, 2003; Salamé & Baddeley, 1986), this did not result in the emergence of a priority effect.

Another factor of the null prioritisation effect might be a lack of motivation. It has been demonstrated that value-directed prioritisation requires sufficient motivation (Atkinson et al., 2019; Berry et al., 2018). The reason for the absence of a prioritisation effect in the first three experiments could be participants did not engage well with the task requirements in the online experimental context. Therefore, conducting this experiment in person could increase motivation for the next experiment.

2.5 Experiment 4

There was no priority effect observed throughout the three experiments, whereas previous studies consistently indicated that individuals could prioritise higher-value items (Atkinson et al., 2018; 2019; 2021; Hu et al., 2014; 2016; Hitch et al., 2018; Sandry et al., 2014; Sandry & Ricker, 2020). However, this research was lab-based, while the current three experiments were online. It can be assumed that there is a more controlled environment in lab-based experiments. Additionally, in online experiments, there might be a lack of motivation to complete tasks, which is in line with the reported 17% loss of data quality in the online experimental context compared to in-person, as reported by Uittenhove et al. (2022). Additionally, taking into account that motivation plays a substantial role in prioritisation tasks (e.g. Atkinson et al., 2019; Berry et al., 2018) and as it demonstrated by Atkinson et al. (2019) prioritisation ability can appear when participants are motivated adequately.

Experiment 4 examined whether individuals can direct their attention to high-value items in different binding types in WM by testing in person. Adjustments made in Experiment 3 remained constant; items were presented in different locations, and AS was used. Conducting the experiment in person could serve to increase participants' motivation and encourage the strategic direction of attention to higher-value items.

2.5.1 Method

2.5.1.1 Participants

Thirty-one students (aged 18-30 years; M = 20.32; SD = 2.34; 25 females) recruited from the University of Leeds participated in this experiment. Most participants were reimbursed for their time with course credits. They were all native English speakers, and none reported a history of neurological disorders. The participants had a correct or corrected-to-normal vision and no colour blindness. Informed consent was acquired in accordance with the guidelines set by the University of Leeds Psychology Ethics Committee (Ethics reference number: PSC-325).

2.5.1.2 Design and Procedure

The method was closely based on Experiment 3, with the same material set, design, and trial procedure. The only exception is that the experiment was conducted in person. Regarding this, there was a difference in the test phase: while participants in the online experiment were asked to type their response via keyboard, in this experiment, participants were asked to verbally recall the name of the colour that was presented with that shape. The experimenter recorded their answers and then pressed the enter button to progress to the next trial.

Same as with Experiment 3, a 2x2x4 repeated measures design was implemented in each experiment, with two types of binding condition (unitised and spatially separated) and priority condition (priority and no-priority) and probed serial position (SP 1:4). Prioritisation condition, trial, and test procedure was identical to Experiment 3.

2.5.1.3 Data analysis

In this experiment, the outcome variable is the accuracy of recalling the correct colour. The independent variables were binding types (unitised and spatially separated), prioritisation (priority and no priority) and serial position (1-2-3-4). Thus, the data were subjected to 2 (binding types) x 2 (prioritisation) x 4(SP) repeated measures ANOVA. Results were initially reported in terms of SP function. The additional planned analysis was conducted at SP1 since the priority manipulations were aimed at this SP. Data analysis was conducted using frequentist and Bayes Factor (BF) methods. The analysis was performed using JASP (Version 0.16) and R.

2.5.2 Results

2.5.2.1 Across Serial Positions

The mean proportion correct in each binding types as a function of priority condition contrasted with the no priority in each SP is displayed in Figure 2.9. The 2 (binding type) x 2 (prioritisation) x 4 (SP) repeated measures ANOVA indicated no main effect of prioritisation (Priority *M* = 0.56, SE = 0.02; No priority *M* = 0.55, SE = 0.02; (F(1,30) = 0.79, p =.380, η_p^2 = 0.03, η_G^2 = 0.001; BF_{10} = 0.18). A main effect of serial position emerged (Greenhouse-Geisser corrected F(1.89, 56.96) = 33.42, p < .001, η_p^2 = 0.53, η_G^2 = 0.28; BF_{10} > 10,000). Pairwise comparisons (corrected using Bonferroni – Holm) revealed significant differences between SP1 (*M* = 0.48, SE = 0.03) and SP3 (*M* = 0.61, SE = 0.03; p = .001), SP1 and SP4 (*M* = 0.73, SE = 0.03; p < .001), SP2 (*M* = 0.40, SE = 0.03) and SP3 (p < .001), SP2 and SP4 (p < 0.001), SP3 and SP4 (p = .002). A main effect of binding type emerged, with higher accuracy in the unitised (*M* = 0.58, SE = 0.02) than spatially separated (*M* = 0.53, SE = 0.02), (F(1,30) = 17.31, p <.001, η_p^2= 0.37, η_G^2 = 0.02; BF_{10} = 11.67).

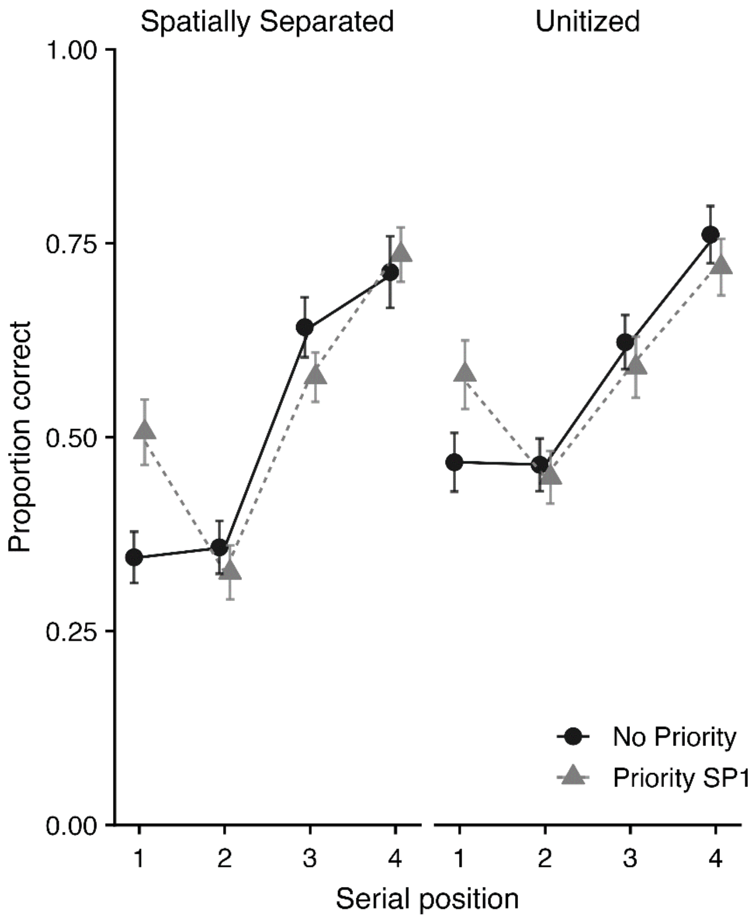

Figure 2.9. Mean proportion correct (with SE) for each binding type, prioritisation, and SP condition in Experiment 4.

There was a significant interaction between SP and prioritisation (Greenhouse-Geisser corrected *F*(2.47,73.97) = 5.95, *p* = .002, η_p^2 = 0.17, η_G^2 = 0.03; BF_{10} = 33.96) and between SP and binding type (Greenhouse-Geisser corrected *F*(2.82, 84.58) = 3.57, *p* = .019, η_p^2 = 0.11, η_G^2 = 0.02; BF_{10}= 1.97). There was no significant interaction between binding type and prioritisation (*F*(1, 30) = 0.26, *p* =.613, η_p^2 = 0.01, η_G^2 < .001; BF_{10}= 0.20); or for the three-way interaction between SP, binding type and prioritisation (*F*(3,90) = .66, *p* =.579, η_p^2 = 0.02, η_G^2 = 0.003 ; BF_{10}= 0.12).

To investigate the interaction between prioritisation and SP, a series of paired sample t-tests were conducted. The mean proportion correct as a function of the prioritisation and SP is displayed in Figure 2.10.(A). A significant difference emerged only at SP1 (prioritised SP), with significantly higher accuracy in the priority condition (M = 0.54, SE = 0.04), than no priority (M = 0.41, SE = 0.03), ($t(30) = 3.91$, $p < .001$, $BF_{10} = 61.63$, $d = 0.70$). No significant differences emerged between priority and no priority conditions at SP2 ($t(30) = -0.86$, $p = .396$, $BF_{10} = 0.27$, $d = -0.16$), SP3 ($t(30) = -1.43$, $p = .164$, $BF_{10} = 0.48$, $d = -0.26$) or SP4 ($t(30) = -0.27$, $p = .792$, $BF_{10} = 0.20$, $d = -0.05$). To sum up, results showed that prioritising the first item increased performance at SP1, but had no significant effect on performance at SP2, SP3 and SP4.

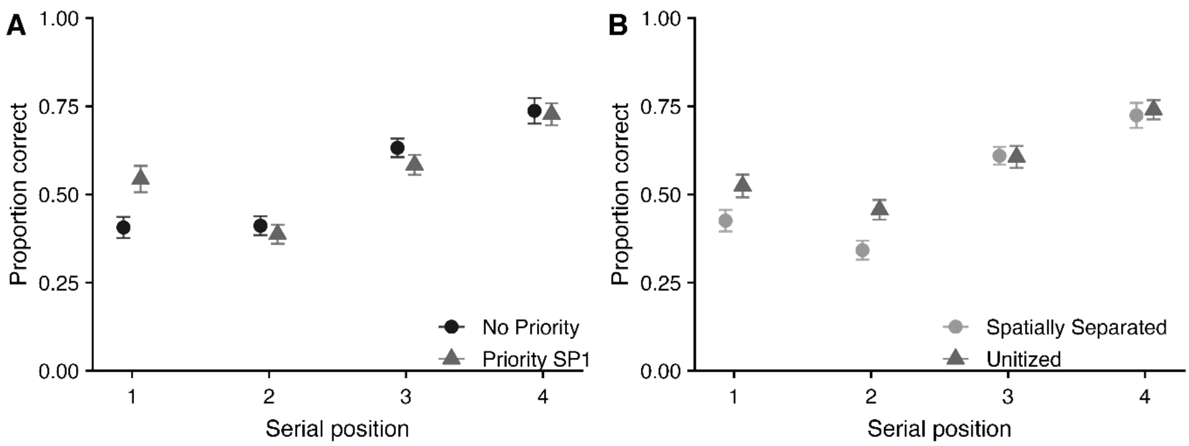

Figure 2.10. A) Mean accuracy (with SE) in Experiment 4 as a function of prioritisation and SP, collapsed across binding type conditions; B) Mean accuracy (with SE) as a function of the binding type and SP, collapsed across prioritisation conditions.

To investigate the interaction between binding type and SP, a series of paired sample t-tests were conducted. The mean proportion correct as a function of the binding type and SP is displayed in Figure 2.10.(B). Participants showed significantly better performance in the unitised binding condition at SP1 (M = 0.52, SE = 0.03), than spatially separated (M = 0.43, SE = 0.03), ($t(30) = 4.06$, $p < .001$, $BF_{10} = 88.54$, $d = 0.73$) and significantly better performance unitised binding condition at SP2 (M = 0.46, SE = 0.03) than spatially separated (M = 0.34, SE = 0.03), ($t(30) = 3.78$, $p < .001$, $BF_{10} = 44.68$, $d = 0.68$). No significant differences emerged between binding types at SP3 ($t(30) = -0.09$, $p = .931$, $BF_{10} = 0.19$, $d = -0.02$) or SP4 ($t(30) = 0.59$, $p = 0.562$, $BF_{10} = 0.23$, $d = 0.11$). To sum up, results showed that accuracy was higher for unitised binding relative to spatially separated bindings at SP1 and SP2, but there was no difference in performance at SP3 or SP4.

2.5.2.2 Serial Position 1

Further planned analysis was conducted at SP1 as the prioritisation manipulation was targeted at this SP. To investigate the interaction between prioritisation and binding type, a 2 (Prioritisation) × 2 (Binding type) repeated-measures ANOVA was conducted. There was a significant main effect of prioritisation ($F(1,30) = 15.27$, $p <.001$, $\eta_p^2 = 0.34$, $\eta_G^2 = 0.09$; $BF_{10} = 49.58$), with higher accuracy in the priority (M = 0.54, SE = 0.04) than no priority condition (M = 0.41, SE = 0.03). There was also a main effect of binding type ($F(1,30) =$

16.45, p <.001 , η_p^2 = 0.35, η_G^2 = 0.05; BF_{10}= 10.85); participant's performance was higher in unitised (M = 0.52, SE = 0.03) than spatially separated binding (M = 0.43, SE = 0.03). There was no significant interaction between prioritisation and binding type (F(1,30) = 0.56, p = 0.462, η_p^2 = 0.02, η_G^2 = 0.003; BF_{10} = 0.40), indicating that increased performance in the priority condition did not differ depending on the binding type. That is, the two manipulations appear to affect performance independently.

2.5.3 Discussion

In line with the first three experiments, there was a recency effect. Differently from the first three experiments, there was a significant interaction between serial position and priority, in which participants showed better memory at SP1 in the prioritisation condition than in the no priority condition. This finding demonstrated further that individuals could allocate their attention to higher-value objects in a visual WM task, consistent with the previous literature (Allen et al., 2021; Atkinson et al., 2018; 2021; Hitch et al., 2018; Hu et al., 2014; 2016). Nonetheless, the prioritisation manipulation did not have a significant overall effect; it did not boost the general WM capacity, but it came with a cost to other items as consistent with previous studies (Astle et al., 2012; Gunseli et al., 2015; Hitch et al., 2018; Hu et al., 2014; 2016). Similar to Experiments 2 and 3, significant binding effects were also observed, whereby the recall performance of participants was higher at the unitised than spatially separated, which can be interpreted as separated binding possibly requiring more capacity than unitised in the WM.

Notably, no significant interactions emerged between binding type and priority or the three-way interaction between SP, binding and priority. This suggests that even though participants showed better overall performance in unitised than separated binding, they can successfully direct their attention to prioritised items in both unitised and spatially separated binding. It is thought that directing attention in prioritisation manipulation relies on executive resources (Hitch et al., 2018; Hu et al., 2014; 2016), but the current results indicated that there was no difference in prioritisation ability between binding types. This suggests that although spatially separated features require more space in working memory, they do not necessitate more executive resources than unitised features. Participants are able to effectively allocate their attention to both forms of binding. Taking this finding, it can be concluded that binding separated features does not require additional attention capacity, and these findings provide further evidence for the conceptualisation that automatic feature binding in the episodic buffer is necessary (Baddeley et al., 2011).

Overall, this in-person experiment resulted in the observation of the predicted priority effect, following its absence in three online experiments. These results demonstrated the critical role of motivation in this particular investigation; this will be further discussed in the next chapters.

Notably, it is crucial to note that although the in-person experiment revealed a priority effect, only a small increase was found in the overall performance between Experiments 3 and 4. Therefore, the possible increase in the motivational context mainly improved the individual's attentional allocation ability and did not have a large effect on the overall WM performance.

Finally, one limitation that should be taken into consideration is that in the first three online experiments participants were required to type their answers on the keyboard in the test phase, while in the fourth in-person experiment they did this verbally and the experimenter recorded their answers. In the online experiment, when participants type their answers on the keyboard, they may spend additional time or become easily distracted, or potentially this can lead to confusion regarding the names of the colours. These effects may be more likely not to be observed in the in-person setting. Although this may not significantly impact the outcome, this difference may also be an important factor to consider as a limitation.

2.6 General Discussion

This thesis chapter explored whether individuals can allocate their attention to higher-value items, specifically when they are presented as unitised and spatially separated shape-colour pairings in online and lab-based experiments. Experiment 1 was conducted online, and the results showed that participants did not successfully allocate their attention to higher point-value items in unitised or spatially separated binding conditions. Additionally, there was no difference in terms of general memory performance between binding types. In experiment 2 (online), the first experiment was repeated but with items in different locations. The findings revealed that participants showed better memory performance in unitised binding than spatially separated. However, again, prioritisation had no effect. Following this, Experiment 3 (online) was a replication of Experiment 2 with utilisation of articulatory suppression. The results of Experiment 3 were similar to Experiment 2: higher memory performance in unitised binding than spatially separated, yet no prioritisation effect. Therefore, it was decided to move to a lab-based experiment; Experiment 4 was a replication of the third experiment in a lab environment. Conducting this experiment in the lab demonstrated that participants successfully prioritised high-value items with no difference across binding types, though again showed overall better performance in unitised binding. This indicates that participants can allocate their attention to higher-value items in both binding conditions when they are in a more controlled environment with the possibility of higher motivation. However, spatially separating the features of items does not cause a decreased ability to direct attention. As a whole, the findings of this chapter provide further evidence that the prioritisation effect can be observed effectively in both unitised and spatially separated binding types when participants are motivated sufficiently. However, understanding how this effect occurs requires further interpretation.

2.6.1 Effect of Motivation

The appearance of the priority effect in the in-person experiment, which was absent in all three online experiments, suggests that motivation is a crucial factor in allocating attention to high-value items. Previously, the critical role of motivation was observed in prioritisation tasks in the 7 to 10-year-old group; while the initial investigation showed that children failed to prioritise (Berry et al., 2018), further research revealed that they were capable of doing so when sufficiently motivated (Atkinson et al., 2019).

Similarly, in the online experiment, it appears that participants could not be motivated enough to prioritise the first item, but in the lab environment, this motivation is higher due to a more controlled environment. A recent study conducted by Uittenhove and colleagues (2022) tested the data quality in different online testing platforms and lab-based studies, and the findings suggested there was a 17% loss in data quality when the experiments were conducted online compared to in person. Therefore, consistent with the previous studies, current findings indicated the increased motivational effect in lab-based experiments, which is critical for prioritisation manipulation.

Additionally, it is important to note that, considering, previous lab studies demonstrated consistent priority boost in the high-value items in comparison to items with equal or no value (Allen & Ueno, 2018; Atkinson et al., 2018; Berry et al., 2018; Hitch et al., 2018; Hu et al., 2014; 2016; Sandry et al., 2014; Sandry & Ricker, 2020) and this effect was not observed in present three online experiments. However, it is worth noting that care needs to be taken when comparing across different testing contexts, and it cannot be necessarily assumed that reliable lab findings can generalise to online settings.

2.6.2 Effects of Prioritisation and Recency

The consistent recency effect throughout four experiments shows that recall was higher for the last seen item. In line with these findings, Hu et al. (2014) suggested that more recently encountered items are most likely to be retained in FoA due to the fact that when items are presented serially, the FoA shifts consistently to subsequent items. However, to achieve prioritisation, participants needed to shift FoA from the final item to the first item presented in the series through executive processes (Hitch et al., 2018; Hu et al., 2014; 2016). This process can occur when these items are held in FoA for a longer time or more frequently than other items (Hitch et al., 2018; Hu et al., 2016; Sandry et al., 2014).

It is probable that effects arise from a process that requires executive control and occurs during the encoding or maintenance process or both (Hu et al., 2016). Retrospective versus prospective prioritisation research conducted by Allen and Atkinson (2021) showed that prioritisation is more effective when it is conducted during encoding. This finding suggests that value-directed prioritisation may be partially attributable to processes that occur during the encoding (Hitch et al., 2020). Alternatively, the accessibility or availability of items for retrospective prioritisation may be decreased.

Regarding investigating the underlying mechanism of how value-directed prioritisation functions in WM, one possibility is that prioritised items are remembered better since these items are consolidated more effectively in WM (Jolicœur & Dell'Acqua, 1998). However, as De Schrijver and Barrouillet (2017) suggested, a refreshing mechanism might be underlying consolidation. Therefore, another possibility for holding high-value items in a privileged place in WM is attentional refreshing (Atkinson et al., 2022; Hitch et al., 2018; Hu et al., 2016; Souza et al., 2015). In this mechanism, information is maintained by refreshing decaying memory traces (Barrouillet et al., 2004; Barrouillet & Camos, 2012; Barrouillet et al., 2011; Vergauwe & Cowan, 2015).

Moreover, prioritisation studies with a post-stimulus suffix identified that there is a constant shift in the contents of the focus of attention, and prioritised items may be susceptible to interference (Allen & Ueno, 2018; Hitch et al., 2018; Hu et al., 2014; 2016). Since the content of FoA was displaced by subsequent objects, the representation could remain active by requiring extended periods of time to refresh the more valuable item (Hitch et al., 2018). Therefore, it can be suggested that high-value items can be held in a privileged state in WM by attentional refreshing, which requires executive resources.

2.6.3 Effect of Binding

Dissimilar to the requirement of executive resources in prioritisation, features binding does not seem to rely on executive resources; findings suggested relatively automatic binding consistent with the literature (Allen et al., 2006; 2009; 2012; Baddeley et al., 2011; Ecker et al., 2013).

Initially, in Baddeley's multicomponent model of WM, binding was assumed to depend on the limited capacity of the central executive. Nevertheless, the absence of a relationship between concurrent tasks and binding indicated that the binding process occurs relatively automatically and is not attentional demanding (Allen et al., 2006; 2009; 2012; Delvenne et al., 2010; Morey & Bieler, 2013; Karlsen et al., 2010; Vergauwe et al., 2014; Yeh et al., 2005). Previous studies showed that prioritisation of high-value objects requires executive functions (Hitch et al., 2018; Hu et al., 2014; 2016). However, the results of the current study showed that prioritisation ability did not decline across two binding types. If the binding also required executive resources, the ability to prioritise high-value items spatially separate would decrease since executive resources would need to be shared between binding and prioritisation simultaneously. Since the participants were able to prioritise successfully in both binding types, it suggests that there is no requirement for an additional executive resource for spatially separated. This provides further evidence that binding does not depend on the allocation of an additional executive resource and supports the conceptualisation that automatic feature binding in the episodic buffer (Allen et al., 2012; Baddeley et al., 2011).

Additionally, in the multicomponent model, the episodic buffer is tasked with retaining and binding information in the form of an integrated format (Baddeley, 2000; Baddeley et al., 2010). Furthermore, recently, FoA has been described as a subsystem incorporated with an episodic buffer responsible for holding items in a privileged state (Hitch et al., 2020; Hu et al., 2014). In this case, the episodic buffer is responsible for both binding and retaining items and prioritising high-value items by directing FoA. Therefore, the capability of an episodic buffer would be reduced if it tries to achieve binding object features and prioritise information simultaneously. However, if the binding process occurs automatically in the episodic buffer (Allen et al., 2012; Baddeley et al., 2011; Ecker et al., 2013), binding of objects' features is not anticipated to disrupt the prioritisation of information. Thus, these aspects also provided further support for the conception of automatic binding in WM (Allen et al., 2012; Baddeley et al., 2011).

Moreover, even though prioritisation ability was not affected when features were presented spatially separated, the total memory performance was lower in spatially separated binding than in unitised, consistent with Karlsen et al. (2010). Participants were able to achieve prioritisation while items were spatially separated as well as when they were unitised, indicating that binding does not require an additional executive function or attentional resource. However, the lower overall memory performance in spatially separated can be interpreted as separating features can occupy more space in the capacity. In account of the recently accepted form of the episodic buffer, it stores chunks of information passively and does not require extra attention (Allen et al., 2012; Baddeley et al., 2011).

This result contradicts with the suggestion of the Wheeler and Treisman (2002). They suggested that features from distinct dimensions might be stored in parallel but this process requires attention, while the current findings indicated that even though features from same dimension occupy more capacity in the WM this is not more attentionally demanding than unitised items.

One possible explanation could be, as Luck and Vogel (1997) suggested, that WM capacity can be restricted by objects, so in this condition, the memory performance in spatially separated conditions should be much lower than unitised objects such as four objects for unitised is equivalent to eight objects for separated binding. Nevertheless, the findings of the present study demonstrated only slightly lower performance in spatially separated binding relative to unitised. Therefore, it might be concluded that separated features are bound in a form that is not maintained as completely as separate objects. However, this binding does not perform as well as unitised form, but it can still occupy more capacity in WM.

Another related explanation is since separated feature binding showed lower recall performance than unitised consistently (Karlsen et al., 2010), it can be indicated that when features are separated, they are not connected as well as unitised features. One potential underlying mechanism of this limited connection may be the critical role of the location. It is evident that location is a critical determinant of visual WM (Delogu et al., 2014; Delogu & Lilla, 2017). Therefore, displaying the information in distinct locations might have had an effect on visual WM, as previous studies suggested that VWM is highly dependent on location (Jiang et al., 2000; Olson & Marshuetz, 2005; Schneegans & Bays, 2017). Schneegans and Bays (2017) utilised both spatial and non-spatial report features to examine the effect of location in visual WM. The findings of this study indicated that there was a spatial binding mechanism between the colour and orientation of each object, and they are independently associated with and only linked by their shared location. Thus, if the visual features are linked through their location, the diminished performance in the spatially separated binding can be explained by the location effect.

Consistent with this location effect, another important finding in this chapter was while all items were presented in the same location in Experiment 1, there was no difference in the performance between binding conditions, but in Experiments 2, 3 and 4 (items presented in different locations) overall better performance in unitised emerged compared to spatially separated. As suggested earlier, this finding can indicate an overwriting effect (Oberauer & Kliegl, 2006) as all items are presented in the same location; since various objects might compete for the same feature, overwriting can occur, resulting in that characteristic being lost in one of the representations. Also, the result of the current study further supports Pertzov and Husain (2014) and Schneegans et al. (2021) by demonstrating presentations of items in different locations increased the performance in unitised binding. It can be concluded that spatial location may have a significant impact on the retention of visual memories (Delogu et al., 2014; Delogu & Lilla, 2017; Jiang et al., 2000; Olson & Marshuetz, 2005; Pertzov & Husain, 2014; Schneegans & Bays, 2017; Schneegans et al., 2021) demonstrating objects in different positions aids in the differentiation of them in working memory.

Furthermore, the presentation of items in different locations increased the memory of unitised binding but not spatially separated. It was suggested that location has an important role specifically in unitised feature binding in WM

(Treisman & Zhang, 2006) and features of items bound to each other via their shared location (Kovacs & Harris, 2019; Schneegans & Bays, 2017; 2019; Schneegans et al., 2022). If features connect via their shared location, it might be the case that in unitised, they were connected automatically as they are in the same location but not spatially separated.

However, it is important to indicate that there are some conflicting findings demonstrating that feature binding can be maintained in WM without spatial information being required and location alterations only had an impact on performance in cases where the task required spatial encoding (Allen et al., 2015; Woodman et al., 2012). Given that the binding types were spatially separated and unitised in the current experiments, there might be a requirement of implicit or explicit location encoding. Therefore, further research should continue to explore the role that location plays across different binding contexts.

2.7 Conclusion

In summary, value-directed prioritisation can improve memory for higher-value items in unitised and spatially separated binding conditions when participants are motivated sufficiently. This suggests that binding does not allocate extra attentional capacity (Allen et al., 2006; 2009). Furthermore, since the episodic buffer is both responsible for binding and holding information and with FoA function maintaining specific items in privileged state (Hu et al., 2014;

Hitch et al., 2020), the absence of any impact of binding on the priority ability indicates that binding takes place automatically in the episodic buffer (Baddeley et al., 2011).

Another notable finding was that there was better overall performance in unitised binding than spatially separated binding, at least when location varied. This can be explained by the possible effect of presenting features of items in spatially separated locations (Schneegans & Bays, 2017).

Moreover, for both binding types, presentations of items in different locations on the screen rather than the screen centre emerged as better memory in unitised binding. This provides further evidence that in sequential presentation, recall of visual items can decline when all items are shown at the same location in unitised binding (Pertzov & Husain, 2014).

Finally, there was a null effect of prioritisation throughout three online experiments, but it appeared when the experimental context was moved to the lab. In lab experiments, it is likely that participants can be motivated more to achieve tasks. This may show the critical role of motivation in prioritisation studies.

CHAPTER 3

PRIORITISATION EFFECTS IN UNITISED AND CROSS-MODAL BINDING IN WORKING MEMORY

3.1. Introduction

Chapter 2 illustrated that the prioritisation effect could be observed in unitised and spatially separated binding at least in controlled lab setting conditions. It has also been observed in numerous studies that participants are capable of directing their attention to particular items, which is a necessity for the prioritisation method (Allen & Ueno, 2018; Atkinson et al., 2018; 2019; 2020; Roe et al., 2024). The findings of Chapter 2 provide further support to these findings by demonstrating that prioritisation is also achievable when features of items are both unitised and spatially separated. The current chapter aimed to further extend this by exploring whether individuals are also capable of prioritising items in cross-modal binding.

As discussed in previous chapters, the prioritisation method requires the ability to direct attention to a specific item, and it is assumed that this process relies on executive resources (Hitch et al., 2018; Hu et al., 2014; 2016). However, there is no general acceptance of how this process occurs in feature-binding. Previous studies mostly showed that binding is not more attentionally demanding by testing memory with extra attentional demanding concurrent tasks and the results generally showed that this concurrent task was not more detrimental for binding (Allen et al., 2006; 2009; Delvenne et al., 2010; Hitch et al., 2018; Hu et al., 2014; 2016; Langerock et al., 2014; Morey & Bieler, 2013; Vergauwe et al., 2014; Yeh et al., 2005). However, there are some other studies that argue that visual feature binding may not occur automatically and requires attention (Brown & Brockmole, 2010; Fougnie & Marois, 2009; Zokaei et al., 2014). Consistently, Elsley and Parmentier (2009) investigated whether binding between letters and spatial locations requires attentional control. The execution of concurrent tasks disrupted the association between letters and spatial locations. Based on these findings, Elsley and Parmentier suggested that binding across domains is attentionally demanding.

Furthermore, prioritisation studies that present similar suffix items after the study array show that the presence of suffixes had a negative impact on both the value and recency effect. Specifically, in the condition where suffixes were introduced, the recall of the most recent and high-value item was diminished. This suggests that FoA has a constant shift to subsequent items; therefore, the maintenance of these bound objects is susceptible to interference (Allen & Ueno, 2018; Hitch et al., 2018; Hu et al., 2014; 2016). Overall, even though there are mixed results, it can be inferred that findings mostly suggest the visual feature binding structure in WM is relatively automatic but fragile to perceptual interference by suffixes.

In the concept of the multicomponent model of WM, the episodic buffer is responsible for holding and binding information as chunks of data in the FoA, as identified by Hu et al. (2014) and Hitch et al. (2020). Since the episodic buffer is responsible for both holding and binding information, the ability to hold prioritised items might be reduced if binding requires executive attention.

However, if automatic feature binding occurs before information enters the episodic buffer, as suggested in Baddeley et al. (2011), we can expect binding will not cause a disrupting effect on prioritised information.

Nonetheless, studies investigating the relationship between attention and binding generally focused on unitised (colour-shape) binding (Allen et al., 2012; Brown & Brockmole, 2010; Delvenne et al., 2010; Morey & Bieler, 2013; Yeh et al., 2005). It is also important to examine binding across different domains to discover the binding mechanism in WM.

Cross-modal binding can be defined as a memory for associations between features that are encountered in different modalities. The typical experimental implementation of cross-modal binding is a simultaneous presentation of audio and visual formatting features of the items. As the information is processed from different modalities, cross-modal binding can be discussed in terms of domain-general (Cowan, 1999; Oberauer, 2002) and domain-specific approaches to WM (Baddeley & Hitch, 1974). Domain general approaches claim shared attentional resources across domains without differentiating audio and visual memory representations (Barrouillet et al., 2007). Domain-specific approaches suggest information from different modalities is represented separately in WM. However, Baddeley's multicomponent model also includes domain-general components such as the episodic buffer (Baddeley, 2000). According to the multicomponent model of WM, a phonological loop processes auditory information and a visuospatial sketchpad processes visual information, and this information is bound in the modality-general episodic buffer.

Moreover, Gao et al. (2017) tested cross-modal binding in a condition with features of items separated by modality (auditory and visual), spatially and temporally, utilising a secondary object-feature report task. The secondary task increased deterioration in the binding task compared to features. However, on the contrary, the study of Allen et al. (2009) explored whether concurrent tasks impact different binding types (unitised- spatially separated - cross-modal) differently. The results indicated impairment in memory performance between high concurrent loads compared to low loads but no difference between the binding types. Therefore, these results showed that cross-modal binding doesn't require any more attention than unitised.

Taking these together, there is mixed evidence that considers whether binding across domains is more attentionally demanding than unitised objects. Therefore, as prioritisation is assumed to rely on executive resources (Hitch et al., 2018; Hu et al., 2014; 2016), investigating prioritisation across different binding can provide further understanding regarding the role of attention in different binding types.

Regarding the prioritisation effect in cross-modal binding, Johnson and Allen (2023) explored binding between colour-olfactory information to explore the prioritisation effect in cross-modal binding. In this study, each odorant was presented in different coloured cubes serially to create a binding between the colour of the cube and the odour. The initial experiment showed that participants were able to bind, and the subsequent experiments examined whether the prioritisation effect could be observed in these bound representations. The results revealed only a weak effect of prioritisation, with a slight increase (4%) in accuracy at the prioritised SP compared to the control condition. In the priority condition, a reduction in accuracy at other SPs was also observed (trade-off effect). These results might show the difficulty of prioritising olfactory-colour binding or, more generally, of doing so for cross-modal binding. The limited effect of prioritisation might be accounted for by dependence on executive resources in cross-modal binding, as conducting both prioritising and binding across modalities tasks simultaneously restricted the capacity of executive function. Another more specific possibility is that this finding shows it is more difficult to prioritise olfactory stimuli. To reveal whether this effect reflects olfactory processing or cross-modal binding more generally, testing with different modalities can provide further comprehension.

Therefore, the findings of previous studies showed that the nature of binding still needs further investigation. The binding types investigated in this study are unitised (coloured shapes) and cross-modal (shapes presented visually in synchrony with auditory colour names). Given the ongoing controversy with regard to the automaticity of binding and the potential for extra attentional load, this study aimed to examine the prioritisation method in the various binding types. For example, is it more difficult to prioritise items in cross-modal binding than unitised? If participants' prioritisation ability decreases in the cross-modal condition, this could indicate that these binding types are more attentionally demanding, so participants do not as successfully direct attention to a specific item.

3.2. Experiment 5

Even though binding has been the subject of much research (Allen et al., 2006; 2012; Delvenne et al., 2010; Geldorp et al., 2015; Morey & Bieler, 2013), there is limited evidence regarding binding from different dimensions. It would be enlightening to investigate whether individuals can direct their attention when information is presented in visual and auditory modalities simultaneously. This could provide further understanding about selective attention and binding information from different modalities and whether this occurs automatically or requires extra attentional capacity.

Experiment 5 aimed to explore whether individuals can direct attention to more valuable information in unitised and cross-modal binding in WM tasks. In this experiment, binding types and priority conditions were manipulated. The two binding types manipulated in this experiment were unitised and cross-modal. In the unitised condition, colours and shapes were presented as single-coloured shapes. In the cross-modal binding condition, shapes were presented visually in synchrony with auditory colour names, the same as in previous studies (Allen et al., 2009).

Prioritised items showed persistently higher recall accuracy in WM (Atkinson et al., 2018; Hu et al., 2014). This effect has been observed across a variety of modalities (visual stimuli; Hitch et al., 2018; Hu et al., 2014; Hu et al., 2016; Infanti et al., 2015) ; Sandry & Ricker, 2020; auditory-verbal stimuli: Atkinson et al., 2021; colour-olfactory binding: Johnson & Allen, 2023; tactile domain: Roe et al., 2024) Nevertheless, prioritisation effects in the visual-auditory binding have not been examined in any research so far.

Based on the findings of previous studies, recall performance is expected to be better in the prioritised SP in the priority condition than in the same SP in both unitised and cross-modal binding, compared with the no priority condition.

In terms of overall memory performance, no overall differences in memory performance for unitised and cross-modal memory are expected, which is in line with previous research (Allen et al., 2009). Moreover, it is also predicted that participants can prioritise high-value SP in cross-modal binding as effectively as unitised. This finding would also be consistent with previous literature, such as Atkinson et al. (2021), which demonstrated that the prioritisation effect can be observed in auditory-verbal stimuli. In terms of cross-modal binding, there is evidence of a small effect of prioritisation on colour-olfactory binding (Johnson & Allen, 2023). In light of these findings, the prediction was that individuals could perform prioritisation in both binding types, and investigating this prediction will develop further knowledge about the ability to allocate attention in unitised and cross-modal binding.

3.1.1 Method

3.1.1.1 Participants

Thirty students (aged 18-22 years; M = 19.23; SD = 1.04; 25 females) recruited from the University of Leeds participated in this experiment. Participants reimbursed for their time with course credits. They were all native English speakers, and none reported a history of neurological disorders. The participants had a correct or corrected-to-normal vision and no colour blindness. Informed consent was acquired in accordance with the guidelines set by the University of Leeds Psychology Ethics Committee (Ethics reference number: PSYC-608).

3.1.1.2 Design and Procedure

The method was closely based on Experiment 4, with the same material set, design, and trial procedure. The only exception is that participants completed cross-modal binding conditions instead of spatially separated binding. In cross-modal binding conditions, shapes were presented visually in synchrony with auditory colour names (see Figure 3.1.). The colour names were presented to the participants through headphones, varying between around 450-600ms per stimulus.

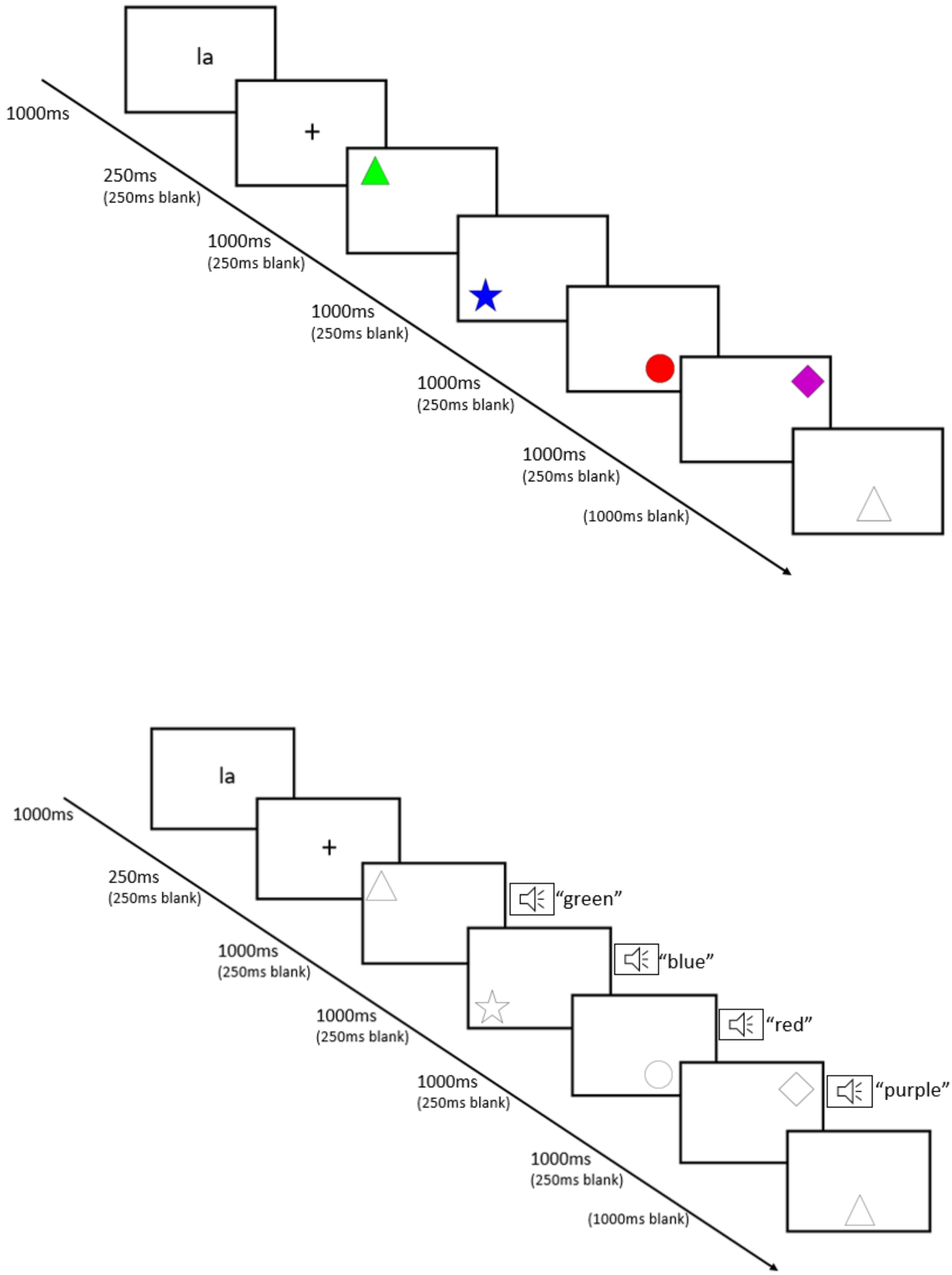

Figure 3.1. Illustration of the paradigm used in Experiment 5.

Figure 3.1. shows the experimental paradigm that was implemented. The procedure was the same as in Experiment 4 for unitised conditions. In

cross-modal conditions, each shape was paired with an auditory colour name. Four paired visual and audio stimuli in each trial were serially presented, after which the visual test trial followed. The test trial was always a shape and provided in the visual modality, and as in Experiment 4 participants needed to recall the name of colour that was paired with the shape.

Same as with Experiment 4, a 2x2x4 repeated measures design was implemented in each experiment, with two types of binding condition (unitised and cross-modal binding) and priority condition (priority and no-priority) and probed serial position (SP 1:4). Prioritisation condition, trial, and test procedure was identical with Experiment 4.

3.1.1.3 Data analysis

In this experiment, the outcome variable is the accuracy of recalling the correct colour. The independent variables were binding types (unitised and cross-modal), prioritisation (priority and no priority) and SP (1-2-3-4). Thus, the data were subjected to 2 (binding types) x 2 (prioritisation) x 4(SP) repeated measures ANOVA.

Results were initially reported in terms of SP function. The additional planned analysis was conducted at SP1 since the priority manipulations were aimed at this SP. Data analysis was conducted using frequentist and Bayes

Factor (BF) methods. The analysis was performed using JASP (Version 0.16) and R.

3.1.2 Results

3.1.2.1 Across Serial Positions

The mean proportion correct in each binding types as a function of priority condition contrasted with the no priority in each SP is displayed in Figure 3.2. The 2(binding type) x 2(prioritisation) x 4(SP) repeated measures ANOVA indicated no main effect of prioritisation (Priority M = 0.55, SE = 0.02; No priority M = 0.56, SE = 0.02; (F(1,29) = 0.21, p =.651, η_p^2 = 0.007, η_G^2 < 0.001; BF_{10} = 0.11) and no main effect of binding type (Unitised M = 0.56, SE = 0.02; Cross-modal M = 0.56, SE = 0.02; F(1,29) = 0.06, p = .817, η_p^2= 0.002, η_G^2 < 0.001; BF_{10}= 0.11).

A main effect of SP emerged (Greenhouse-Geisser corrected F(2.06, 59.65) = 23.63, p < .001, η_p^2 = 0.45, η_G^2 = 0.22; BF_{10} > 1000). Pairwise comparisons (corrected using Bonferroni-Holm) revealed significant differences between SP1 (M = 0.51, SE = 0.03) and SP4 (M = 0.75, SE = 0.02; p < 0.01), SP2 (M = 0.47, SE = 0.03) and SP4 (p < 0.001), and SP3 (M = 0.51, SE = 0.03) and SP4 (p < 0.001).

There was a significant interaction between SP and prioritisation (Greenhouse- Geisser corrected $F(2.08, 60.35) = 3.47$, $p = .035$, $\eta_p^2 = 0.11$, $\eta_G^2 = 0.02$; $BF_{10} = 2.34$, albeit with weak Bayes Factor support), and between SP and binding (Greenhouse- Geisser corrected $F(2.81, 81.55) = 8.40$, $p < .001$, $\eta_p^2 = 0.22$, $\eta_G^2 = 0.03$; $BF_{10} > 10{,}000$). There was no significant interaction between binding type and prioritisation ($F(1, 29) = 0.26$, $p = .612$, $\eta_p^2 = 0.01$, $\eta_G^2 < .001$; $BF_{10} = 0.20$); or for the three-way interaction between SP, binding type and prioritisation (Greenhouse- Geisser corrected $F(2.79, 80.91) = 2.37$, $p = .081$, $\eta_p^2 = 0.08$, $\eta_G^2 = 0.01$; $BF_{10} = 1.65$).

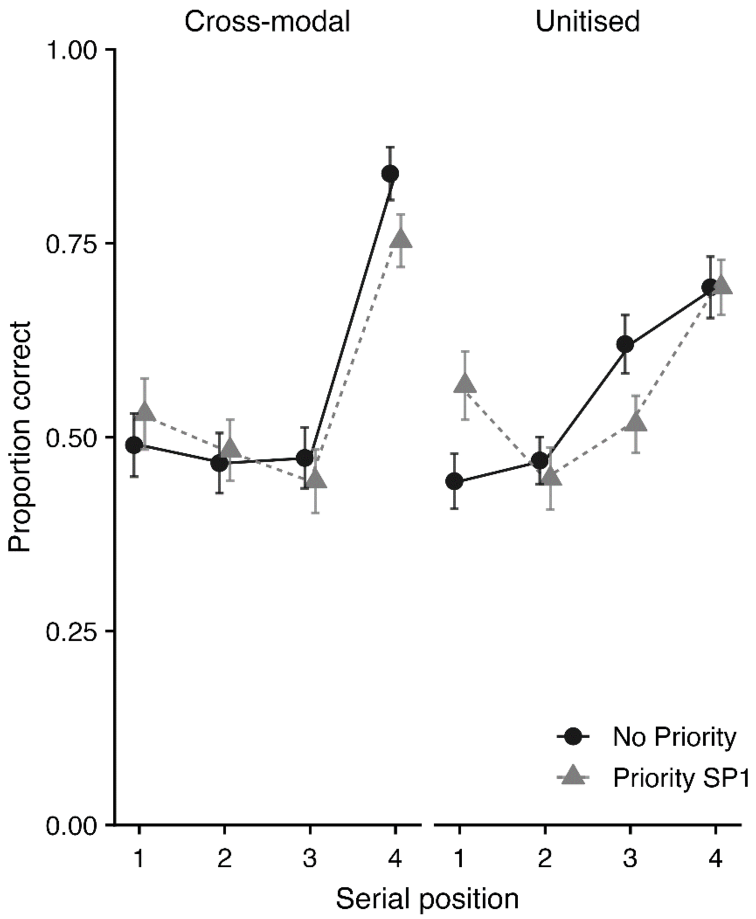

Figure 3.2. Mean proportion correct (with SE) for each binding (cross-modal and unitised) and priority condition in Experiment 5. Data are presented by serial position.

To investigate the interaction between prioritisation and SP, a series of paired sample t-tests were conducted. The mean proportion correct as a function of the prioritisation and SP is displayed in Figure 3.3.(A). Results corrected using Bonferroni-Holm. A significant difference emerged only at SP3; the performance of participants was significantly better in the no priority condition (M = 0.55, SE = 0.03) in SP3 relative to priority (M = 0.48, SE = 0.03), (t(29) = 2.65, p = .013, BF10 = 3.62, d = 0.48). No significant difference emerged at SP1 ($t(29) = -2.01$, $p = .054$, BF10 = 1.12, $d = -0.37$), or SP2 ($t(29) = 0.11$, $p = .917$, BF10 = 0.20, $d = 0.02$), or SP4 ($t(29) = 1.09$, $p = .285$, BF10 = 0.33, $d = 0.20$). To sum up, the results showed that prioritisation of the first item did not have a significant effect on the performance of this item (SP1) but decreased performance at the third item (SP3). Additionally, it had no significant effect on performance at SP2 and SP3.

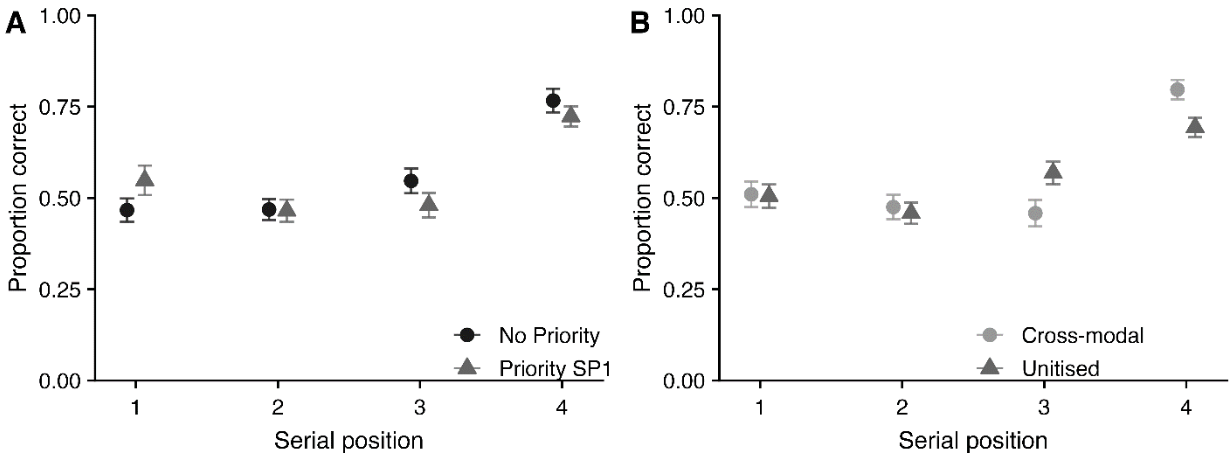

Figure 3.3. A) Mean accuracy (with SE) in Experiment 5 as a function of prioritisation and SP, collapsed across binding conditions; B) Mean accuracy (with SE) as a function of the binding type and SP, collapsed across priority conditions. Data are presented by serial position.

To investigate the interaction between binding type and SP, a series of paired sample t-tests were also conducted. The mean proportion correct as a function of binding type and SP is displayed in Figure 3.3.(B). Participants showed significantly better performance in the unitised binding condition at SP3 (M = 0.57, SE = 0.03) than cross-modal (M = 0.46, SE = 0.04) ($t(29) = -4.25$, $p < .001$, $BF_{10} > 10,000$, $d = -0.78$), but at SP4 significantly better performance was in the cross-modal (M = 0.80, SE = 0.03) than unitised binding (M = 0.69, SE = 0.03), ($t(29) = 3.77$, $p < .001$, BF_{10} >10,000, $d = 0.69$). No significant differences emerged between binding types at SP1 ($t(29) = 0.17$, $p = .870$, $BF_{10} = 0.20$, $d = 0.03$) or SP2 ($t(29) = 0.44$, $p = .664$, $BF_{10} = 0.21$, $d = 0.08$). To sum up, accuracy was higher for unitised bindings relative to cross-modal bindings at SP3 and vice versa at the SP4, but there was no difference in performance at SP1 or SP2.

3.1.2.2 Serial Position 1

A planned 2 (Prioritisation) × 2 (Binding type) repeated-measures ANOVA was conducted focusing on serial position 1. There was a marginal effect of priority, with anecdotal Bayesian support ($F(1,29) = 4.02$, $p = .054$, $\eta_p^2 = 0.12$, $\eta_G^2 = 0.03$; $BF_{10} = 1.28$), characterised by a higher accuracy in the priority (M = 0.55, SE = 0.04) than no priority condition (M = 0.47, SE = 0.04). There was no effect of binding type ($F(1,29) = 0.03$, $p = .870$, $\eta_p^2 < .001$, $\eta_G^2 < .001$; $BF_{10} = 0.26$) or no significant interaction between prioritisation condition and binding type ($F(1,29) = 2.32$, $p = .138$, $\eta_p^2 = 0.07$, $\eta_G^2 = 0.01$; $BF_{10} = 0.86$), indicating that the marginally increased performance in the priority condition was equivalent across the two binding type conditions.

3.1.3 Discussion

In addition to the significant recency effect, findings of the present experiment indicated an interaction between serial position and priority, in which participants showed better memory performance at SP1 in the priority condition than in the no priority condition; however, this effect was only marginal. Results might not be compelling compared with the previous experiment (Experiment 4) in addition to the literature, in which Atkinson et al. (2021) showed a significant prioritisation effect in auditory-verbal stimuli.

Additionally, the results showed that there was no interaction between binding and priority, and there was no three-way interaction between SP, binding and priority. Therefore, although the prioritisation advantage appeared to be numerically larger in the unitised case, it cannot be strongly inferred that prioritisation was less effective in cross-binding, as there was no three-way interaction and no two-way when only SP1 (prioritised SP) was investigated.

Although there was no binding effect, there was an interaction between binding type and SP, with higher memory performance at SP3 in unitised and higher performance at SP4 in cross-modal binding, in addition to no difference at SP1 and SP2. Thus, even though an interaction does not reveal much about differences between binding types, speculatively, it might be concluded that the recency advantage for cross-modal can reflect the auditory component, which has a greater recency effect in audio information than visual. The auditory nature of the object, as opposed to its visual presentation, may have led to a more pronounced recency effect. Hearing the last item just before responding verbally may have resulted in better recall of that item compared to its visual presentation. Despite this minor difference, overall, from the findings of the present experiment, it can be concluded that individuals' overall memory performance does not differ in unitised and visual-auditory cross-modal binding parallel with previous research (Allen et al., 2009).

The results of the present experiment were not clearly revealed about the individual's ability to allocate their attention to higher-value items when items were presented in visual-audio cross-modal binding. One factor to consider might be the nature of the presented audio information, as the presenting longest colour name was 600ms, whereas the presentation time of visual information was always 1000ms. Thus, the participants were presented with visual information for a duration of 1000ms, auditory information for 600ms, and in the last 400ms, they were solely exposed to the visual stimuli. This asynchrony might lead to disparities in the retention of information, and this might be problematic for direct comparisons between visual and cross-modal conditions.

Another factor could be that exposure duration can influence the perceived difficulty in the task. If the task was perceived as easy and had a longer duration, participants may not have been motivated to prioritise by assuming that they would be able to remember the whole array. Therefore, decreasing encoding time might motivate participants to prioritise higher-value items. As an example of this effect, in the study of Allen et al. (2021) (Experiment 2), three items were presented to participants, and they were required to prioritise the second item in the sequence. The effect of the presentation duration of the items was examined using 500ms and 1000ms presentation time in the young and older age groups. Even though there was no significant effect, the numerical differences and limited interaction shown in younger adults indicated that the prioritisation effect was more notable in 500ms presentation time than in 1000ms. The more extended duration period might not be challenging enough to emerge a prioritisation boost. Therefore, the task might be perceived to be an inadequate level of challenge in the present experiment, which may potentially result in a lack of sufficient motivation to accomplish this task successfully. Reducing presentation time to 600ms might not only remove the timing asynchrony but also help encourage participants to prioritise high-value items.

In conclusion, the lack of challenge or disparity between presentation time of different modalities could potentially account for the absence of a priority boost in cross-modal binding. In regard to further investigation of this conclusion, a follow-up experiment with 600ms exposure duration for all items would yield further insightful data regarding prioritisation in cross-modal binding.

3.2 Experiment 6

This experiment aimed to reveal whether individuals can prioritise high-value items when presented with unitised and cross-binding (visual and auditory) conditions. It was identical to experiment 5, with the only difference being that all items were presented for 600ms. Since the previous experiment detected unclear results with longer and uneven presentation duration between visual and auditory stimuli, this experiment aims to repeat that with a shorter and equal exposure duration.

Some research findings indicated that cross-modal binding requires more attention compared to unitised binding (Gao et al., 2017). However, some other studies indicated that binding across different modalities was not more attention-demanding (Allen et al., 2009). Additionally, in the study conducted with older and younger adults, Guazzo et al. (2020) showed that even though memory performance was lower in the older population, their performance was similar in both unitised and cross-modal binding; thus, binding ability did not change with age. Considering the mixed findings regarding visual and audio information in the literature (Allen et al., 2009; Delogu et al., 2014; Delogu & Lilla, 2017; Gao et al., 2017; Guazzo et al., 2020), further research is required to gain a more comprehensive understanding on visual-audio binding.

Additionally, as prioritisation tasks require strategic allocation of attention (Hu et al., 2014), motivation is required to accomplish this task (Atkinson et al., 2019). In the 1000ms exposure duration, the perceived challenge might not be enough to create sufficient motivation to prioritise. Even though there was only a numerical effect, the study conducted by Allen et al. (2021) supports this possibility by demonstrating that young adults show higher prioritisation performance when items are presented with a shorter duration. An extended period of time may not present sufficient difficulty to create a priority boost. As a consequence, the perceived difficulty in the current experiment may not sufficiently motivate participants to successfully complete the task. The prioritisation effect may emerge when the presentation duration is reduced to

600ms. Additionally, the elimination of disparity between presentation times can aid in confidently detecting the emergence of the prioritisation effect.

Therefore, the follow-up experiment explored whether individuals can direct their attention to a high-value item in cross-modal binding as well as unitised binding with 600ms exposure duration for all items in the study array.

3.2.1 Method

3.2.1.1 Participants

Thirty students (aged 18-21 years; M = 19.13; SD = 0.72; 27 females) recruited from the University of Leeds participated in this experiment. Participants reimbursed for their time with course credits. They were all native English speakers, and none reported a history of neurological disorders. The participants had a correct or corrected-to-normal vision and no colour blindness. Informed consent was acquired in accordance with the guidelines set by the University of Leeds Psychology Ethics Committee (Ethics reference number: PSYC-608).

3.2.1.2 Design and Procedure

The method was closely based on Experiment 5, with the same material set, design, and trial procedure. The only exception is that the presentation time of stimuli was 600ms rather than 1000ms. These changes were applied to minimise asynchrony between visual and auditory stimuli as the duration of auditory stimuli (colour names) varied between 444ms and 600ms. Each trial began with the 1000ms presentation of the word "la," which participants were asked to repeat until the retrieval phase to prevent verbal rehearsal. A fixation cross then appeared at the centre of the screen for 250ms, followed by a 250ms blank screen. Each of the four visual stimuli was presented on a white background in the randomly four different corners of the screen for 600ms with an inter-stimulus interval of 250ms. A 1000ms blank screen delay followed the presentation of the four stimuli, and then the test cue was presented.

Same as with Experiment 5, a 2x2x4 repeated measures design was implemented in each experiment, with two types of binding condition (unitised and cross-modal binding) and priority condition (priority and no-priority) and probed serial position (SP 1:4). Prioritisation condition, trial, and test procedure was identical with Experiment 5.

3.2.1.3 Data analysis

In this experiment, the outcome variable is the accuracy of recalling the correct colour. The independent variables were binding types (unitised and cross-modal binding), prioritisation (priority and no priority) and SP (1-2-3-4).

Thus, the data were subjected to 2 (binding types) x 2 (prioritisation) x 4(SP) repeated measures ANOVA.

Results were initially reported in terms of SP function. The additional planned analysis was conducted at SP1 since the priority manipulations were aimed at this SP. Data analysis was conducted using frequentist and Bayes Factor (BF) methods. The analysis was performed using JASP (Version 0.16) and R.

3.2.2 Results

3.2.2.1 Across Serial Positions

The mean proportion correct in each binding types as a function of priority condition contrasted with the no priority in each SP is displayed in Figure 3.4. The 2 (binding type) x 2 (prioritisation) x 4 (SP) repeated measures ANOVA indicated no main effect of prioritisation (Priority *M* = 0.57, SE = 0.02; No priority *M* = 0.56, SE = 0.02; ($F(1,30) = 0.75$, $p = .394$, $\eta_p^2 = 0.02$, $\eta_G^2 = 0.002$; $BF_{10} = 0.15$) and no main effect of binding type (Unitised *M* = 0.57, SE = 0.02; Cross-modal *M* = 0.56, SE = 0.02; $F(1,30) = 0.26$, $p = .615$, $\eta_p^2 = 0.01$, $\eta_G^2 < .001$; $BF_{10} = 0.11$). A main effect of SP emerged ($F(3,90) = 34.07$, $p < .001$, $\eta_p^2 = 0.53$, $\eta_G^2 = 0.25$; $BF_{10} > 1000$). Pairwise comparisons (corrected using Bonferroni-Holm) revealed significant differences between SP1 (*M* = 0.51, SE =

0.03) and SP4 (*M* = 0.75, SE = 0.02; $p < .001$), SP2 (*M* = 0.46, SE = 0.02) and SP4 ($p < .001$), and SP3 (*M* = 0.54, SE = 0.02) and SP4 ($p < .001$).

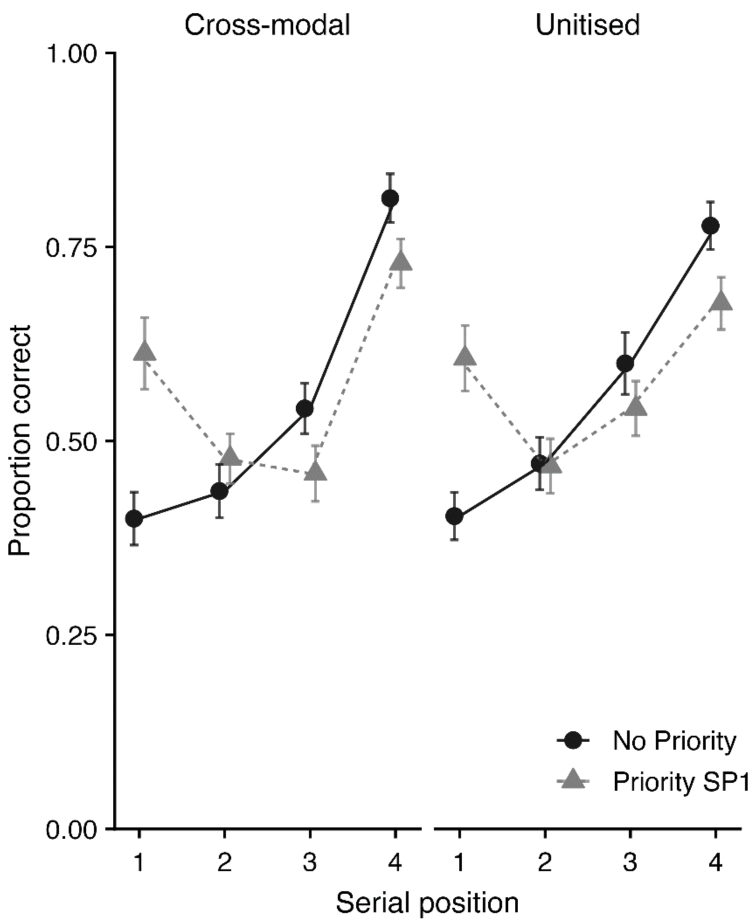

Figure 3.4. Mean proportion correct (with SE) for each binding type (cross-modal and unitised), prioritisation, and SP in Experiment 6.

There was a significant interaction between SP and prioritisation ($F(3,90) = 19.75$, $p < .001$, $\eta_p^2 = 0.40$, $\eta_G^2 = 0.09$; $BF_{10} > 10000$). There was no significant interaction between SP and binding type (Greenhouse-Geisser corrected $F(2.53, 67.59) = 2.97$, $p = .052$, $\eta_p^2 = 0.09$, $\eta_G^2 = 0.01$; $BF_{10} = 0.55$) or between binding type and prioritisation ($F(1, 30) = 0.15$, $p = .699$,$\eta_p^2 = 0.01$, η_G^2

< .001; BF_{10}= 0.33); or for the three-way interaction between SP, binding type and prioritisation ($F(3,90) = 0.27$, p =.850 , η_p^2 = 0.01, η_G^2 = 0.001 ; BF_{10}= 5.74).

To investigate the key interaction between prioritisation and SP, a series of paired sample t-tests were conducted. The mean proportion correct as a function of prioritisation and SP is displayed in Figure 3.5.(A). A significant difference emerged at SP1 (prioritised SP), SP3 and SP4, with significantly higher accuracy in the priority-SP1 condition in SP1 (M = 0.61, SE = 0.04) than no priority (M = 0.40, SE = 0.02), ($t(30) = 4.88$, $p < .001$, $BF_{10} > 10{,}000$, d = 0.88). In contrast, performance was significantly better in the no priority condition at SP3 (M = 0.57, SE = 0.02) than priority (M = 0.50, SE = 0.03), ($t(30) = -2.62$, p = .014, BF_{10} = 3.40, d = -0.47) and significantly better in the no priority condition at SP4 (M = 0.80, SE = 0.03) than priority (M = 0.70, SE = 0.03), ($t(30) = -3.01$, p = .004, BF_{10} = 8.92, d = -0.55). No difference emerged between priority and no priority conditions at SP2 ($t(30) = 0.69$, p = .495, BF_{10} = 0.24, d = 0.12). To sum up, the results showed that prioritising the first item increased performance at SP1, decreased performance at SP3 and SP4, and had no significant effect on performance at SP2.

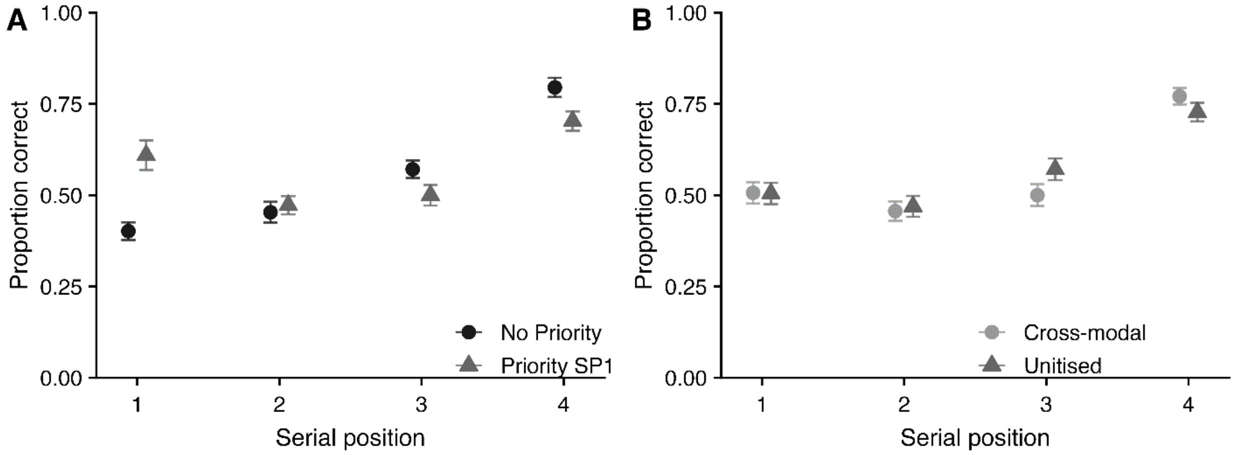

Figure 3.5. A) Mean accuracy (with SE) in Experiment 6 as a function of priority and SP, collapsed across the binding type conditions; B) Mean accuracy (with SE) as a function of the binding type and SP, collapsed across the prioritisation conditions.

3.2.2.2 Serial Position 1

Finally, a planned 2 (Prioritisation) × 2 (Binding type) repeated-measures ANOVA was conducted, targeted at SP1. There was a main effect of prioritisation (F(1,30) = 23.82, p < .001, η_p^2 = 0.44, η_G^2 = 0.19; BF_{10} > 10000), with higher accuracy in the priority condition (M = 0.61, SE = 0.03) relative to the no priority condition (M = 0.40, SE = 0.03). There was no main effect of binding type (F(1,30) = 0.003, p = .955, η_p^2 < .001, η_G^2 < .001; BF_{10} = 0.24), or no interaction between prioritisation and binding type (F(1,30) = 0.03, p = .862, η_p^2 = 0.001, η_G^2 < .001; BF_{10}= 0.27).

3.2.3 Discussion

In line with the previous experiments, findings revealed a significant recency effect. While the previous experiment indicated only a marginal relationship between SP and priority, this effect was significant in the current experiment. Thus, participants showed better memory performance at SP1 in the prioritisation condition than in the no-priority condition. These findings provide evidence that individuals can allocate attention to more valuable items in both visual and visual-auditory attention. This extends previous findings of prioritisation boost on high-value items with visual stimuli (Allen et al., 2021; Hitch et al., 2018; Hu et al., 2014; 2016), auditory-verbal stimuli (Atkinson et al., 2021), olfactory-visual stimuli (Johnson & Allen, 2023) and in the tactile domain (Roe et al., 2024), illustrating that the prioritisation effect can be observed across WM domains and is not modality-specific.

As in Experiment 5, there was no binding effect; in terms of overall performance between binding types, the memory performance of participants was comparable, suggesting that connecting information from different modalities does not impact WM capacity (Allen et al., 2009; Atkinson et al., 2021; Guazzo et al., 2020; Johnson & Allen, 2023).

Notably, there was no interaction between binding and priority, nor was there a three-way interaction between SP and binding and priority. Regardless of binding type, participants focused their attention on prioritised items. These findings provide further evidence for the automatic feature binding that occurs in the episodic buffer and for this component to be modality-general in nature (Baddeley et al., 2011).

Additionally, it is crucial to note that a significant priority effect was observed in both binding types. One reason for the appearance of a priority boost is the equalising of the exposure duration for the visual and audio components. As there is improved synchrony between components, directing attention to certain items can be more feasible. Another reason may be shorter exposure time; the task might be more challenging with shorter exposure duration, resulting in participants directing their attention strategically to high-value items, which is consistent with a numerically higher prioritisation boost with shorter exposure duration observed in Allen et al. (2021). This shows the critical point of the presentation duration. Based on the results, it is not possible to conclude that better prioritisation ability in visual binding is due to extra attentional demanding cross-modal binding (Gao et al., 2017; Johnson & Allen, 2023).

As the two previous experiments indicate, the prioritisation boost came with a cost on some other items in the study array and did not cause an overall improvement in memory. These findings are in consonance with the literature, which has discovered that improvements to a specific item may result in decreased performance for other items that are presented during the same trial (Atkinson et al., 2018; Astle et al., 2012; Chun et al., 2011; Hitch et al., 2018; Hu et al., 2014; 2016).

3.3 Cross-experiment Analysis

Two experiments in this chapter showed somewhat differing results in prioritisation effects. It has appeared that the differences between items' presentation times can change the effect of priority boost. This is consistent with numerical evidence in Allen et al. (2021). To examine further the effect of presentation time, the data from two experiments were merged and analysed together in this section.

3.3.1 Data analysis

In this section of the thesis, cross-experiment analyses were conducted by merging the data from two experiments in this chapter. The outcome variable is the accuracy of recalling the correct colour. The independent variables were binding types (unitised and cross-modal binding), prioritisation (priority and no priority), serial position (1-2-3-4) and timing (1000ms and 600ms). Thus, the data were subjected to a mixed design with 2 (binding types) x 2 (prioritisation) x 4 (SP) repeated measures and x 2 (timing) between-subjects ANOVA.

3.3.2 Results

3.3.2.1 Across Serial Positions

The 2(binding type) x 2(priority) x 4(SP) x 2(timing) mixed design ANOVA indicated no main effect of prioritisation (Priority *M* = 0.56, SE = 0.01; No priority *M* = 0.56, SE = 0.01; (*F*(1,59) = 0.10, *p* = .75, η_p^2 = 0.002, η_G^2 < .001; BF_{10} = 0.11) and no main effect of binding emerged (Unitised *M* = 0.56, SE = 0.01; Cross *M* = 0.56, SE = 0.01; *F*(1,59) = 0.06, *p* = .81, η_p^2 < .001, η_G^2 < .001; BF_{10} = 0.10).

A main effect of serial position emerged (*F*(3,177) = 56.08, *p* < .001, η_p^2 = 0.49, η_G^2 = 0.23; BF_{10} > 10000). Pairwise comparisons revealed significant differences between SP1 (*M* = 0.51, SE = 0.02) and SP4 (*M* = 0.75, SE = 0.02; *p* < .001), SP2 (*M* = 0.47, SE = 0.02) and SP3 (*M* = 0.52, SE = 0.02; *p* < .05) and SP4 (*p* < 0.001), SP3 and SP4 (*p* < 0.001).

There was a significant interaction between SP and priority (*F*(3,177) = 18.67, *p* < .001, η_p^2 = 0.24, η_G^2 = 0.05; BF_{10} > 10000) and between SP and binding (*F*(3,177) = 10.87, *p* < .001, η_p^2 = 0.16, η_G^2 = 0.02; BF_{10} > 1000), and there was a marginal non-significant three-way interaction between SP, priority and timing (*F*(3,177) = 2.55, *p* = .06 , η_p^2 = 0.04, η_G^2 = 0.006; BF_{10} = 0.72) tentatively implying that the effect of priority and binding type may have differentiated depending on the SP tested and priority effect differentiated based on SP and timing (see Figure 3.6.). There was no any other significant interaction between SP, priority, binding and timing.

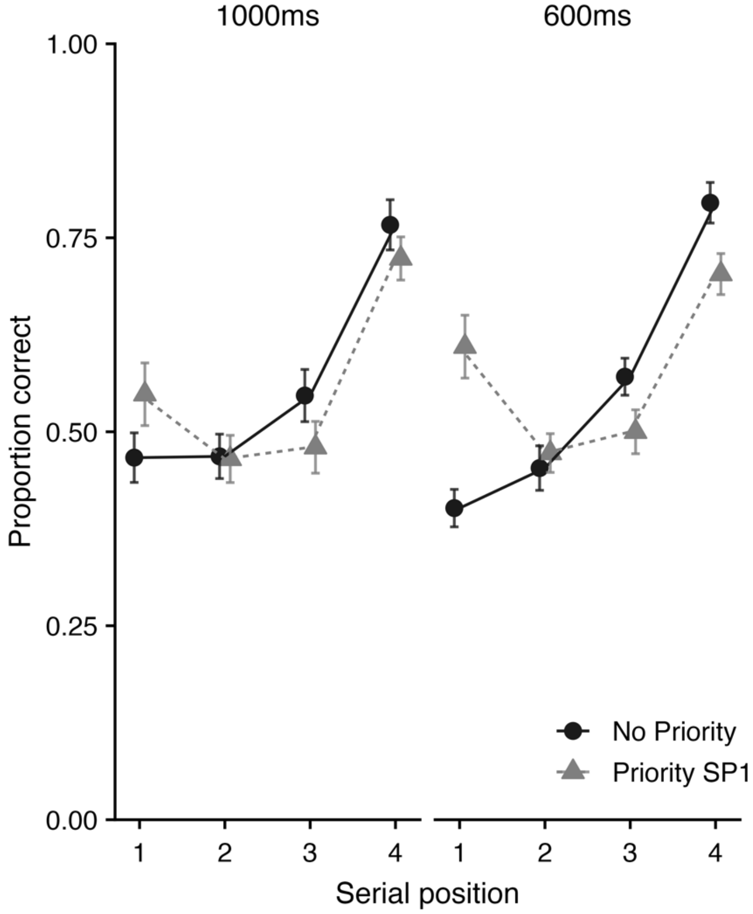

Figure 3.6. Mean proportion correct (with SE) in each presentation time (600ms and 1000ms), priority condition contrasted with the control (no priority) condition collapsed across binding conditions from Experiment 5 and 6. Data are presented by serial position.

3.3.2.2 Serial Position 1

Further analysis was conducted at SP1 as the priority manipulation was targeted at this SP. To investigate the interaction between priority condition and binding type, a 2 (Priority condition) × 2 (Binding type) and 2 (Timing) mixed design ANOVA was conducted. There was a main effect of priority (F(1,59) = 24.10, p < .001, η_p^2 = 0.29, η_G^2 = 0.10; BF_{10} > 1000), with higher accuracy in the priority condition. Also, there was a significant interaction between priority condition and timing (F(1,59) = 4.59, p = 0.04, η_p^2 = 0.07, η_G^2 = .02; BF_{10} = 1.73), showing that the prioritisation boost was affected by presentation time (see Figure 3.7.). There was no main effect of binding (F(1,59) = 0.03, p = .87 , η_p^2 < .001, η_G^2 < .001; BF_{10} = 0.17) or interaction between binding and timing (F(1,59) = 0.01, p = .94 , η_p^2 < .001, η_G^2 < .001; BF_{10} = 0.22), or between binding and priority (F(1,59) = 0.90, p = .35 , η_p^2 = .02, η_G^2 = 0.002; BF_{10} = 0.31), nor the three-way interaction.

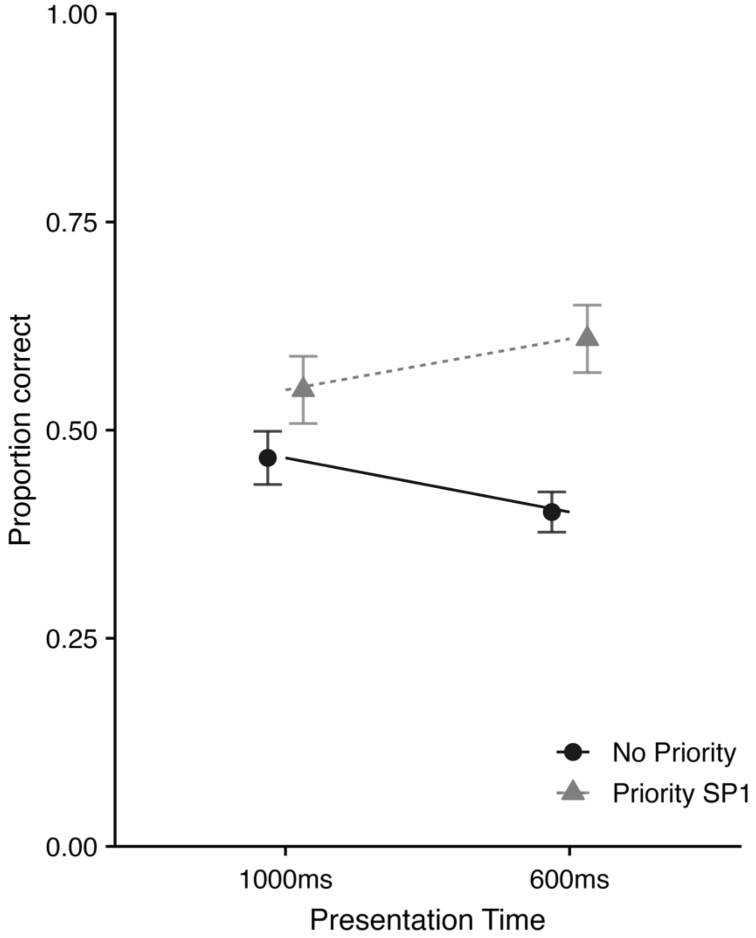

Figure 3.7. Mean accuracy (with SE) as a function of the presentation time and priority, collapsed across binding types from Experiment 5 and 6. Data are presented by only SP1 (prioritised SP)

3.4 General Discussion

In this chapter, individuals' ability to allocate attention to specific items was explored in different binding conditions. Specifically, it was examined whether value-directed prioritisation can create a memory boost for high-value items in unitised and cross-modal binding. In experiment 5, the results showed only a marginal effect of prioritisation, with the appearance of being numerically larger in the unitised than cross-modal binding.

However, the absence of a three-way relationship means that there was no strong evidence that prioritisation was more difficult in cross-modal binding. Considering the possibility that a longer presentation duration can eliminate priority boosts as well as the disparity in the exposure duration for visual and auditory items, the follow-up experiment was conducted. In experiment 6, the display duration of all items was designed to be the same as the longest audio item (600ms). Findings showed that high-value items can successfully prioritised in cross-modal binding as well as unitised items. Shorter and/or equal presentation times of visual and auditory features showed that attention could be successfully allocated in both binding types. As a whole, the findings of this chapter provide further evidence that the prioritisation effect can be observed in unitised and cross-modal binding, with tentative results when using longer exposure duration. It is important to consider how such an effect could occur.

As discussed in the second chapter, the FoA is assumed to have a constant shift to subsequent items in sequential presentation; this is thought to occur automatically (Hitch et al., 2018; Hu et al., 2014; 2016). However, in prioritisation, executive processes are assumed to be required due to the requirement to allocate FoA onto high-value items consciously, which automatically moves to the subsequent item (Atkinson et al., 2018; Hitch et al., 2018; Hu et al., 2014; 2016; Sandry et al., 2014). This process can occur through holding this item in FoA for a longer duration than others. (Hitch et al., 2018; Hu et al., 2016; Sandry et al., 2014). Attentional refreshing (Hitch et al., 2018; Hu et al., 2016; Souza et al., 2015) can regulate this process; in this mechanism information is maintained by reactivating decaying memory traces (Barrouillet et al., 2004; 2011; Barrouillet & Camos, 2012; Vergauwe & Cowan, 2015).

Previous prioritisation studies supported this concept, with the utilisation of suffixes that present similar items after the study array showing that the appearance of the suffix had a disputing effect on the last encountered and high-value item. This, though, is evidence that FoA has a constant shift to subsequent items; therefore, the maintenance of these bound objects was susceptible to interference (Allen & Ueno, 2018; Hitch et al., 2018; Hu et al., 2014; 2016). As the content of FoA was replaced by subsequent items, participants could maintain representational activity by refreshing the more valuable item for a longer time (Atkinson et al., 2022).

The FoA has been incorporated within the episodic buffer in a multicomponent model of WM to retain items in a privileged state (Hu et al., 2014). This approach states that there are different subsystems for the storage of visual and auditory information, and the episodic buffer is responsible for holding and binding information from different subsystems in an integrated format (Baddeley, 2000; Baddeley et al., 2010). This binding is relatively automatic and not attentionally demanding (Allen et al., 2006; 2009; 2012; Baddeley et al., 2011; Delvenne et al., 2010; Ecker et al., 2013; Morey & Bieler, 2013; Karlsen et al., 2010; Vergauwe et al., 2014; Yeh et al., 2005).

However, it is important to note that there are other studies presenting contrary arguments. For example, Gao et al. (2017) argued that binding between visual and auditory modalities requires attention since additional concurrent tasks cause a decrease in the performance of binding. They suggested that the episodic buffer operates independently of the central executive as it is not a slave buffer like the phonological loop and visuospatial sketchpad. It functions as an autonomous storage buffer driven by object-based attention (Gao et al., 2017).

Although certain studies have demonstrated varying findings, the results of this chapter indicated that the possibly executively demanding prioritisation task did not decrease across binding types. Considering that the episodic buffer is assumed to perform both prioritisation and binding tasks simultaneously, the capacity would be diminished if both of these processes require executive attention. Since results showed that binding within the same or different modalities did not disrupt the process of prioritisation, we can conclude that binding from different modalities does not require additional executive resources. Therefore, it can be suggested that binding occurs automatically in the episodic buffer (Allen et al., 2012; Baddeley et al., 2011; Ecker et al., 2013).

Additionally, since the prioritisation effect is demonstrated in visual-auditory cross-modal binding as well as visual objects, it can be concluded that value-directed prioritisation is not modality-specific; it can be observed across WM domains. These findings are in line with previous studies that found prioritisation boost in visual stimuli (Hitch et al., 2018; Hu et al., 2014; 2016), auditory-verbal stimuli (Atkinson et al., 2021), olfactory-visual stimuli (Johnson

& Allen, 2023), visually presented verbal stimuli (Sandry et al., 2014; 2020) and in the tactile domain (Roe et al., 2024).

Although results showed that individuals could bind features across modalities and prioritise successfully, this does not necessarily imply that unitised and cross-modal bound object representations are identical. The underpinning mechanism in the binding process could be distinct even though both are stored in the passive episodic buffer. In unitised binding, automatic feature binding could occur before information enters the episodic buffer, as suggested in Baddeley et al. (2011). However, in cross-modal binding, audio and visual information might proceed through the phonological loop and visual information from a visuospatial sketchpad; these two pieces of information can unify via an automatic binding process in the episodic buffer.

One salient possible explanation to develop an understanding of the underlying mechanism of the process in cross-modal binding could relate to a contextual timing signal, as Farrell (2008) conceptualised. Firstly, it can occur through shared time between audio and visual information. Participants were exposed to visual and auditory stimuli simultaneously in these experiments; thus, this can result in automatic binding. The absence of a prioritisation effect in the first experiment cross-modal binding might result from this time difference as exposure duration for visual and audio information was different, compared to the appearance of the effect in the second experiment, in which the exposure duration was consistent across information types.

Another possibility is that participants can use the serial position of the item as a signal to bind information from different modalities to each other

(Burgess & Hitch, 1992; Farrell, 2008). For example, participants can bind the first exposed audio and visual information to each other, then the second, and so forth. This binding process can happen by the possible occurrence of the serial order effect, which is explored widely in verbal (Hitch et al., 2005) visuo-spatial (Jones et al., 1995), audio-spatial (Parmentier & Jones, 2000) and visual items (Avons & Mason, 1999). It was suggested that regardless of the stimulus type, identical mechanisms are in operation, which is the processes of working memory are task-dependent as opposed to stimulus-dependent (Tremblay et al., 2006) (also for detailed review; Hurlstone et al., 2014).

As the Wheeler and Treisman (2002) suggested, features from distinct modalities might be stored in parallel, whereas features from the same modality compete for storage capacity. Information from the same modality may occupy more space than information from distinct modalities in WM, regardless of the requirement of attention allocation. This could explain the reason why, in terms of overall memory performance, there is no difference between unitised and cross-modal binding, but in the previous chapter, spatially separated was lower than unitised objects.

Another notable finding was that participants did not successfully prioritise high-value items in Experiment 5 with a 1000ms exposure duration to the same extent as when items were presented for 600ms. As indicated earlier, participants were exposed to the visual stimuli for a duration of 1000ms, whereas the audio colour name was presented to them for the longest duration of 600ms. By decreasing presentation time, the ability to prioritise emerged in cross-modal binding. Another critical possibility is that as prioritisation tasks require strategic allocation of attention (Hu et al., 2014), participants need to be motivated enough to accomplish this task (Atkinson et al., 2019). Longer presentation duration might not be perceived as challenging enough for participants to motivate them to focus on recalling high-value objects, as observed by Allen et al. (2021). The cross-experiment analysis provided further evidence of the significant differences between presentation times. Participants showed better memory performance at the higher priority SP in 600ms compared to 1000ms. However, although there is some research about the differences in exposure time in WM (Sander et al., 2011), this area requires further investigation.

Furthermore, it is essential to note that when participants successfully prioritised the first item, this did not improve overall WM capacity; it came with a cost to other items in the sequence. Due to the limited capacity of the WM system, participants' performance at recalling the other items was reduced when they tried to prioritise the first object in the sequence. Thus, there was a trade-off between primacy and recency. Hu et al. (2014) demonstrated a trade-off in which prioritising the first item improved primacy while decreasing recency as compared to prioritising the last item. It can be concluded that a limited number of items can have heightened accessibility for recall, and these items could be prioritised items or recently presented items (Hu et al., 2014).

Since, in this study, audio information was auditorily presented visual information (colour), further research could also explore how cross-modal binding effect changes if audio information has no visual or verbal representation in WM (Del Gatto et al., 2015; Delogu et al., 2014) or different kind of audio types such as animal, human actions or tools (Klatt et al., 2020; Olivetti Belardinelli et al., 2004). In the current experiments, although colour names were presented in audio formatting, the representation in WM might have a visual element. It is uncertain whether this information is retained auditory or visually. It is suggested that cross-modal binding occurs prior to entry into the episodic buffer as it does not require additional attention resources (Baddeley et al., 2011). However, the automaticity of this process might be influenced by the way in which the information is perceived. In a context where auditory information does not have a visual representation, attentional demands might be increased in non-visual sounds and visual stimuli binding. Further research might provide additional understanding of the binding in different modalities.

3.5 Conclusion

In summary, value-directed prioritisation can improve memory for higher value items in unitised binding, whereas this effect was only not clear in the longer presentation duration for cross-modal binding. However, in shorter presentation times of items, priority boost was clear in both binding types. This result suggests that individuals allocate their attention to cross-modal binding as well as unitised binding. Furthermore, since the episodic buffer is responsible for both binding and holding information and with FoA function maintaining specific items in privileged state (Hitch et al., 2020; Hu et al., 2014), the absence of any impact of cross-modal binding on the priority ability indicates that binding takes place automatically in the episodic buffer (Baddeley et al., 2011). Finally, observing the priority effect in different binding types showed that this effect is not modality-specific and can be observed in different domains (Atkinson et al., 2021).

Another notable finding was that there were no differences in terms of overall memory performance in unitised binding and cross-modal binding. Accordingly, it can be concluded that it does not require more capacity to encode and maintain cross-modal bound representations than unitised representations in WM (Allen et al., 2009).

Additionally, the null prioritisation effect in 1000ms presentation duration in Experiment 5 and the emerging effect in 600ms exposure duration in Experiment 6 showed that shorter presentation duration can motivate participants to prioritise higher value items in WM.

These findings provide further evidence about the relationship between attention and binding from the same and different modalities in WM, emphasising automatic binding across modalities.

CHAPTER 4

INVESTIGATING THE EFFECT OF MONETARY REWARD ON AN ONLINE WORKING MEMORY TASK IN THE CONTEXT OF PRIORITISATION

4.1 Introduction

In Chapter 2, through three online experiments and one laboratory experiment, it was examined whether individuals can direct their attention to higher-value items. Unexpectedly, participants were able to prioritise higher-value objects only in the lab experiment. This disparity suggests potential problems with control and motivation in the online experimental setting. Thus, this chapter aimed to address this discrepancy by examining the motivational role in online experiments through monetary rewards that correspond to point values.

To date, a number of studies have examined the influence of reward systems, suggesting that rewards have the potential to improve the functioning of several cognitive functions, including long-term memory (Adcock et al., 2006; Gruber & Otten, 2010; Murty & Adcock, 2014; Shigemune et al., 2010; Wittmann et al., 2005), working memory (van den Berg et al., 2023; Lytle et al., 2020; Xu et al., 2022), cognitive inhibition (Diao et al., 2016; Paulsen et al., 2015) and attention (Anderson et al., 2011). However, with regard to value-directed prioritisation in WM, the majority of studies have utilised notional reward. In this reward system, stimuli were paired with different point values (high, low or equal). Participants were instructed that if they could recall an item correctly, they would earn a point value assigned to that item, and the aim was to collect the highest possible score (Hu et al., 2014). It has been consistently indicated in numerous studies that participants demonstrated better memory performance for high-point value items in comparison to items with equal or low value (Allen & Ueno, 2018; Atkinson et al., 2018; Berry et al., 2018; Hitch et al., 2018; Hu et al., 2014; 2016; Sandry et al., 2014; Sandry & Ricker, 2020). Alongside the apparent evidence of the prioritisation effect, an additional characteristic shared by these investigations is their laboratory-based design. The same results were not achieved in the online experiments, as demonstrated in Chapter 2.

In recent years, the adoption of online sampling methodologies in various disciplines of psychology has increased dramatically (Buhrmester et al., 2018). Chandler and Shapiro (2016) observed a substantial increase in the utilisation of online sampling (Amazon Mechanical Turk), with the number of publications employing online settings increasing from less than 50 in 2011 to over 500 in 2015. In addition to this trend, the COVID-19 pandemic have further accelerated the utilisation of online sampling (Gagné & Franzen, 2023).

Online studies often exhibit higher variability in sample demographics compared to traditional lab-based studies (Greene et al., 2021). This variability in participant demographics may have some challenges, such as controlling the sample, but it also brings some opportunities for extensive generalisation of results. Bridges et al. (2020) conducted a comprehensive evaluation of various web browsers, devices and online and lab-based experiment platforms. The findings demonstrated that internet-based research tends to exhibit marginally more variance in some variables such as, reaction time, which was less precise in online studies relative to lab-based (Bridges et al., 2020)

Regarding the comparability of lab and web-based participant recruitment methods, Germine et al. (2012) investigated the data quality in various cognitive and perceptual assessments such as verbal episodic memory, emotion perception, and visual and working memory. In contrast with Bridges et al. (2020), no notable difference emerged in findings between web and lab samples with regard to overall performance, performance variance and internal reliability. These results showed that data quality did not diminish even for demanding tasks when data was collected from self-selected, anonymous, unsupervised participants.

Regarding the online experimental setting, Uittenhove et al. (2022) investigated whether recruiting participants from various sources affects the quality of testing. They administered a standardised working-memory task to 256 university students, 300 Prolific participants, and 196 MTurk participants to compare the quality of the data across multiple participant pools. Furthermore, the data quality was also explored online and in laboratory settings by testing 215 students online and 40 students in person in a laboratory setting. To assess data quality, the distribution of various variables, such as reaction time, was examined. The findings indicated that regarding the data quality, the participants in the test pool (university, MTurk, Prolific) are more important than the employed testing modality (online vs. in-person). More specifically, a comparison between online and in-person testing indicated a 17 % loss of data quality in the online experiment compared to in-person, while there were more noteworthy differences between test pools (MTurk – Prolific). In summary, Uittenhove et al. (2022) argued that the utilisation of online testing can give satisfactory results even though there is a limited loss in data quality.

Nevertheless, another important difference between laboratory and online experiments was the presence of a researcher in the concept of the WM task. There is some conflicting evidence regarding the impact of an examiner on working memory tasks. For example, Belletier and Camos (2018) showed that in WM tasks, the presence of the examiner allocates attention and impairs WM performance by distracting attention away from task progress. However, Belletier and Camos (2018) focused on overall WM performance, yet in the current prioritisation task, the aim was to direct attention to valuable items rather than increasing overall WM performance. Furthermore, according to over a century of research in social psychology, it has been determined that the presence of others enhances performance on relatively straightforward tasks (Bond & Titus, 1983) by stimulating the motivational drive, which increases the physiological arousal to improve performance (Triplett, 1898; Zajonc, 1965). Parallel with that, in Chapter 2, the presence of the examiner might have affected the emergence of the prioritisation effect, whereas the absence of the researcher in the online experimental setting has reduced this effect. This might reflect decreased motivation to follow task instructions in the online setting without the observation of the examiner.

More specifically, value-directed prioritisation is considered as a strategic approach to maintaining information in the FoA, with the aim of improving memory for that information (Hitch et al., 2018; Hu et al., 2014; 2016). During this process, it is thought that participants are required to effectively use their executive resources to strategically focus their attention on high-value objects (Hitch et al., 2018; Hu et al., 2014; 2016). Therefore, this strategic mechanism may be highly vulnerable to possible changes in motivation. As an example of the important effect of motivation in prioritisation, Atkinson et al. (2019) conducted a study with children between the ages of 7 and 10 years, demonstrated that children can prioritise high-value items under the suitable motivation condition while the findings of Berry et al. (2018) showed no evidence that they are capable of focusing their attention on high-value items.

In plenty of previous studies, the same test paradigm was utilised in a lab-based setting (Allen & Ueno, 2018; Atkinson et al., 2018; Hitch et al., 2018; Hu et al., 2014; 2016; Sandry et al., 2014; Sandry & Ricker, 2020). These previous studies showed that attentional shifts with the prioritisation manipulation could be observed in young adults (Hitch et al., 2018; Hu et al., 2014; 2016; Sandry et al., 2014; Sandry & Ricker, 2020); older adults (Allen et al., 2021) and children (Atkinson et al., 2019). Furthermore, this effect is also observed in different domains of WM, such as visual (Allen & Ueno, 2018; Hitch et al., 2018; Hu et al., 2014; 2016), visual-verbal (Sandry et al., 2014; Sandry & Ricker, 2020), verbal (Atkinson et al., 2021), tactile domain (Roe et al., 2024). Despite the consistently apparent effect across different age groups and modalities in previous studies, the main reason for its absence in the current experiment could be the study's online administration.

One possible solution for the decreased motivation can be compensation with a monetary reward. In the research they conducted, Ryan and Campbell (2021) demonstrated that the main motivation for young adults to participate in experiments was the prospect of getting monetary compensation or course credits. Additionally, it was indicated that monetary compensation may enhance the motivation of younger adults to perform accurately on cognitive tasks (Seli et al., 2021).

Adcock et al. (2006) tested whether monetary effect can be observed in long–term memory. In this study, a recognition test was administered 24 hours after the participants were shown memory items to recall. Participants were informed beforehand that the memory items had a high or low value ($5.00 or $0.10, respectively) prior to their presentation. At the test, participants were shown both the previously encoded and new objects not previously presented, and their task was to identify which items were previously encoded. Participants recognised high-value objects more than low-value items. This effect has also been observed in other studies investigating long-term memory; Gruber and Otten (2010) and Shigemune et al. (2010) found increased memory for items associated with high monetary reward. Additionally, Murty and Adcock (2014) demonstrate that reaction time to memory objects was lower when the monetary reward was higher.

Regarding the effect of monetary incentives on WM, Xu et al. (2022) investigated the effect of conscious and unconscious monetary rewards on increasing working memory performance. In this task, participants were required to complete the N-back task in high (2-back) and low (1-back) difficulty. In the study array, participants were presented with the reward amount, which was 1 cent for low value and 1 yuan (100 cents) for high value. However, it is important to note that distinctively from the current study, the monetary reward was provided on the task level, not the item level. Namely, correct responses in each trial were linked with different monetary rewards rather than individual items being linked to monetary rewards within each array. The amount of reward value for each trial was presented to participants in advance of encoding. In the conscious reward value condition, the reward value was presented for 300ms, and in the unconscious condition, it was presented for 17ms. The results of this study showed that when the task was easier (1-back), participants' memory performance was higher, and there was a higher reward for both conscious and unconscious conditions. However, when the task was difficult (2-back), memory performance for high-value items was only better than low-value items in the conscious condition. While the effect of unconscious reward was only observed in easier tasks, there was a consistent effect of high value in the conscious reward condition.

Furthermore, several researchers have examined the potential for monetary incentives to influence attention and prioritisation in WM. For instance, Morey et al. (2011) utilised monetary rewards to manipulate attention during working memory tasks, where accurate responses led to monetary compensation. Similar with Xu et al. (2022) the monetary reward was provided on the task level. The results demonstrated a significant impact of monetary incentives on overall performance. Similarly, Klyszejko et al. (2014) demonstrated that monetary rewards can enhance the precision of items in working memory.

In line with this, van den Berg et al. (2023) explored whether individuals could regulate the total number of items held in working memory through monetary incentives. Across three experiments, bonus monetary rewards were offered, ranging from $0 to $10 (e.g. $1 base reimbursement and $0, $2, $6 and $10 bonus according to their performance in the Experiment 1; $5 base reimbursement and $0.50, $1, $2 and $4 bonus in the Experiment 2). Although the base reimbursement and the amount of the bonus reward varies between experiments, in this study, participants received the base reimbursement for completing the study and additional monetary incentives depending on their performance. The finding demonstrated no significant effect of reward magnitude on total working memory performance. Thus, the monetary reward did not increase the visual WM capacity.

However, very few studies have specifically examined the impact of item-level monetary reward in WM (Zheng et al., 2022). Zheng et al. (2022) investigated whether reward increases in VWM are determined by the nature of the reward. To investigate the potential impact of reward type on recall performance, this study manipulated the magnitude of reward (high, low, and equal reward) and the reward type (monetary and notional) in the first experiment. Additionally, in the second experiment, it was attempted to determine whether task difficulty influences reward increases by manipulating the quantity of high-reward items (1, 2 and 3) in addition to the magnitude of reward and reward type. The reward magnitude was displayed by a numerical cue (1, 1, 1, 5) at the same location as the four memory items prior to the memory array. In this context, 1 represented a low reward, while 5 represented a high reward value. In the equal-reward item condition, a numerical cue (2, 2, 2, 2) was displayed. Each numerical cue represented the point value of the memory item at that location. During each trial, participants were shown the numerical value of each item, followed by the simultaneous presentation of four memory items (coloured shapes) at each of the locations of the point values. Then, a test cue appeared (either colour or shape), and participants were asked to recall the colour or shape of the probed item. Participants were informed that there was a monetary compensation for the points they collected in the monetary reward condition, while they only collected points in the notional reward condition.

The result of the first experiment indicated that memory performance was greater in the monetary reward condition compared to the notional reward. Additionally, high-reward items had a greater memory boost than low-reward or equal-reward items. Nevertheless, there was no significant relationship between the magnitude and type of reward. Monetary and notional reward manipulations were both capable of motivating participants to focus on high-value items, and reward type (monetary-notional) may not be a key factor in triggering a priority boost, as demonstrated by these findings. Another notable finding of the first experiment was that although there was better memory on the high-reward items, it did not come with a cost to low-reward items when only one item was prioritised. The suggested reason for this was that in the task condition, there was the same probability of testing all items; even though participants prioritised high-value items, they did not discard lower-value items. Therefore, in the second experiment, the difficulty of the task was manipulated by requiring participants to prioritise more items (1, 2 and 3) in the study array. Results showed that participants' memory performance increased when more items were prioritised. In the condition that two items were prioritised, the boost for high-value items came with a cost to low-value items, indicating that individuals were able to prioritise two items. Additionally, given that no three-way interaction was identified between the reward method, number and magnitude in the performance, the findings indicate that the memory boost in the condition that more items were prioritised was independent of the reward type (notional-monetary). Thus, the results of the second experiment indicated that reward boosts were modulated by the difficulty of the task, not the type of incentives. Additionally, there was no three-way interaction between reward method (monetary-notional), task difficulty (1, 2 or 3 high reward items) and magnitude of reward (high, low, and equal reward), indicating that reward method did not modulate the relationship between task difficulty and reward boost. To sum up, the results showed that reward boosts were modulated by the difficulty of the task, not the type of incentives.

Therefore, there is a variety of evidence demonstrating that monetary reward value can enhance LTM (Adcock et al., 2006; Gruber & Otten, 2010; Murty & Adcock, 2014; Shigemune et al., 2010; Wittmann et al., 2005) and WM (Morey et al., 2011; van den Berg et al., 2023; Lytle et al., 2020; Xu et al., 2022). However, very few studies have applied this at an item level in WM

(Zheng et al., 2002); therefore, there is not much clear evidence so far. Examination of the effect of monetary reward would be advantageous in providing further understanding of the motivation mechanism in value-directed prioritisation tasks in WM.

Given that the presence of value effects so far in this thesis is only in lab-based studies and not online, it may reflect reduced motivation to engage with instruction to prioritise in the latter case. Hence, adding monetary value may enhance motivation and resolve this difference between online and lab-based studies. The present experiment explored whether providing monetary rewards in exchange for their recall performance precisely at an item level can motivate participants to prioritise high-value items in an online experiment setting.

4.2 Experiment 7

4.2.1 Method

4.2.1.1 Participants

Forty-five participants (aged 19-30 years; M = 26.60; SD = 2.92; 30 females) recruited from Prolific participated in this experiment. They were all native English speakers, and none reported a history of neurological disorders. The participants had a correct or corrected-to-normal vision and no colour blindness. Informed consent was acquired in accordance with the guidelines set by the University of Leeds Psychology Ethics Committee (Ethics reference number: PSYC-608).

4.2.1.2 Design and Procedure

The method was similar with Experiment 3 in Chapter 2 with the same material set and conducted online. However, there were some differences in design and trial procedure.

Firstly, in this experiment only the unitised binding condition was used (see Figure 4.1). Additionally, participants received monetary reward according to their performance.

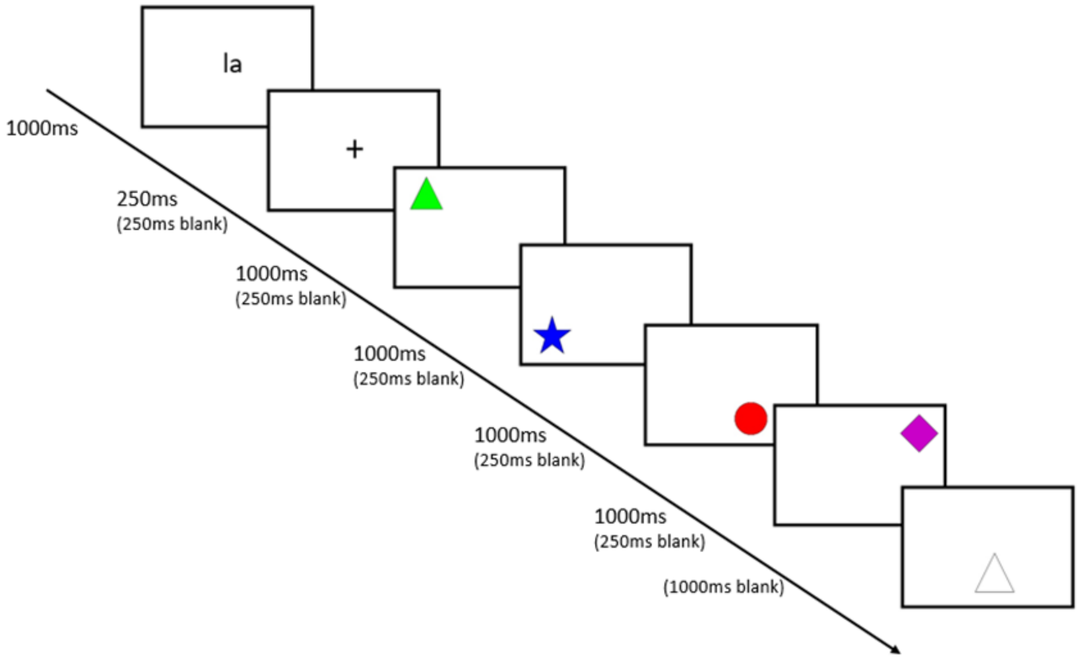

*Figure 4.1***.** The experimental paradigm used in this experiment.

The point values were different in this experiment compared to previous experiments. In the prioritisation condition, the first item was worth 5 points while the other three stimuli were allocated 1 point if tested and correctly recalled. In the no-priority condition, all stimuli were worth 2 points. Participants received £3 base reimbursement in exchange for their participation in this study. Additionally, they received extra monetary award according to the points score they collected. They were rewarded with a cash prize for each point, corresponding to 2p per point. The maximum they could receive would be £6.34 (including the base rate). Completing the experiment took approximately 25 minutes.

There were also differences in the number of trials. There were 2 different prioritisation conditions (priority and no priority) and each condition included 48 test trials. Each serial position was tested an equal number of times (12 times) in a random order for each block. As in the other experiments, there were two practice trials before each condition.

A 2x4 repeated measures design was implemented, with two types of prioritisation condition (priority and no-priority) and probed serial position (SP 1:4).

4.2.1.3 Data analysis

As in previous experiments, in this experiment, the outcome variable was the accuracy of recalling the correct colour. The independent variables were prioritisation (priority and no priority) and SP (1-2-3-4). Thus, the data were subjected to 2 (prioritisation) x 4 (SP) repeated measures ANOVA.

Results were initially reported in terms of SP function. Additional planned analysis were then conducted at SP1 since the priority manipulations were aimed at this SP. Data analysis was conducted using frequentist and Bayes Factor (BF) methods. The analysis was performed using JASP (Version 0.16) and R.

4.2.2 Results

4.2.2.1 Across Serial Positions

The 2 (prioritisation) x 4 (SP) repeated measures ANOVA indicated no main effect of prioritisation (Priority *M* = 0.63, SE = 0.02; No priority *M* = 0.60, SE = 0.02; (*F*(1,44) = 3.02, *p* =.089, η_p^2 = 0.06, η_G^2 = 0.01; BF_{10} = 0.53). A main effect of SP emerged (*F*(3,132) = 40.73, *p* < .001, η_p^2 = 0.48, η_G^2 =0.20; BF_{10} > 10,000). Pairwise comparisons (corrected using Bonferroni – Holm) revealed significant differences between SP1 (*M* = 0.52, SE = 0.03) and SP3 (*M* = 0.66, SE = 0.03; *p* < .001) and SP4 (*M* = 0.77, SE = 0.02; *p* < .001), SP2 (*M* = 0.52, SE = 0.03) and SP3 (*p* < .001) and SP4 (*p* < .001), and SP3 and SP4 (*p* < .001).

There was no significant interaction between SP and priority (*F*(3,132) = 0.93, *p* = .428, η_p^2 = 0.02, η_G^2 = 0.004; BF_{10}= 0.07) showing that the effect of priority did not differentiate depending on the SP tested (see Figure 4.2.).

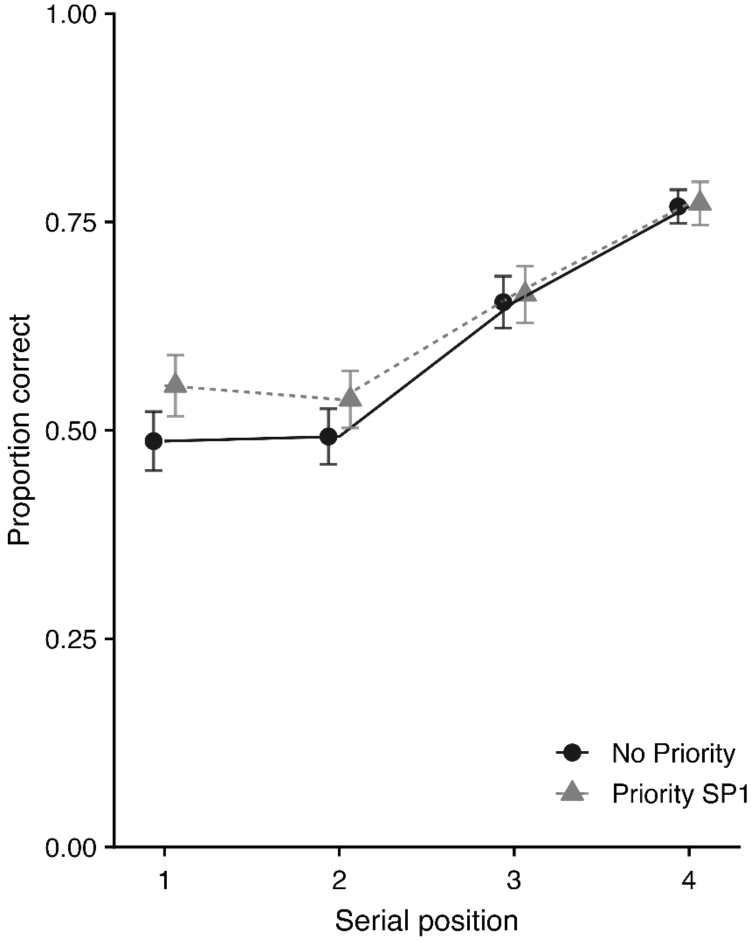

Figure 4.2. Mean proportion correct (with SE) in each priority and control (no priority) condition from Experiment 7. Data are presented by serial position.

4.2.2.2 Serial Position 1

As the priority manipulation was targeted at SP1, paired sample t-tests were also conducted at this SP. There was no significant difference emerge between priority and no priority condition in SP1 ($t(44) = 1.66$, $p = 0.105$, BF_{10} =

0.57, *d* = 0.25). Thus, accuracy was numerically higher for the priority-SP1 condition, but this difference was not significant.

4.3 Discussion

The present study examined whether individuals could prioritise high point-value items in online experiments when point value corresponds to monetary reward in WM. However, there was neither a main effect of prioritisation nor an interaction between serial position and prioritisation. Namely, there was no significant increase in the recall performance of SP1 (prioritised SP) compared to SP1 in the no-priority condition. Similar to the results of previous experiments, SP had an effect, with better performance at the most recent item.

Although the current study did not find clear effects of monetary value, previous studies have shown that monetary value can motivate participants to improve memory performance in WM (Brissenden et al., 2021; Morey et al., 2011; Xu et al., 2022) and LTM (Adcock et al., 2006; Wittmann et al., 2005). However, distinctively from previous studies, the present study provided monetary rewards at the item level, where individual items were linked to different monetary rewards within each array. In this regard, the study by Zheng et al. (2022) appears more comparable to the current study, as both employed a methodology in which monetary rewards were provided at the item level. The findings of Zheng et al. (2022) demonstrated that monetary and notional rewards were both capable of motivating participants to allocate their attention to high-value items, with the suggestion that reward type (monetary-notional) may not be a key factor in triggering a priority boost. While the finding of Zheng et al. (2022) suggested that the memory boost in the higher-value items in both monetary and notional reward conditions, the result of the current study indicated no priority boost in the high-value items with the monetary reward.

Therefore, it is critical to investigate the reason for the null effect of prioritisation. One possible explanation might be the relatively modest magnitude of the monetary reward. In the current experiment, the prioritised item was assigned a value of 5 points, while the other items were linked with 1 point each in the priority condition. Conversely, in the equal value condition, all items were assigned a value of 2 points. The point values were associated with monetary rewards, with every 1 point collected corresponding to 2p in monetary incentives. Therefore, participants received 10p for accurately remembering the high-value item, 4p for the equal-value items, and 2p for the low-value items. Even though the higher monetary reward was linked with the prioritised items, one possibility might be that the monetary component was not explicit enough for participants to recognise. For example, it would have been more explicit to indicate that the first item was worth "10p" instead of 5 points. By doing so, participants may develop a clearer understanding of the item values, and this can encourage participants to direct their attention to higher-value items.

Another possibility can be that the distinctions between high, equal, and low values may not have been sufficient to effectively motivate participants to prioritise high-value items in the online context. For instance, Brissenden et al.

(2021) investigated whether the inclusion of monetary rewards could improve overall VWM performance or affect the distribution of resources within working memory without affecting total availability. In this study, monetary reward was at the trial level, where participants were presented with a monetary reward ($1, $10 or $20) for that trial, and then memory items followed. The results indicated increased recall in cued items in addition to a trade-off between cued and non-cued items; the correct recall rate increased for cued items but decreased for non-cued items. Furthermore, the probability of effectively encoding an item into working memory was observed to be modulated by the magnitude of rewards. Higher reward was associated with an increased probability of successfully encoding cued items while decreasing the likelihood of successfully encoding non-cued items.

Similarly, in a LTM task, Gruber and Otten (2010) examined encoding-related activity by recording electrical brain activity in an EEG study when high (£2) and low (20p) rewards were paired with memory items. In the memory test, encoding-related brain activity emerged. Nevertheless, this activity was only observed when memory words were paired with a high monetary reward. Similar findings were demonstrated in a PET scanning study by Shigemune et al. (2010); in this study, participants were required to complete an LTM task while receiving either high or low monetary rewards. Participants showed better memory performance in the high-monetary reward condition, and PET scanning demonstrated higher activation in brain regions (orbitofrontal cortex), which has been demonstrated to be related to reward value processing when exposed to high rewards compared to low rewards.

Based on the previous investigations, one can conclude that a substantially greater monetary incentive enhances motivation and facilitates improved memory performance in individuals. On the contrary, smaller amounts of monetary incentives do not yield the same effect (Brissenden et al., 2021; Gruber & Otten, 2010; Shigemune et al., 2010). Given the relatively modest monetary reward in the current study, this may account for the null effect.

An alternative rationale for the absence of a boost in recall of high-value items in the present study could be the lack of motivation in the online experiment, which is not resolved by monetary incentives. This conclusion, nevertheless, may vary depending on the form of investigation. According to Gagné and Franzen (2023), conducting online experiments presents several challenges, including restricted control over the testing environment, a greater possibility of distractions, and a raised lack of motivation and attention resulting from prolonged computer usage in general. Additionally, Jun et al. (2017) specified that the results of an investigation may be influenced by motivation, and when devising and analysing data from volunteer-based online experiments, researchers need to consider the motivation of the participants.

With regard to the online experimental setting, Uittenhove et al. (2022) examined whether the quality of testing is influenced by the recruitment of participants from a variety of sources. The results suggested that the participants' characteristics (university, MTurk, Prolific) have a greater impact on the quality of the data than the method of testing used (online vs. in-person). Nevertheless, while comparing online and in-person testing, it was observed that the online experiment exhibited a 17% decline in data quality compared to the in-person experiment, even though there were more substantial discrepancies observed between the test pools (MTurk and Prolific). Uittenhove et al. (2022) suggested that online testing can yield comparable findings despite a minor decline in data quality. Similarly, Germine et al. (2012) discovered comparable data quality between laboratory and online trials by evaluating mean performance, performance variance, and internal reliability.

Therefore, while some online studies provide approximately the same data quality and results as the lab-based ones (Germine et al., 2012; Uittenhove et al., 2022), throughout this thesis, it was consistently observed that no priority boost observed in the higher value items in the online experimental setting (Experiment 1, 2, 3 and 7) yet effect emerged in lab-based setting (Experiment 4-5-6). It can be concluded that, depending on the nature of the study, the test method (online-lab) can be affected differently. Motivation may be a more substantial factor in prioritisation studies since executive resources are required (Hitch et al., 2018; Hu et al., 2014; 2016).

To reduce the impact of lack of motivation and control in online experiments, Chandler et al. (2019) proposed the implementation of a pre-screening test. Their study compared two online data collection platforms, MTurk and Prime Panels, and identified that, respectively, 94% and 68% of participants were able to pass the pre-screening test. This test evaluated participants' attentiveness and basic English comprehension by asking basic questions to test whether participants read and understand questions and instructions. The results demonstrated that when participants passed the pre-screening task, their data quality was high. However, this high data quality was achieved only after removing numerous participants who failed the screening task. Thus, the results provided compelling evidence that utilising a pre-screening test in online research is critical for higher data quality. Additionally, respondents who failed the screener showed notably low reliability scores, pass rates on attention tests, and effect sizes. Regarding the high failure rates in the pre-screening test, in experiments, pre-screening was not utilised, as in the current study, participants who did not pay attention and did not follow the instructions may have affected the results. The parallel conclusion suggested by Chandler et al. (2020) in online research is that the data quality depends on participants' attention to the questions. Therefore, for future studies, implementing a pre-screening procedure for online studies may be an effective measure for ensuring data quality and improved engagement of participants.

4.4 Conclusion

In summary, participants in the online WM experiment showed no clear indication to direct their attention to higher-value items in exchange for monetary compensation.

As the value-directed prioritisation task requires regulating attention consciously, a lack of motivation may cause the absence of observed effects. It is possible that monetary incentives were inadequate to improve motivation, as research has shown that participants' memory performance is influenced by greater monetary compensation (Brissenden et al., 2021). Another potential factor is that participants did not sufficiently engage with the instructions of the experiment in an online-based study. Thus, although the effect was evident in the laboratory experiment, its absence in the online setting may be attributed to the nature of the online assessment, which could make it more challenging to control motivation.

These results indicate that participants in online experimental contexts might have challenges in allocating their attention to higher-value items and engaging with the experiment, while such an issue does not appear to arise in laboratory experiments.

CHAPTER 5

INVESTIGATING THE EFFECT OF DIFFERENT TEST TYPES ON AN ONLINE WORKING MEMORY TASK

5.1 Introduction

In Chapter 4, it appeared that in the online working memory experiment, individuals showed no evidence of shifting their attention towards greater value items in return for monetary reward. One potential explanation for this outcome could be that the monetary reward was not high enough to increase motivation. Previous studies demonstrated that higher monetary rewards increase motivation, whereas lower rewards might not have the same effect (Gruber & Otten, 2010; Shigemune et al., 2010). Another critical reason for the absence of a boost in the recall of high-value items, even though incentives were monetary rewards, could be that the test method employed was suboptimal for the online experiment. This indicates that adjustments may be necessary to implement the prioritisation study in an online setting as the possibility of diminished motivation (Gagné & Franzen, 2023).

In lab settings, it is well established that prioritisation tasks improve the recall accuracy of valuable items for different age groups and different domains (Allen & Ueno, 2018; Atkinson et al., 2018; 2019; 2021; Berry et al., 2018; Hitch et al., 2018; Hu et al., 2014; 2016; Roe et al., 2024; Sandry et al., 2014; Sandry & Ricker, 2020). Nevertheless, adjustments and adaptations are likely to be required to meet the requirements and specifications of the online setting more precisely.

As Reips (2021) summarised, there are several advantages of online experiments. For example, compared to laboratory research, it is more cost-effective in terms of administration, time and effort. It is easy to access different groups of participants, such as those with uncommon characteristics and those from diverse cultural backgrounds. Additionally, since the materials are publicly accessible, they are replicable and reusable.

The majority of testing methods in psychology research are transferrable to the web in principle; however, they are often likely to require adjustments and adaptations to suit the online environment, and consequently, novel challenges frequently emerge (Reips, 2021). For example, psychological tests must undergo an assessment and validation process as web-based instruments prior to their simple transition from paper-and-pencil to electronic format (Buchanan & Smith, 1999). Therefore, in the present study, the objective was to develop a test format that was better suited to online experimentation, as value-directed prioritisation does appear to be readily revealed through an online experiment despite the fact that they are widely achievable in lab-based experiments.

A variety of test formats are frequently used in working memory assessment, such as serial recall, cued recall, recognition and change detection. The recognition test involves displaying a single probe item to each participant following the presentation of items; in half of the trials, the item was previously presented, while the other half was not. Participants are then asked whether these items were previously presented or not (e.g., Allen et al., 2006; 2009; Karlsen et al., 2010; Kyllingsbaek & Bundesen, 2009; Makovski et al., 2010; Rouder et al., 2011; Wheeler & Treisman, 2002). In the cued recall paradigm typically used in this area, following the presentation of paired shape-colour items, the recall task requires the individual to recall the corresponding colour when the test cue is displayed in the form of a shape and recall the shape when the test cue is presented as a colour. The requirement was to correctly recall the shape-colour pair to respond (Atkinson et al., 2018; Gajewski & Brockmole, 2006; Hitch et al., 2018; Hu et al., 2014; 2016; Ueno et al., 2011). In the change detection paradigm, participants are presented with a visual stimuli memory array. Following a short interval, memory is evaluated through the implementation of a test display. In this test display, participants are typically tasked with determining whether the test display is different from the memory array, with the test display consisting of an equivalent number of items as the memory array (Rensink, 2002; Jiang et al., 2000). Previous studies investing value-directed prioritisation found priority boost in both recognition (Allen et al., 2006; 2009; Karlsen et al., 2010) and cued recall test (Atkinson et al., 2018; Hitch et al., 2018; Hu et al., 2014; 2016; Ueno et al., 2011). However, this priority boost could not observed in the online setting.

Research findings indicated that minor alterations in the testing procedure can have a significant impact on memory sensitivity (Makovski et al., 2010). For instance, Makovski et al. (2010) examined the validity of the assumption that visual WM representations are vulnerable to interference at the test phase. In this study, the participants were presented with a variety of colours to retain. Following a brief period of retention, memory for one of the items was assessed using either a same-different task or a two-alternative-forced-choice task. The same-different task was a widely used recognition task in which participants were required to indicate whether the probed item was the same item previously presented at that location in the study array. In the two-alternative-forced-choice task, two probes were shown to participants, and they were tasked to indicate which item had been previously shown to them in the study array. The results showed that performance was significantly diminished during the two-alternative-forced-choice task compared to the same-different task. Thus, it can be concluded that even slight modifications to the testing modalities can have a significant impact on the ability to remember visual information in WM tasks.

Furthermore, in the study conducted by Kyllingsbaek and Bundesen (2009), the presentation of visual memory items was followed by a recognition task in which participants were asked to determine whether the probe item was the same or different from the items provided in that study array. In addition to the same or different options, the effect of the additional option of "don't know" was examined. In this study, variance of estimates was calculated for the capacity of visual STM. It was observed that the variance of estimates decreased by 50% when the "don't know" option was included. Results demonstrated that the inclusion of the response options "don't know" alongside "same" and "different" decreased the variability in the capacity estimates of visual WM. Thus, the variability in the working memory capacity was reduced due to decreases in the guess rate when participants were given the opportunity to say "don't know". This illustrates that variety in the test method has an influence on the measurement of WM capacity.

Instead of utilising recognition, Gajewski and Brockmole (2006) implemented an explicit recall task; in this task, participants were required to report the characteristics (precisely, the colour and/or shape) of an object that was being investigated. The explicit recall test was later adopted in prioritisation studies (Allen et al., 2014; Hitch et al., 2018; Hu et al., 2014; 2016; Ueno et al., 2011), which was named a cued recall test. In these studies, a series of coloured shapes were briefly displayed, and this was followed by the test cue. The test cue was the item probed from the four stimuli in the study array, and participants needed to recall either the name of the colour or shape; when the test cue was shape, participants were asked to recall the name of the colour and when test cue was colour, they required to remember the shape it was paired with. The explicit/cued recall task provides information about the probability of recalling features of items together to test whether individuals can recall colour and shape together or not (Gajewski & Brockmole, 2006). Moreover, possible additional insights into the fundamental mechanism could be obtained through the recall error analysis (Ueno et al., 2011).

With regard to the comparison between the recognition and cued recall test, in the recognition test, as participants are solely expected to indicate whether the item had been presented previously or not, the chance of guessing a correct answer was 1/2. The estimated guess probability in the cued recall test paradigm is proportional to the number of items utilised in the experiment. By utilising six colours and six shapes, the chance of guessing an accurate response is 1/6. Given that the probability of reaching the correct answer through guess is lower, one could suggest that the cued recall test yields a more dependable result (Allen et al., 2014; Ueno et al., 2011). Thus, the cued recall test might be more revealing in testing memory performance compared to the recognition test.

Nevertheless, the fact that only one of the items was examined in the cued recall task, while three or four items were presented in the study array (Allen et al., 2014; Hitch et al., 2018; Hu et al., 2014; 2016; Ueno et al., 2011) may have an impact on motivation with regard to the value-directed prioritisation method. This effect may be greater in the online experiment, as observed in the online experiments in Chapters 2 and 4 of this thesis; the participants did not show any clear sign of prioritisation. Therefore, while small differences in the method can have an effect on memory performance (Kyllingsbaek & Bundesen, 2009; Makovski et al., 2010), another important aspect that may have influenced the absence of prioritisation outcome may be the low frequency of testing the prioritised item.

In previous experiments (Experiment 1-2-3-4-5-6-7), participants were asked to prioritise one item among four items presented in the study array; however, this item is examined only in 25% of the trials; thus, it can be specified that the cue reliability was 25%. Cue reliability is related to whether the cued (prioritised) item is tested. Trials in which the cued item is tested are valid, while trials in which the cued item is not tested are invalid. Cue reliability is the ratio of valid to invalid trials. In previous studies employing the cued recall test, four items are presented sequentially; one of the items is assigned a higher priority and is selected for inclusion in the test portion; however, the likelihood of all items being asked remains constant (Hitch et al., 2018; Hu et al., 2014; 2016). Therefore, cue reliability (whether the cued (prioritised) item is tested) may be one of the important factors influencing motivation in the online prioritisation test. Modifying the test format, such as increasing cue reliability, could facilitate the emergence of a priority boost in online WM tasks.

Frequently, the retro-cue paradigm is used to investigate test reliability. In this paradigm, spatial cues indicate the location of a particular memory item following a memory array to inform participants of the increased probability that the cued item will be tested (Lepsien & Nobre, 2007; Rerko & Oberauer, 2013). In valid retro-cues, the item indicated by the cue is tested, whereas in invalid retro-cues, it is not tested. Numerous studies (Astle et al., 2012; Griffin & Nobre, 2003; Pertzov et al., 2013; Gunseli et al., 2015) have demonstrated that retro-cues enhance the recall performance of the item being cued. For example, Berryhill et al., (2012) conducted a comparison between retro-cues that ranged from 100% reliable (testing all cued items) to entirely unreliable (not testing any of the cued items). In this study, four colours were presented to participants, and one of them was probed. Participants were required to distinguish whether the location of the probe item was correct. The retro cue reliability effect varied with increasing reliability (0% - 25% - 100%). The results provide evidence for the crucial effect of cue reliability on memory performance.

Additionally, Shimi et al., (2014) contrasted the performance of young and adult age groups who were exposed to retro-cues with either 50% or 100% reliability. Under the condition of low reliability, retro-cue benefits were diminished and were only statistically significant when compared to invalid-cue trials.

Similarly, Gunseli et al. (2015) demonstrated that the magnitude of the enhancement relies on the cue's validity by manipulating the validity of the retro-cue. The reliability of the cue was examined in this study using the retro-cue paradigm. Four bars were presented to the participants in various spatial locations. They were subsequently tasked with recalling the orientation of the object that was being examined. Cued items were evaluated at varying rates of 50% in some trials and 80% in others. A greater advantage was observed when cued items were evaluated in 80% of the trials, as opposed to when they were evaluated in half of the trials. Gunseli et al. (2015) indicated that when a cue has high reliability (high probability of testing), individuals allocate their attentional resources to the cued item and not the non-cued items since the chance of testing is low for non-cued items. However, in low cue reliability conditions (not high probability of testing), the probability of retaining non-cued items in memory increased since it also has a higher/equal probability of being tested.

The retro cue validity effect has been widely observed, but this effect has also been observed in value-directed prioritisation research. The investigation conducted by Atkinson et al. (2018) aimed to discover whether priority effects increase when equal or low-value items are tested less frequently than valuable items. Similar to previous prioritisation investigations (Hitch et al., 2018; Hu et al., 2014; 2016), participants were presented with a sequence of four items, and one of them was tested in the test phase. In the equal probe frequency condition, the higher-value SP was evaluated at the same rate as the remaining items (25 percent of the time), whereas, in the differential probe frequency condition, the prioritised SP was evaluated 70% of the time, and the remaining items were investigated 10% of the time. There were increases in accuracy with both increased value and probe frequency. While the effects were found to be independent of one another, it was noted that item recall performance improved with increased testing of the prioritised items. Consequently, within the prioritisation paradigm, recall performance is enhanced when the frequency of testing highly valued items is increased (Atkinson et al., 2018). Thus, increasing the frequency of testing/reliability of the prioritised item in the current experiment may encourage participants to prioritise high-value items.

Additionally, prioritisation of items frequently comes at a cost to others. This effect is widely observed in both retro-cue studies (Gunseli et al., 2015; Griffin & Nobre, 2003) and value-directed prioritisation studies (Atkinson et al., 2018; Hitch et al., 2018; Hu et al., 2014; 2016). In these previous studies, although the reliability of the cue changed, only one item from the study array was tested in the test phase. To date, only a few value-directed prioritisation studies have used full sequence recall in verbal (Atkinson et al., 2021) and tactile (Roe et al., 2024) domains with one significant difference from the current study was that while those studies utilised serial recall, the current study used full set recall. In the full set recall task, the trade-off effect might be more clearly observed when all items in the study array are tested.

Furthermore, testing all items rather than one in each trial can provide additional insights into participants' memory strategies.

With regard to the current study, as demonstrated in Chapters 2 and 4 of this thesis, although participants were able to show prioritisation gains in the lab-based experiment with a variety of test types, no such effect was observed in an online setting (Chapter 2), even when a monetary reward was provided (Chapter 4). Regarding this, the testing frequency of the high-value items can be a crucial element for WM evaluation, as demonstrated by retro cue tests (Gunseli et al., 2015) and prioritisation research (Atkinson et al., 2018). Additionally, plenty of studies showed that lower reliability of cued items can decrease recall in WM (Astle et al., 2012; Griffin & Nobre, 2003; Gunseli et al., 2015; Pertzov et al., 2013). Therefore, this study attempted to make prioritisation studies more compatible with the online paradigm. To achieve this, conducting an online experiment testing all the items in the study array is expected to enhance participants' motivation as it increases the reliability of the prioritised item and yields more informative outcomes.

5.2 Experiment 8

5.2.1 Method

5.2.1.1 Participants

Thirty-three students (aged 18 – 20 years; M = 19.03; SD = 0.68; 25 females) recruited from the University of Leeds participated in this experiment. Participants reimbursed for their time with course credits. They were all native English speakers, and none reported a history of neurological disorders. The participants had a correct or corrected-to-normal vision and no colour blindness. Informed consent was acquired in accordance with the guidelines set by the University of Leeds Psychology Ethics Committee (Ethics reference number: PSYC-608).

5.2.1.2 Design and Procedure

The method was similar with Experiment 7, with the same material set. There were some differences in design and trial procedure. Same as experiment 7, this experiment was conducted online with only unitised binding condition.

There were two priority conditions (priority and no priority) and each condition included 24 test trials. Same as other experiments, there was two practice trials before each condition.

The substantial difference in this experiment was that following the sequential presentation of four visual stimuli in each trial, in the test screen, participants were asked to recall all items in that study array. The test stimuli were shapes in each trial, and participants were asked to recall the colour that paired with each shape. All shapes presented to the participant in that study array were listed vertically on the test screen in random order on each trial, and all six colours (black, red, blue, green, yellow, and purple) used in the study were presented for each shape separately. The order of colours were always the same in alphabetical order. When participants select a colour for a shape, that shape and colour are removed from the list on the screen. There was a "next" button that participants clicked to process the next trial.

The participants need to click the name of the colour they think is paired with each shape. The participants were not restricted in their decision regarding the sequence in which they would provide their responses. Besides, there was no restriction to responding for each item. Participants could click the "next" button to continue the next trial without answering with all colour shape pairing (see Figure 5.1).

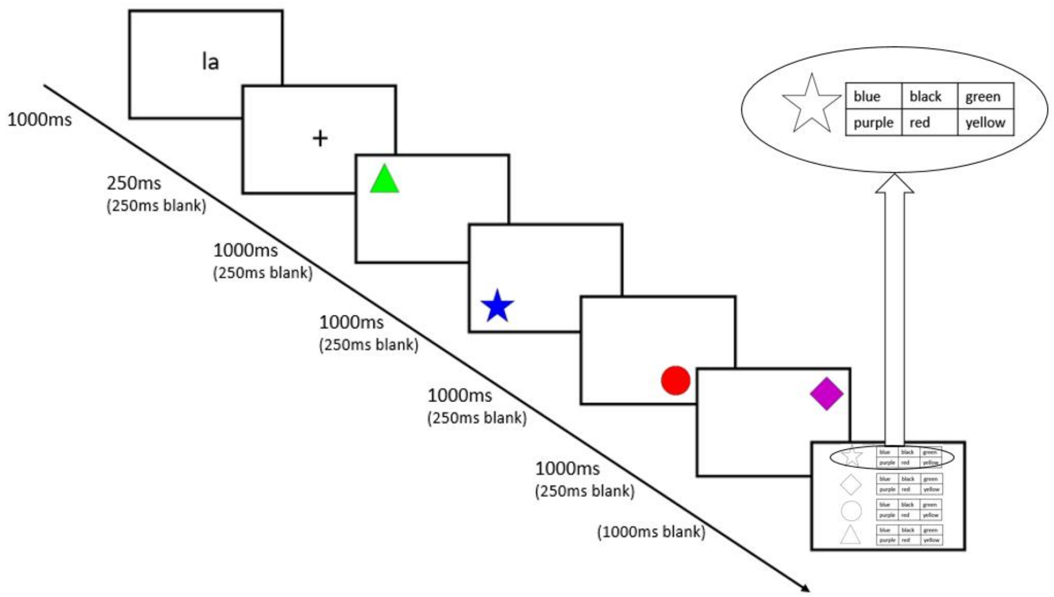

Figure 5.1. The experimental paradigm used in Experiment 8.

The design was same as that in Experiment 7, a 2x4 repeated measures design was implemented in each experiment, with two types of priority condition (priority and no-priority) and probed serial position (SP 1:4).

5.2.1.3 Data analysis

In this experiment, the outcome variable is the accuracy of recalling the correct colour. The independent variables were prioritisation (priority and no priority) and SP (1-2-3-4). Thus, the data were subjected to 2 (prioritisation) x 4(SP) repeated measures ANOVA.

Results were initially reported in terms of SP function. The additional planned analysis was conducted at SP1 since the priority manipulations were aimed at this SP. Data analysis was conducted using frequentist and Bayes Factor (BF) methods. The analysis was performed using JASP (Version 0.16) and R.

5.2.2 Results

5.2.2.1 Accuracy (Proportion Correct)

The 2(priority) x 4(SP) repeated measures ANOVA indicated a main effect of prioritisation (Priority *M* = 0.52, SE = 0.02; No priority *M* = 0.57, SE = 0.03; ($F(1,32) = 8.88$, $p < .01$, $\eta_p^2 = 0.22$, $\eta_G^2 = 0.03$; $BF_{10} = 4.59$), indicating higher memory in the no priority condition. A main effect of serial position emerged ($F(3,96) = 20.24$, $p < .001$, $\eta_p^2 = 0.39$, $\eta_G^2 = 0.19$; $BF_{10} > 10{,}000$). Pairwise comparisons revealed significant differences between SP1 (*M* = 0.63, SE = 0.03) and SP2 (*M* = 0.43, SE = 0.03; $p < .001$) and SP3 (*M* = 0.49, SE = 0.03; $p < 0.001$), SP2 and SP4 (*M* = 0.63, SE = 0.03; $p < 0.001$), and SP3 and SP4 ($p < 0.001$).

There was a significant interaction between SP and priority ($F(3,96) = 29.66$, $p < .001$, $\eta_p^2 = 0.48$, $\eta_G^2 = 0.13$; $BF_{10} > 10000$), showing that the effect of priority differentiated depending on the SP tested (see Figure 5.2).

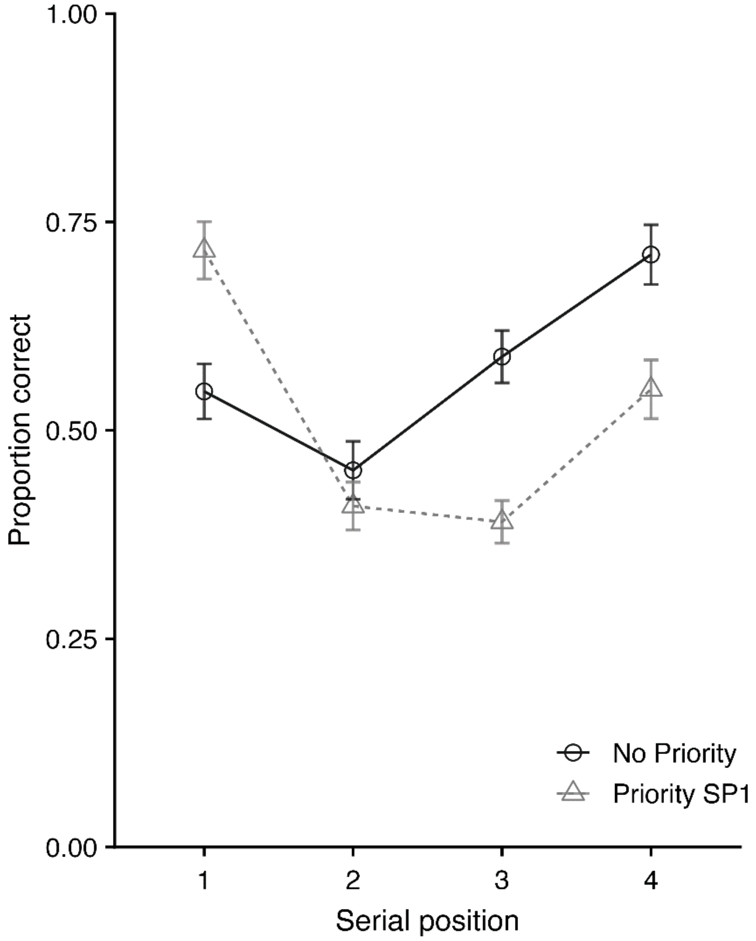

Figure 5.2. Mean proportion correct (with SE) in each priority and control (no priority) condition from Experiment 8. Data are presented by serial position.

To investigate the interaction between priority and SP, a series of paired sample t-tests were conducted. A significant difference emerged at SP1 (prioritised SP); the performance of participants was significantly better in the priority condition ($t(32) = -4.78$, $p < .001$, $BF_{10} = 619.33$, $d = -0.83$). Additionally, significant differences emerged between priority and no priority conditions in SP3 ($t(32) = 7.54$, $p < .001$, $BF_{10} > 10000$, $d = 1.31$) and SP4 ($t(32) = 4.67$, $p < .001$, $BF_{10} = 458.78$, $d = 0.81$) But there was no significant difference in SP2 ($t(32) = 1.25$, $p = 0.22$, $BF_{10} = 0.38$, $d = 0.22$). To sum up, results showed that prioritising the first item increased performance at SP1 and decreased performance at SP3 and SP4 but had no significant effect on performance at SP2.

5.2.2.2 Response Order

In this experiment, in addition to the accuracy analysis of the response, the response order was also investigated (see Figure 5.3). The results showed that in the priority condition, participants initially responded with the prioritised item (SP1), followed by the last item, and the third and second items, respectively. In the no-priority condition, they recalled the last item and then the first, third and second items. To sum up, results showed that participants initially answered with the prioritised item in the priority condition, whereas they initially answered with the last encountered item in the no priority condition.

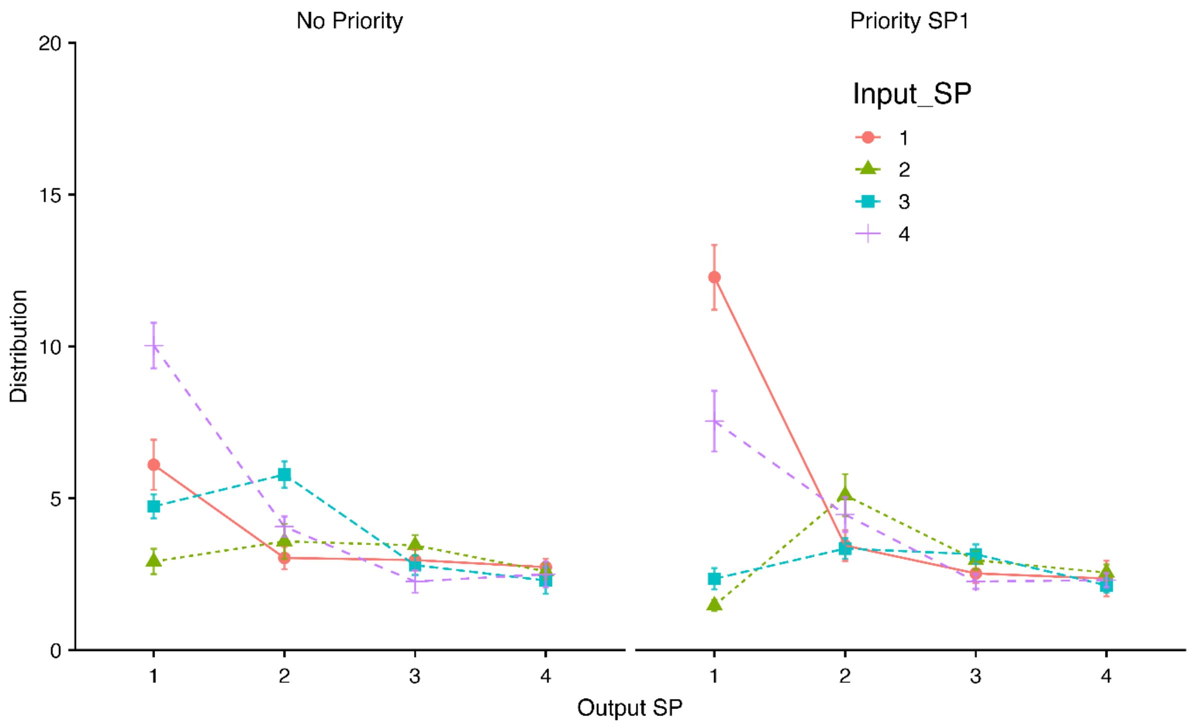

*Figure 5.3***.** The distribution of the response order of participants in each priority and control (no priority) condition from Experiment 8. Input_SP represented the presentation SP of items, while Output SP represented the order of response.

Analysis was conducted for the response order data at SP1 as the priority manipulation was targeted at this SP. A 2 (priority) x 4 (SP) repeated measures ANOVA indicated a main effect of priority (Priority M = 5.01 , SE = 0.16; No priority M = 5.38, SE = 0.16; (F(1,32) = 6.80, p =.014, η_p^2 = 0.18, η_G^2< .002). A main effect of serial position emerged (F(3,96) = 28.37, p < .001, η_p^2 = 0.47, η_G^2 = 0.39). Pairwise comparisons (corrected using Bonferroni-Holm) revealed significant differences between SP1 (M = 0.36, SE = 0.03) and SP2 (M = 0.06, SE = 0.03; p < .001) and SP3 (M = 0.12, SE = 0.03; p < .001), between SP2 and SP4 (M = 0.33, SE = 0.03; p < .001) and between SP3 and

SP4 ($p < .001$). In summary, participants were more likely to produce the first or final item as their first response, overall.

There was a significant interaction between SP and priority ($F(3,96) = 36.26$, $p < .001$, $\eta_p^2 = 0.53$, $\eta_G^2 = 0.21$).

One-way ANOVA was conducted particularly to identify the effect of response order separately in both priority and no priority. There was a significant effect of selected SP in the no priority condition ($F(3,96) = 20.48$, $p < .001$, $\eta_p^2 = 0.39$, $\eta_G^2 = 0.38$). Pairwise comparisons (corrected using Bonferroni-Holm) revealed significant differences between SP1 and SP2 ($p = .005$) and SP4 ($p < .001$), between SP2 and SP4 ($p < .001$), and between SP3 and SP4 ($p < .001$). There was a significant effect of selected SP in the priority condition ($F(3,96) = 37.34$, $p < .001$, $\eta_p^2 = 0.54$, $\eta_G^2 = 0.53$). Pairwise comparisons (corrected using Bonferroni-Holm) revealed significant differences between SP1 and SP2 ($p < .001$), SP3 ($p < .001$) and SP4 ($p < .001$), between SP2 and SP4 ($p < .001$) and between SP3 and SP4 ($p < .001$). To sum up, the participants' response order showed a significant difference between SP4 and all other SPs in the no priority condition and in the priority condition there was a significant difference between SP1 and all other SPs. This suggests participants answer with the prioritised item in the priority condition and show a recency advantage when none of the items were prioritised.

5.3 Discussion

The present study examined whether participants can allocate their attention to high-value items in an online paradigm that tests whole items in the study array. Firstly, as previous findings indicated, there was a recency effect. Additionally, the finding indicated a main effect of priority with better memory performance in the no priority condition than priority. Moreover, there was a significant interaction between the serial position of the item and the priority condition.

Performance was significantly enhanced at SP1 in the prioritisation condition compared to SP1 in the no-priority condition. This result further illustrated that individuals were capable of focusing their attention on greater value items in online VWM tasks, consistent with prior research (Allen et al., 2021; Atkinson et al., 2018; 2021; Hitch et al., 2018; Hu et al., 2014; 2016). Nevertheless, distinctively from previous research, the overall memory performance of participants was lower in the priority condition than in the no-priority condition. In previous research, prioritising an item did not affect overall memory capacity (Astle et al., 2012; Gunseli et al., 2015; Hitch et al., 2018; Hu et al., 2014; 2016); even though it came with a cost to other items. Particularly, in the previous research, prioritised items showed improvement in recall performance while the memory of remaining items in the same trial declined. The current study, however, found that prioritising a single item out of four stimuli increased the memory for that item but reduced overall memory compared to no prioritisation condition.

Furthermore, in addition to the accuracy of participants' responses, the sequence in which they provided these responses was also investigated in the current study. The results showed that in the priority condition, participants initially answered with the prioritised item (SP1) and then the last item, and the third and second items, respectively. However, in the no-priority condition, they initially recalled the last item and then the first, third and second items. Additionally, within the study, participants were not required to respond to every shape-item pairing in the test screen. Participants could continue to the next trial without recalling all items. Thus, it is possible that participants would devote more attention to the first item and less to the others in the priority condition as they were permitted to respond to the items in any order they desired.

Notably, Chapters 2 and 4 demonstrated that participants showed no evidence of directing their attention to high-value items in online experiments with cued recall testing paradigms, but this effect appeared in the lab setting (last Experiment in Chapter 2 and Chapter 3). Furthermore, the current experiment showed that in an online setting, this effect emerged by testing the whole array. The presence of the priority effect in this study, which was not observed in the four previous online experiments (Experiment 1-2-3-7), suggests that the test method plays a vital role in encouraging and directing attention strategically towards high-value items. The findings broadly align with previous in-person prioritisation studies with younger ages. Initially, in the 7 to 10-year-old group, it was observed that this age group was not capable of allocating their attention to high-value items with prioritisation (Berry et al., 2018). However, a subsequent study by Atkinson et al. (2019) demonstrated that they were capable of prioritising effectively when sufficient motivational elements were provided.

Additionally, one could suggest that motivation may be a factor in the emerging difference between online and lab test methods, given that the prioritisation studies require engagement with executive resources (Hitch et al., 2018; Hu et al., 2014; 2016). In the lab environment, motivation can be higher due to the greater control over the conditions. However, in the online setting, the lack of motivation and control (Gagné & Franzen, 2023) can be overcome with a suitable adaptation to the online environment (Buchanan & Smith, 1999; Jun et al., 2017) as the result of the present study showed.

Regarding the observed priority boost and the contrast with the earlier observed null effects, this is also likely to result in increased test reliability. While in previous online studies, the higher-value item was tested in only 25% of the trials, in the current experiment, high-value items were tested in all trials in addition to other items in the study array. Thus, in the cued recall test paradigm, presenting four items and probing only one of them can prevent the prioritisation effect from emerging in an online setting, as has also been observed in lab settings when looking at visual cueing (Astle et al., 2012; Griffin & Nobre, 2003; Gunseli et al., 2015; Pertzov et al., 2013). Building on previous studies which demonstrated priority effect on higher-value items (Allen & Ueno, 2018; Atkinson et al., 2018; Berry et al., 2018; Hitch et al., 2018; Hu et al., 2014; 2016; Sandry et al., 2014; Sandry & Ricker, 2020), the findings of null effect in Chapters 2 (Experiment 1-2-3) and 4 further indicated that testing method and environment affects WM performance. This conclusion is also consistent with WM studies that utilised different test types. For example, Makovski et al. (2010) demonstrated this effect by comparing a recognition (same-different) task and a two-alternative-forced-choice task. The results demonstrated that working memory performance was considerably impaired during the two-alternative forced-choice task in comparison to the recognition task. Therefore, it can be concluded that the testing method had an impact on WM performance, and higher reliability of the prioritised items (testing high-value items in each trial) can improve priority boost.

Furthermore, the order of answers given by the participants may also provide information about the underlying mechanism of how value-directed prioritisation functions in WM. In the prioritisation condition, participants often responded first to the prioritised SP. One can think that individuals might refresh the high-value item until the test screen appears, and they might prefer to respond first on the test screen. Thus, this might suggest that high-value items are held in a privileged state in WM, likely by attentional refreshing (Hitch et al., 2018; Hu et al., 2016; Souza et al., 2015). In the no priority condition, the first response of participants was typically the last encountered item. These findings were also consistent with previous literature. According to Hu et al. (2014), recent items are more likely to be maintained in the focus of attention (FoA) since the FoA tends to shift to subsequent items when several items are presented serially. In order to prioritise, participants had to change their focus of attention from the last item to the first item in the series using executive processes (Allen & Ueno, 2018; Hitch et al., 2018; Hu et al., 2014; 2016). This phenomenon can occur when these items are held in FoA for an extended period or are consistently retained more frequently than others. (Hitch et al., 2018; Hu et al., 2016; Sandry et al., 2014). This framework appears to be compatible with the participants' response order. Thus, it can be suggested that, in the no priority condition, participants responded to the last item first as it was already in the FoA. In the priority condition, they responded to the high-value item first, as it was kept refreshed in WM with the help of executive resources.

Another noteworthy finding that necessitates more consideration is the diminished overall performance in priority settings. These results may be attributed to the characteristics of the testing methodology. Despite the lack of consensus, several studies have observed a decline in overall memory in the condition that the whole study array tested compared to the partial (Makovski et al., 2008; Sperling, 1960).

For instance, Makovski et al. (2008) tested VWM performance in the change detection paradigm and compared whole report and partial report procedures. Findings showed that implementing a partial-report procedure has the potential to enhance performance in the presentation of retrospective cues. Similarly, Sperling (1960) also indicated that the testing process has a substantial impact on the estimation of memory capacity. It suggested that a partial report is more advantageous than a whole report since memory deteriorates during the testing procedure.

However, in the general studies that compared single-probe and whole-array displays, the requirement was to decide whether one of the items from the study array was the same or different (Kyllingsbaek & Bundesen, 2009).

This is notably different from the current study, in which all of the items in the study array were tested with a cued recall paradigm. Even though the method used was not the same as previous literature exploring whole vs. partial testing and the current study, the effect of testing all items on overall performance may explain the reduced performance observed in the prioritisation condition in the current study. As previous research demonstrated that testing the whole study array might have a disruptive effect compared to a partial report (Makovski et al., 2008; Sperling, 1960). Furthermore, in the current study, participants were required to prioritise one item and still recall all the other items in the study array, while they were only required to recall as many items as possible in the no-priority condition. Therefore, the requirement to recall all arrays in the priority condition can have a detrimental effect on overall memory ability.

Another possible relevant reason for reduced performance in prioritisation conditions could be output interference, which is the influence of testing other items on memory performance; this effect is generally shown with word list recognition tasks (Criss et al., 2011; Murdock & Anderson, 1975; Norman & Waugh, 1968; Schulman, 1974). An increase in the number of items tested was associated with adverse effects, as observed in several previous studies (Criss et al., 2011; Norman & Waugh, 1968; Schulman, 1974). Schulman (1974) also specified that the processing of early information diminishes the recognisability of late information, and early recognition judgements complicate subsequent judgements. Upon analysing the data of the present study, it appears that there was a decrease in the memory performance for SP3 and SP4 in the condition that the first item was prioritised.

One could suggest that when participants are required to prioritise the first item, the memory of the subsequent ones can be decreased due to output interference.

Another possible effect can be temporal decay (Barrouillet et al., 2004; Barrouillet & Camos, 2012; Barrouillet et al., 2011; Vergauwe & Cowan, 2015). According to the time-based resource-sharing model, there is a time-related decay in memory traces (Barrouillet et al., 2004). As the model suggested, processing and storage are both considered limited resources and are in competition for attention. A trade-off arises between these two activities as a result of the attention being divided between processing and maintenance due to the limited resources. Thus, considering the present study, the reduced performance in the third and fourth items in the priority condition compared to those with no priority can be consistent with that conceptualisation. Namely, individuals might try to maintain the prioritised item in the FoA, and this results in deteriorated memory for the subsequent items, which is more evident in the third and fourth items in this experiment, where there is no such pattern in equal-value conditions.

Moreover, reduced recall performance in the priority condition might be attributed to the test paradigm employed in the study. It might be possible that when participants are permitted to respond to each item in any order they wish, they pay more attention to the prioritised item and less to the others. Furthermore, in the present experiment, participants were not required to respond to all items; they would respond to items they could recall and skip the remaining items. In the condition that their attention was allocated to the first item, their recollection of the remaining items may be diminished, and as they were not forced, they might not be motivated enough to recall other items. By employing forced choice recall wherein participants are required to respond to all tested items to make progress in the task, future studies can provide more enlightening results.

5.4 Conclusion

In summary, participants were able to direct their attention to a prioritised item in the online WM experiment when the prioritised item was tested in whole trials.

As observed in Chapters 2 and 4, participants might not have sufficient motivation to prioritise the high-value item in the online experiment. The findings of the current study support that this challenge can be overcome by testing high-value items in all trials since motivation increases. These results can be caused by the higher reliability of the prioritised items, which is consistent with the previous studies (Atkinson et al., 2018; Gunseli et al., 2015), as they provided evidence of enhancing the memory of high-value items by increasing the testing in trials.

Another notable finding of this experiment was the participants' response order. Participants initially responded to the prioritised item in priority condition, possibly due to the refreshing mechanism for high-value items (Hu et al., 2016).

However, they responded firstly to the most recent item in no-priority condition owing to the automatic maintenance of recently encountered items as a result of the constant shifting mechanism of FoA (Hu et al ., 2014).

Lastly, there was a decrease in the overall memory performance in the priority condition compared to no-priority. As previous studies suggested, this can be caused by output interference since the processing of early information can reduce the memory of subsequent information (Schulman, 1974) or prioritising one item and recalling others at the same time can reduce overall performance (Barrouillet et al., 2004).

Thus, overall, these results indicated that the testing method can affect allocating attention and memory performance in WM and participants are capable of prioritising effectively with optimal methodology.

CHAPTER 6

GENERAL DISCUSSION

6.1 Thesis Overview

WM is critical regarding broader cognitive abilities such as reading and mathematics (Gathercole et al., 2006), vocabulary and arithmetical reasoning (Henry & MacLean, 2003), comprehension ability (Marshall & Nation, 2003) and future academic success (Gathercole et al., 2003). However, WM has a limited capacity to temporarily store and process information (Baddeley et al., 2021). Consequently, there has been a growing interest in the investigation of how individuals can enhance the efficiency of WM to ensure this limited-capacity system is used most efficiently. Specifically, how one can enhance the efficiency of current resources to accommodate higher-priority and more value items in WM. To improve the efficiency of utilising WM, cueing and value-directed prioritisation are used. Cueing methods are typically based on the use of spatial location to inform participants which stimuli will (or is most likely to) be tested with either the presentation of a cue before or after the visual array (Astle et al., 2012; Souza & Oberauer, 2016; Vogel et al., 2005). Although the cueing method is used more commonly, the method of value-directed prioritisation can be more compatible with everyday life. In this method, participants are informed that one or more particular items are relatively more valuable than the other items and memory performance is improved for high-value items (Allen et al., 2024). Since the value and importance of everyday objects can differ naturally, value-directed prioritisation can be considered more similar to real-life scenarios for examining WM. Additionally, this approach could easily be implemented to add value to particularly valuable information. Research to date investigated how priority effects work from various domains such as visual (Hitch et al., 2018; Hu et al., 2014; 2016; Sandry et al., 2014), verbal-auditory (Atkinson et al., 2021), olfactory-visual (Johnson & Allen, 2022) and tactile (Roe et al., 2024). Despite the variety of research examining the effects of value-directed prioritisation, the effect on binding across different domains in WM has been limited to date.

Therefore, in this thesis, the prioritisation effect was investigated by exploring:

A) Whether individuals can direct their attention to high-value items in spatially separated (shape outlines and coloured blobs were presented in close proximity but not as a unitised object) objects and whether this effect is consistent in online and in-person testing paradigms
B) Whether individuals can direct their attention to high-value items in cross-modal binding (each shape is presented visually in pairing with an auditory colour name) in WM in an in-person study
C) Whether individuals can successfully prioritise high-value items in online contexts, investigating the role of motivation in online experiments through monetary rewards
D) Whether the prioritisation effect emerges in an online value-directed prioritisation task when all items in the study array are tested

These research questions were investigated in eight experiments across four experimental chapters. In the following sections, the findings are summarised, and then the implications of each chapter are examined.

6.2 Summary of the key findings

6.2.1 Chapter 2 – Unitised and Spatially Separated Binding

In the prioritisation task, it has been widely observed that recall performance is enhanced for items that are linked with a high point value as opposed to those that are linked with a low point value (Allen & Ueno, 2018; Atkinson et al., 2018; 2019; 2020; Berry et al., 2018; Hitch et al., 2018; Hu et al., 2014; 2016; Roe et al., 2024). The prioritisation boost has been demonstrated in visual (Hitch et al., 2018; Hu et al., 2014; 2016), verbal (Atkinson et al., 2021) and tactile (Roe et al., 2024) domains in WM. Additionally, although a number of studies have investigated binding in VWM, the typically utilised method has been unitised objects (Allen et al., 2006; Luck & Vogel, 1997; Morey & Bieler, 2013; Wheeler & Treisman, 2002). However, to the best of our knowledge, no research investigated the value-directed prioritisation effect in WM when features of items are presented spatially separately. Thus, Chapter 2 examined this effect with three online and one in-person experiment.

In Experiment 1, an interaction between serial position and priority was found. There was no increase in the recall of the prioritised item, yet there was a significant decrease in the recall of the final item when the first item was prioritised. These findings indicated that although the priority condition did not do what was intended, it reduced the recency effect, which is consistent with previous studies showing that prioritising one item results in lower performance for others (Astle et al., 2012; Atkinson et al., 2018; Chun et al., 2011; Hitch et al., 2018; Hu et al., 2014; 2016). In this experiment, the memory items were displayed in the same location sequentially, which could have resulted in overwriting of the items' features. To overcome the possible overwriting effect, a second experiment was conducted with the display of items in different locations on the screen.

In Experiment 2, although no priority boost was observed, the binding effect emerged, with higher overall performance in unitised than spatially separated binding. Therefore, the results suggested that when items were presented in different spatial locations, participants showed better performance in unitised binding compared to spatially separated, consistent with previous findings by Karlsen et al. (2010). One possibility for the null effect of prioritisation could be that participants may have been less likely to direct their attention to the prioritised item if they relied on verbal rehearsal to remember each item on a visual prioritisation test. Due to that reason, articulatory suppression was utilised in Experiment 3 since it increases the dependence on visual memory (Hanley & Bakopoulou, 2003; Salamé & Baddeley, 1986).

The result of Experiment 3 was similar to that of Experiment 2, demonstrating that there was no priority effect. However, individuals again showed higher memory performance in unitised binding than spatially separated.

Since the priority boost was not observed in all three online experiments, the same effect was examined by conducting an in-person experiment in Experiment 4. The results showed a significant interaction between serial position and priority, in which participants showed better memory performance at SP1 in the prioritisation condition than in the no-priority condition and this effect did not differ between binding conditions. This finding demonstrated further that individuals could direct their attention to higher-value objects when features of items were visually separated in the WM task, extending previous literature (Allen et al., 2021; Atkinson et al., 2018; 2021; Hu et al., 2014; 2016; Hitch et al., 2018). Additionally, similarly to Experiments 2 and 3, it was indicated that the recall performance of participants was higher for the unitised binding than at spatially separated.

These findings have implications for the relationship between WM and attention by showing that the prioritisation effect could be observed in unitised and spatially separated binding, at least under controlled lab setting conditions. This supported the concept that directing attention to high-value items is not more attention-demanding when features of items are spatially separated compared to unitised. Moreover, even though the prioritisation boost remained constant when features were presented spatially separated, the total memory performance was lower in spatially separated binding than in unitised, which can be interpreted as separating features possibly requiring more capacity in the WM.

6.2.2 Chapter 3 – Unitised and Cross-Modal Binding

As Chapter 2 showed, a prioritisation effect could be observed in unitised and spatially separated binding, at least under controlled lab setting conditions. Chapter 3 aimed to explore whether individuals are also capable of prioritising items in cross-modal binding. The binding types investigated in this study were unitised (coloured shapes) and cross-modal (shapes presented visually in synchrony with auditory colour names) with two in-person experiments.

In Experiment 5, findings of the present experiment indicated a marginal interaction between serial position and priority, in which participants showed better memory performance at SP1 in the priority condition than in the no priority condition; however, this effect was only marginal and not well supported by Bayesian analysis. Additionally, there was no significant difference in the overall memory performance between binding types.

In this experiment, there was a timing asynchrony between the visual and audio components; the exposure duration of the audio component vary between 450-600ms while presentation time was 1000ms for the visual component. This might have impact on prioritisation effect. Moreover, as numerical effect observed in the Allen et al. (2021) - even though this effect is tentative - shorter display duration may increase the priority boost. Therefore, it can be suggested that with 1000ms presentation time, perceived ease was not sufficient to motivate participants to prioritise.

Therefore, to match exposure duration for the binding conditions and to increase the perceived difficulty, it was decided to reduce the presentation time of items to 600ms in Experiment 6. The findings of Experiment 6 revealed a significant interaction between SP and priority. Participants showed better memory performance at SP1 in the prioritisation condition than in the no-priority condition. These findings provide evidence that individuals can allocate attention to more valuable items in both visual and visual-auditory WM.

The findings of this experiment extend previous findings of prioritisation boost on high-value items with visual stimuli (Allen et al., 2021; Hu et al., 2014; 2016; Hitch et al., 2018), auditory-verbal stimuli (Atkinson et al., 2021), olfactory-visual stimuli (Johnson & Allen, 2023) and in the tactile domain (Roe et al., 2024), illustrating that the prioritisation effect can be observed across WM domains and is not modality-specific.

Another important finding was that there was no difference in the overall performance between binding types, suggesting that connecting information from different modalities does not impact WM capacity (Allen et al., 2009; Atkinson et al., 2021; Guazzo et al., 2020; Johnson & Allen, 2023).

Finally, while the priority effect was only marginal in Experiment 5, the significant effect appeared with a shorter exposure duration. It can be suggested that in the shorter exposure duration and encoding time, participants might be more motivated to allocate their attention strategically to high-value items, which is consistent with a numerically higher prioritisation boost with a shorter exposure duration observed in Allen et al. (2021).

6.2.3 Chapter 4 – Online Study with Monetary Reward

In Chapter 2, three online experiments and one laboratory experiment revealed that participants showed prioritisation effects only in the lab experiment. This disparity suggests potential problems with control and motivation in the online experimental setting. This chapter aimed to address this discrepancy by examining the motivational role in online experiments through monetary rewards linked to point values.

There is a variety of evidence demonstrating that monetary reward value can enhance LTM (Adcock et al., 2006; Gruber & Otten, 2010; Murty & Adcock, 2014; Shigemune et al., 2010; Wittmann et al., 2005) and WM (Morey et al., 2011; van den Berg et al., 2023; Lytle et al., 2020; Xu et al., 2022). However, very few studies have applied this at an item level in WM (Zheng et al., 2002). Therefore, Experiment 7 explored whether providing monetary rewards in exchange for their recall performance can motivate participants to prioritise high-value items in an online experiment setting. In this experiment, the financial reward was at the item level, in which the items were associated with low, equal and high point values in the memory array, and the points were associated with the money reward.

The results of Experiment 7 showed that there was no interaction between serial position and priority. Namely, there was no significant increase in the recall performance of SP1 (prioritised SP) compared to SP1 in the no-priority condition.

These results indicate that participants in online experimental contexts might have challenges in allocating their attention to higher-value items and engaging with the experiment, while such an issue does not appear to arise in laboratory experiments.

One possible explanation for the null effect might be the relatively modest magnitude of the monetary reward. Based on the previously mentioned investigations, one can conclude that a substantially greater monetary incentive enhances motivation and facilitates improved memory performance in individuals. On the contrary, smaller amounts of monetary incentives do not yield the same effect (Brissenden et al., 2021; Gruber & Otten, 2010; Shigemune et al., 2010).

Another potential factor is that participants did not sufficiently engage with the instructions of the experiment in an online-based study. Thus, although the effect was evident in the laboratory experiment, its absence in the online setting may be attributed to the nature of the online assessment, which could make it more challenging to control motivation. One possible reason for lower motivation is the test type. Within this thesis, in the studies so far, participants have been asked to prioritise one item, but only one item is being tested in each trial. Therefore, in 75% of trials, the prioritised item was not tested. Thus, the testing method can be one of the reasons for the lower motivation.

6.2.4 Chapter 5 – Online Study with Whole Array Testing

In Chapter 4, it appeared that in the online working memory experiment, individuals showed no evidence of shifting their attention towards greater value items in return for monetary reward. One critical reason for the absence of a boost in the recall of high-value items could be that the test method employed was suboptimal for the online experiment. Thus, in this chapter, the objective was to develop a test format that was better suited to online experimentation, as research findings indicated that minor alterations in the testing procedure could have a significant impact on memory sensitivity (Kyllingsbaek & Bundesen, 2009; Makovski et al., 2010).

In previous experiments (Experiment 1-7), participants were asked to prioritise one item among four items presented in the study array, and only one item in each trial was tested in random order. Therefore, the prioritised item was examined only in 25% of the trials. This could affect the reliability of the cued/prioritised item. Reliability is related to the frequency of the cued (prioritised) item being tested (Gunseli et al., 2015). Thus, reliability was 25% in the previous experiments in this thesis. Numerous studies have demonstrated that the recall performance enhances the item being cued (Griffin & Nobre, 2003; Astle et al., 2012; Pertzov et al., 2013; Gunseli et al., 2015) and lower reliability of cued items decreased recall in WM (Astle et al., 2012; Griffin & Nobre, 2003; Gunseli et al., 2015; Pertzov et al., 2013). Furthermore, within the prioritisation paradigm, recall performance is enhanced when the frequency of testing highly valued items is increased (Atkinson et al., 2018). Since the reliability (frequency of testing) was only 25% in the previous study, in Experiment 8, the aim was to increase this to 100% by testing all items in the study array in each trial.

The results of Experiment 8 indicated a main effect of priority with better memory performance in the no priority condition than priority, in addition to a significant interaction between the serial position of the item and the priority condition. Performance was significantly enhanced at SP1 in the prioritisation condition compared to SP1 in the no-priority condition. This result illustrated that individuals were indeed capable of focusing their attention on greater value items in VWM tasks in the online setting. Therefore, it can be concluded that the testing method had an impact on WM performance, and increased reliability of the prioritised items (testing high-value items in each trial) can improve this priority boost. Additionally, one can suggest that participants in online settings need greater motivation to engage with instruction of prioritise.

Furthermore, in addition to the accuracy of participants' responses, the sequence in which they provided their responses was also investigated in this experiment. The results showed that in the priority condition, participants tended to initially answer with the prioritised item (SP1), then the last item, and, respectively, the third and second items. However, in the no-priority condition, they were more likely to initially recall the last item and then the first, third and second items. The order of answers given by the participants may also provide information about the underlying mechanism of how value-directed prioritisation functions in WM. In the prioritisation condition, participants often responded first to the prioritised SP; this might imply that prioritisation makes high-value items more accessible in WM (Hitch et al., 2018; Hu et al., 2016; Souza et al., 2015). If individuals have refreshed the high-value item until the test screen appears or refreshed this item more relative to the other items (Atkinson et al., 2022), they might prefer to respond first on the test screen. In the no-priority condition, the first response of participants was typically the last encountered item, as this is already likely to have been in the FoA (Hu et al., 2014).

6.3 Theoretical implications

The main aim of this thesis was to discover whether individuals are able to prioritise more valuable information in working memory across several different task contexts. The results of the study may also offer important insights into the cognitive mechanisms that may be responsible for these effects.

One of the primary findings of this thesis was that individuals could prioritise higher-value items in unitised, spatially separated and cross-modal binding in WM under at least controlled lab setting conditions.

One persistent finding through eight experiments was the recency effect, which indicated that memory was higher for the last seen item. This further supports the notion that when items are presented serially, the FoA shifts consistently to subsequent items; hence, recently encountered items are most likely to be retained in FoA (Hu et al., 2014).

However, to achieve prioritisation in the sequential presentation, participants need to strategically shift FoA from the final item to the first item presented in the series through executive processes (Hitch et al., 2018; Hu et al., 2014; 2016). Given this, what cognitive mechanisms may be responsible for the value effects in WM? As observed in those experiments that showed the effect, participants do prioritise high-value items, but it comes with a cost to less-value items, indicating individuals allocated their attentional resources to the retention of the more valuable object. This suggested that the cognitive mechanism responsible for the prioritisation effect in WM is likely to be dependent on attentional resources (Hu et al., 2016).

This process, therefore, might occur since the prioritised items are consolidated more effectively in WM (Jolicœur & Dell'Acqua, 1998) or due to attentional refreshing (Atkinson et al., 2022). To reveal which mechanism is more pertinent, prioritisation studies with a post-stimulus suffix may provide critical evidence. It is demonstrated that after displaying a set of items, being exposed to suffixes (to be ignored items) disrupted the prioritisation effect in the WM (Allen & Ueno, 2018; Hitch et al., 2018; Hu et al., 2014; 2016). As consolidation is thought to protect items from perceptual interference, these results are not coherent with the consolidation concept (De Schrijver &

Barrouillet, 2017). Therefore, since the content of FoA was displaced by subsequent objects, the representation could remain active by requiring extended periods of time to refresh the more valuable item (Hitch et al., 2018).

Additionally, given that prioritisation is more effective when it is conducted during encoding, as showed by retrospective versus prospective prioritisation research conducted by Allen and Atkinson (2021), it is likely that the effect occurs during the encoding phase.

The previous studies mostly suggested relatively automatic binding in that it is not more attentional demanding than single feature memory in WM (Allen et al., 2006; 2009; 2012; Baddeley et al., 2011; Delvenne et al., 2010; Ecker et al., 2013; Morey & Bieler, 2013; Karlsen et al., 2008; 2010; Vergauwe et al., 2014; Yeh et al., 2005).

Similarly, in this thesis, participants were required to engage with attention to prioritise high-value items, and results demonstrated that participants could manage to perform prioritisation in unitised, spatially separated and cross-modal binding, at least in lab settings. If additional attention is required for the binding since attention would be divided between binding and prioritisation, a notable decline would be expected in prioritisation abilities in different binding tasks. Therefore, it can be suggested speculatively that the results of the present thesis further extended previous binding-attention studies by suggesting that binding across different modalities and spatial locations does not require more attention than unitised binding. However, these conclusions are hypothetical and necessitate additional research to explore the cognitive mechanisms that underlie prioritisation effects in WM.

However, it is important to note that different binding types differ in terms of overall memory performance. While participants showed better performance in unitised binding compared to spatially separated, which is consistent with previous findings (Karlsen et al., 2010), there was no difference in the overall performance between unitised and cross-modal binding. This suggests that connecting information from different modalities does not impact WM capacity (Allen et al., 2009; Atkinson et al., 2021; Guazzo et al., 2020; Johnson & Allen, 2023), yet connecting visual information from different spatial locations may impact on the overall capacity.

The findings demonstrated in this thesis can be explained by using and extending further WM models in a variety of ways. According to multicomponent theories of working memory (WM), information is received from the outside world and then divided into various domain-specific stores (Baddeley, 2000; Logie, 2011). The central executive, as described by Baddeley (1986; 2000), is responsible for carrying out control processes. Within this model, the last and goal-relevant items can be stored in a domain-general FoA within the episodic buffer. This briefly enhances the accessibility of those items (Hu et al., 2014). Specifically, the episodic buffer serves as an interface between different subsystems to bind various basic forms of memory information as integrated chunks of data (Baddeley et al., 2010). The present findings are in line with this concept by indicating that the FoA within the episodic buffer is modality general (Chapters 2 and 3); individuals retain the goal-relevant items and recently encountered items in this FoA (Chapters 2, 3 and 5) and this creates a temporary memory boost for this items. In addition, these results showed that strategic memory boosts may be more challenging to achieve in the online experiment setting due to possible problems in motivation and control (Chapters 2 and 4), indicating that testing all items in the study array can increase engagement with the task (Chapter 5).

Additionally, the present research is consistent with the numerous critical components of Cowan's embedded processes model (Cowan, 1999; 2016). This model suggested a hierarchical structure of WM; the broadest component is LTM, followed by the currently activated subset of LTM, and the narrowest component is activated memory in the FoA. FoA can store a limited amount of information by zooming in and out, and information can reach the systems via voluntary or automatic processes (Cowan, 1999). The findings of this thesis are also coherent with Cowan's modal. For example, the recency and priority effect can be explained by the function of FoA representations, which can enter the system by automatic and voluntary process (Chapters 2, 3 and 5). Additionally, the results of the current study showed that both visual and visual-audio information can be held in the FoA, which provides further evidence of the modality-general system of FoA (Chapter 3).

Therefore, the present findings are in line with the components of both Baddeley's multicomponent model and Cowan's embedded processes model. This emphasises the key similarities between the models with regard to the FoA and temporary storage of the goal-relevant information, as well as the automatic entry of information into the WM. Although different WM approaches may have varying viewpoints, both models fit these findings and have started to come together on shared ground (Gray et al., 2017; Hu et al., 2016). This demonstrates that despite the definitions being distinct across different models of WM, they can be comparable to explain findings.

6.4 Limitations

One limitation of the online studies conducted within this thesis can be the participants' engagement with instructions. It is worth noting that the reason the initial investigations were conducted online was the COVID-19 pandemic and lockdown. During online experiments, participants may exhibit reduced time allocation or attention towards the instructions. Throughout the thesis in the lab experiments, the examiner verbally provided instructions and ensured that the participants understood them in the practical trial before each condition. However, this control mechanism could not be applied in the online experiments. To solve this engagement problem in the online experiment, Chandler et al. (2019) proposed that the implementation of a pre-screening test can be advantageous in reducing the impact of lack of motivation and control in online experiments. Therefore, implementing a pre-screening procedure, which is a simple test that evaluates participants' attentiveness and basic English comprehension, might be an effective measure for ensuring data quality in online studies. In addition to this, expanding the sample size may enhance the effectiveness of the study. Specifically, in online experiments, participants' engagement may be diminished; therefore, increasing the sample size might appropriately enhance the power of the experiment and enable detection of smaller effects.

Another limitation is that the relatively small amounts of monetary incentives in Chapter 4 can explain why the prioritisation effect cannot be found. Literature showed that substantially greater monetary incentive enhances motivation and facilitates improved memory performance in individuals, yet smaller amounts of monetary incentives do not yield the same effect (Brissenden et al., 2021; Gruber & Otten, 2010; Shigemune et al., 2010). If the high-value reward could be more notably greater than the low and equal reward, this could evaluate the priority boost.

Additionally, none of the studies in this experiment were pre-registered. Pre-registration minimises the risk of biased decisions by promoting outcome-independent decision-making and enhancing transparency (Hardwicke & Wagenmakers, 2023). Thus, it is important to take into consideration the pre-registration of the experiments for the future studies.

Moreover, implementing an end-of-session questionnaire would be beneficial for understanding participants' motivation, attention orientation, the strategy they used when performing experiments, and following instructions. Therefore, by examining the outcome of the questionnaires, appropriate arrangements might be implemented to enhance the experiment's efficiency. It is substantial to add end-of-session questionnaires in future studies to make more effective administration of the experiment.

Finally, another important limitation was that within the study in Chapter 5, participants were not required to respond to every shape-item pairing in the test screen. Participants could continue to the next trial without recalling all items. Thus, it is possible that participants may have selectively answered with the items they can recall more vividly and then proceeded to the next ones. In order to overcome this issue, future research using forced choice recall, wherein participants are required to respond to all tested items to make progress in the task, can provide more enlightening results.

6.5 Future directions

Chapters 2 and 3 demonstrated that the prioritisation effect can be observed in unitised, spatially separated and cross-modal binding. There is also some evidence in the literature showing that the prioritisation effect can be observed in auditory-verbal (Atkinson et al., 2021), tactile (Roe et al., 2024) domains and a weak effect in olfactory-visual (Johnson & Allen, 2022) binding. However, Chapter 3 demonstrated that there is a significant prioritisation effect in visual-audio cross-modal binding. While prioritising is achievable in visual-audio binding, results showed that it can be more difficult in olfactory-visual binding. Therefore, further studies could investigate whether the observed prioritisation effect in cross-modal binding is due to the nature of visual-auditory binding or whether the same effect can be observed in different types of cross-modal binding, such as audio-tactile or olfactory-audio cross-modal binding.

This can provide more insights into the binding information from various domains in the WM and whether this process requires extra attention.

In Chapter 3, in the cross-modal binding, the audio information was auditorily presented with visual information (colour). Thus, the representation in WM might have a visual element, and it is uncertain whether this information is retained auditorily or visually. Even though the stimuli presented are auditory, the representation of it might be visual. Therefore, there is a potential for this cross-modal binding to be visual–visual binding in the conscious representation. If the audio information has no visual representation, the required attention may change to bind that information. Further research could explore whether the prioritisation effect differs in the visual-audio cross-modal binding if audio information has no visual or verbal representation in WM. For example, Del Gatto et al. (2015) utilised percussive sounds as an auditory stimulus; similarly, a future study can investigate prioritisation in cross-modal binding with colours as visual stimuli and percussive sounds as auditory stimuli.

Another important observed effect in Chapter 3 was that participants did not successfully prioritise high-value items in Experiment 5 with a 1000ms exposure duration to the same extent as when items were presented for 600ms. By decreasing presentation time, the ability to prioritise emerged in cross-modal binding. A similar effect was also observed with a numerically higher prioritisation boost with shorter exposure duration by Allen et al. (2021). One critical possibility is that as prioritisation tasks require strategic allocation of attention (Hu et al., 2014), participants need to be motivated enough to accomplish this task (Atkinson et al., 2019). It can be suggested that in the shorter exposure duration and encoding time, participants might be more motivated to allocate their attention strategically to high-value items. Conducting a study that precisely explores this effect, such as whether the prioritisation effect changes in different exposure durations, can yield insights into the mechanism of prioritisation. In addition to this, varying a range of memory loads can be another possible future direction, given that only 4-item set sizes are utilised throughout this thesis. Changing the number of items in the memory array can also be insightful to have a further understanding of prioritisation. In some previous studies, the ceiling effect was observed with the utilisation of a 3-item sequence (Sandry et al., 2014); however, conducting this includes cross-modal binding to understand whether there is potentially more load in cross-modal by changing the memory load can provide more knowledge about binding.

In Chapter 5, it is observed that the prioritisation effect was evident in the online experiment when all items in the memory array were tested. Nevertheless, in this chapter, this test paradigm was only applied to unitised binding. Applying this test formatting to other binding types (spatially separated and cross-modal) in the online experiments may provide important information in terms of the critical role of the testing formats and how this effect changes the online and in-person experimental paradigms. In addition to that, since prioritisation requires strategic directing of attention (Hu et al., 2014), allowing participants to recall the items in the order they choose can give further insights into strategic mechanisms in the different binding types. Furthermore, to date, only a few value-directed prioritisation studies have used full sequence recall in verbal (Atkinson et al., 2021) and tactile (Roe et al., 2024) domains; this did not apply in the visual and visual-audio (cross-modal binding) information. Thus, as a future study, applying full set recall while allowing participants to recall the items in the order they choose in spatially separated and cross-modal can extend knowledge about the prioritisation mechanism and pave the way for comparing the prioritisation effect between online and lab-based studies.

Finally, it could provide further knowledge to investigate the effects of prioritisation in a variety of binding types in older age and Alzheimer’s disease groups. It is accepted that the WM capacity is reduced in older adults (Naveh-Benjamin et al., 2007) as well as people who have been diagnosed with various neurological and developmental disorders (Martinussen et al., 2005; Chai et al., 2018). Additionally, a meta-analysis conducted by Cecchini et al. (2023) revealed that impairment in feature binding in WM is considered a cognitive marker for Alzheimer's disease. However, Guazzo et al. (2020) showed that although Alzheimer's disease patients showed impaired performance, this was independent of the binding types in addition to no age-related difference between cross-modal and unitised binding. In addition, studies with older adults (Allen et al., 2021) showed that the prioritisation effect can be observed in the older age group. Thus, there are controversial findings regarding binding in Alzheimer's disease and older age groups, and it has been observed that older age groups are able to perform prioritisation despite the general decrease in WM. In that case, since prioritisation effects are thought to depend on executive resources (Hu et al., 2016), examining the prioritisation effect in different binding forms both in the older age and Alzheimer's disease group may provide an extended understanding of whether attention allocation and binding decreased in that age. Additionally, in this thesis, as binding did not decrease while participants were required to perform prioritisation at the same time in the young adult group, binding was assumed to be an automatic process. Testing this finding in different age groups may provide further information about the mechanism of binding.

6.6 Conclusion

This thesis has extended existing value-directed prioritisation literature by providing evidence that individuals are able to direct their attention to higher-value items in unitised, spatially separated and cross-modal binding, at least under a controlled lab environment. Since prioritisation is thought to rely on executive resources and this effect did not differ in different binding types, this may be taken as evidence that binding across modalities and spatial locations is not more attentionally demanding than unitised binding. However, the total memory performance was lower in spatially separated binding than in unitised, which can be interpreted as separated features requiring more capacity in the WM. Contrary to the spatially separated condition, there was no difference in the overall performance between unitised and cross-modal binding, suggesting that connecting information from different modalities does not impact WM capacity. Moreover, the results of the online experiments in Chapter 2 indicated that allocation of attention might be challenging in the online experimental paradigm. Therefore, in Chapters 4 and 5, the effect of prioritisation in the online experiment was explored in more detail. Participants did not show a clear indication of prioritisation by receiving monetary rewards in exchange for their performance in Chapter 4. This challenge was overcome by testing all items in the memory array in Chapter 5, and a clear priority boost was observed in the online WM prioritisation task.

Finally, the overall theoretical suggestion of this thesis was that the FoA within the episodic buffer is modality general. Individuals are able to maintain both goal-relevant and recently encountered information in this FoA, and this results in a temporary memory boost for these items. Additionally, these results showed that strategic memory boosts might be more challenging to achieve in the online experiment setting due to potential issues with motivation and control. However, testing prioritised items in each trial can increase engagement/motivation in the task.

REFERENCES

Adcock, R.A., Thangavel, A., Whitfield-Gabrieli, S., Knutson, B. and Gabrieli, J.D.E. (2006). Reward-Motivated Learning: Mesolimbic Activation Precedes Memory Formation. *Neuron*, *50(3),* pp.507–517. doi:https://doi.org/10.1016/j.neuron.2006.03.036.

Allen, R. J., & Atkinson, A. L. (2021). Retrospective and prospective prioritization in visual working memory. *PsyArXiv* (OSF Preprints). https://doi.org/10.31234/osf.io/4x8zu

Allen, R. J., Atkinson, A., & Hitch, G. J. (2024). Getting value out of working memory through strategic prioritisation; implications for storage and control. *Quarterly Journal of Experimental Psychology*. doi.org/10.1177/17470218241258

Allen, R. J., Atkinson, A. L., & Nicholls, L. A. B. (2021). Strategic prioritisation enhances young and older adults' visual feature binding in working memory. *Quarterly Journal of Experimental Psychology, 74(2*), 363-376. https://doi.org/10.1177/1747021820960712

Allen, R., Baddeley, A., & Hitch, G. (2006). Is the binding of visual features in working memory resource-demanding?. *Journal Of Experimental Psychology: General*, *135*(2), 298-313. doi: 10.1037/0096-3445.135.2.298

Allen, R. J., Baddeley, A. D., & Hitch, G. J. (2014). Evidence for two attentional components in visual working memory. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, 40(6), 1499–1509. https://doi.org/10.1037/xlm0000002

Allen, R. J., Castellà, J., Ueno, T., Hitch, G. J., & Baddeley, A. D. (2015). What does visual suffix interference tell us about spatial location in working memory? *Memory & Cognition*, *43*(1), 133–142. https://doi.org/10.3758/s13421-014-0448-4

Allen, R., Hitch, G., & Baddeley, A. (2009). Cross-modal binding and working memory. *Visual Cognition*, *17*(1-2), 83-102. doi: 10.1080/13506280802281386

Allen, R. J., Hitch, G. J., Mate, J., & Baddeley, A. D. (2012). Feature binding and attention in working memory: A resolution of previous contradictory findings. *Quarterly Journal of Experimental Psychology,* 65(12), 2369–2383. https://doi.org/10.1080/17470218.2012.687384

Allen, R. J., & Ueno, T. (2018). Multiple high-reward items can be prioritized in working memory but with greater vulnerability to interference. *Attention,* *Perception & Psychophysics*, 80(7), 1731–1743. https://doi.org/10.3758/s13414-018-1543-6

Anderson, B. A., Laurent, P. A., & Yantis, S. (2011). Value-driven attentional capture. *Proceedings of the National Academy of Sciences*, *108*(25), 10367-10371.

Anwyl-Irvine, A. L., Massonnié, J., Flitton, A., Kirkham, N., & Evershed, J. K. (2020). Gorilla in our midst: An online behavioral experiment builder. *Behavior research methods*, 52, 388-407. https://doi.org/10.3758/s13428-019-01237-x

Astle, D. E., Nobre, A. C., & Scerif, G. (2012). Attentional control constrains visual short term memory: Insights from developmental and individual differences. *The Quarterly Journal of Experimental Psychology*, *65*(2), 277-294.

Awh, E., & Jonides, J. (2001). Overlapping mechanisms of attention and spatial working memory. *Trends In Cognitive Sciences*, *5*(3), 119-126. doi: 10.1016/s1364 6613(00)01593-x

Atkinson, A., Berry, E., Waterman, A., Baddeley, A., Hitch, G., & Allen, R. (2018). Are there multiple ways to direct attention in working memory?. *Annals Of The New York Academy of Sciences*, 1424(1), 115-126. doi: 10.1111/nyas.13634

Atkinson, A. L., Waterman, A. H., & Allen, R. J. (2019). Can children prioritize more valuable information in working memory? An exploration into the effects of motivation and memory load. *Developmental Psychology,* 55(5), 967–980. https://doi.org/10.1037/dev0000692

Atkinson, A. L., Allen, R. J., Baddeley, A. D., Hitch, G. J., & Waterman, A. H. (2021). Can valuable information be prioritized in verbal working memory? *Journal of Experimental Psychology: Learning, Memory, and Cognition*.

Atkinson, A. L., Oberauer, K., Allen, R. J., & Souza, A. S. (2022). Why does the probe value effect emerge in working memory? Examining the biased attentional refreshing account. *Psychonomic Bulletin & Review,* 29(3), 891-900. https://doi.org/10.3758/s13423-022-02056-6.

Atkinson, R. C., & Shiffrin, R. M. (1968). Human memory: A proposed system and its control processes. *In Psychology of learning and motivation* (Vol. 2, pp. 89–195).

Avons, S. E., & Mason, A. (1999). Effects of visual similarity on serial report and item recognition. *Quarterly Journal of Experimental Psychology: Section A. Human Experimental Psychology*, 52, 217–240. doi: 10.1080/713755809

Baddeley, A. D. (1986). *Working memory*. Oxford, UK: Oxford University Press, Clarendon Press

Baddeley, A. (2000). The episodic buffer: a new component of working memory?. *Trends In Cognitive Sciences*, *4*(11), 417-423. doi: 10.1016/s1364-6613(00)01538-2

Baddeley, A. (2010). Working memory. *Current biology,* 20(4), R136-R140.

Baddeley, A. (2012). Working memory: Theories, models, and controversies. *Annual review of psychology,* 63, 1-29. https://doi.org/10.1146/annurev-psych-120710-100422.

Baddeley, A. D., & Hitch, G. (1974). Working memory. In G.H. Bower (Ed.), *The Psychology of Learning and Motivation: Advances in Research and Theory,* 8, pp. 47–89. New York: Academic Press

Baddeley, A., Allen, R. J., & Hitch, G. (2010). Investigating the episodic buffer. *Psychologica Belgica*, *50*(3), 223-243.

Baddeley, A., Allen, R., & Hitch, G. (2011). Binding in visual working memory: The role of the episodic buffer. *Neuropsychologia*, *49*(6), 1393-1400. doi: 10.1016/j.neuropsychologia.2010.12.042

Baddeley, A. D., Hitch, G. J., & Allen, R. (2021). A multicomponent model of working memory. *Working memory: State of the science*, 10-43.

Baddeley, A., Lewis, V., & Vallar, G. (1984). Exploring the articulatory loop. *Quarterly Journal of Experimental Psychology*, 36, 233–252. https://doi.org/10.1080/14640748408402157

Barrouillet, P., Bernardin, S., & Camos, V. (2004). Time constraints and resource sharing in adults' working memory spans. *Journal of Experimental Psychology: General,* 133(1), 83–100. https://doi.org/10.1037/0096- 3445.133.1.83

Barrouillet, P., Bernardin, S., Portrat, S., Vergauwe, E., & Camos, V. (2007). Time and cognitive load in working memory. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, 33(3), 570–585. https://doi.org/10.1037/0278-7393.33.3.570

Barrouillet, P., & Camos, V. (2012). As Time Goes By: Temporal Constraints in Working Memory. *Current Directions in Psychological Science*, 21(6), 413–419. https://doi.org/10.1177/0963721412459513

Barrouillet, P., Portrat, S., & Camos, V. (2011). On the law relating processing to storage in working memory. *Psychological Review*, 118(2), 175–192. https://doi.org/10.1037/a0022324

Belletier, C. and Camos, V. (2018). Does the experimenter presence affect working memory? *Annals of the New York Academy of Sciences*, 1424(1), pp.212–220. doi:https://doi.org/10.1111/nyas.13627.

Berry, E. D. J., Waterman, A. H., Baddeley, A. D., Hitch, G. J., & Allen, R. J. (2018). The limits of visual working memory in children: Exploring prioritization and recency effects with sequential presentation. *Developmental Psychology*, 54(2), 240–253. https://doi.org/10.1037/dev0000427

Berryhill, M. E., Richmond, L. L., Shay, C. S., & Olson, I. R. (2012). Shifting Attention among Working Memory Representations: Testing Cue Type, Awareness, and Strategic Control. *Quarterly Journal of Experimental Psychology*, 65(3), 426–438. https://doi.org/10.1080/17470218.2011.604786

Bond, C.F. and Titus, L.J. (1983). Social facilitation: A meta-analysis of 241 studies. *Psychological Bulletin*, 94(2), pp.265–292. doi:https://doi.org/10.1037/0033-2909.94.2.265.

Bridges, D., Pitiot, A., MacAskill, M. R., & Peirce, J. W. (2020). The timing mega-study: comparing a range of experiment generators, both lab-based and online. *PeerJ*, 8, e9414. https://doi.org/10.7717/peerj.9414

Brissenden, J. A., Adkins, T. J., Hsu, Y. T., & Lee, T. G. (2021). Reward influences the allocation but not the availability of resources in visual working memory. *bioRxiv*.

Brown, L. A., & Brockmole, J. R. (2010). The Role of Attention in Binding Visual Features in Working Memory: Evidence from Cognitive Ageing. *Quarterly Journal of Experimental Psychology*, 63(10), 2067–2079. https://doi.org/10.1080/17470211003721675

Brown, L. A., Niven, E. H., Logie, R. H., Rhodes, S., & Allen, R. J. (2017). Visual feature binding in younger and older adults: Encoding and suffix interference effects. *Memory*, 25, 261–275.

Buchanan, T., & Smith, J. L. (1999). Using the Internet for psychological research: Personality testing on the world wide web. *British Journal of Psychology*, 90(1), 125–144. https://doi.org/10.1348/000712699161189

Buhrmester, M. D., Talaifar, S., & Gosling, S. D. (2018). An evaluation of Amazon's Mechanical Turk, its rapid rise, and its effective use. *Perspectives on*

Psychological Science, 13(2), 149–154. https://doi.org/10.1177/1745691617706516

Burgess, N., & Hitch, G. J. (1992). Toward a network model of the articulatory loop. *Journal of memory and language*, 31(4), 429-460.

Camos, V., Lagner, P., & Barrouillet, P. (2009). Two maintenance mechanisms of verbal information in working memory. *Journal of Memory and Language*, *61*(3), 457–469. https://doi.org/10.1016/j.jml.2009.06.002

Castel, A. D., Murayama, K., Friedman, M. C., McGillivray, S., & Link, I. (2013). Selecting valuable information to remember age-related differences and similarities in self regulated learning. *Psychology and Aging*, *28*(1), 232.

Ceraso, J. (1985). Unit Formation in Perception and Memory*. Psychology of Learning and Motivation,* 19, 179-210.

Chandler, J., Rosenzweig, C., Moss, A.J., Robinson, J. and Litman, L. (2019). Online panels in social science research: Expanding sampling methods beyond Mechanical Turk. *Behavior Research Methods*, 51. doi:https://doi.org/10.3758/s13428-019-01273-7.

Chandler, J., & Shapiro, D. (2016). Conducting clinical research using crowdsourced convenience samples. *Annual Review of Clinical Psychology*, 12, 53–81. https://doi.org/10.1146/annurev-clinpsy-021815-093623

Chandler, J., Sisso, I. and Shapiro, D. (2020). Participant carelessness and fraud: Consequences for clinical research and potential solutions. *Journal of Abnormal Psychology*, 129(1), pp.49–55. doi:https://doi.org/10.1037/abn0000479.

Cecchini, M. A., Parra, M. A., Brazzelli, M., Logie, R. H., & Della Sala, S. (2023). Short-term memory conjunctive binding in Alzheimer's disease: A systematic review and meta-analysis. Neuropsychology, 37(7), 769–789. https://doi.org/10.1037/neu0000825

Chai, W. J., Abd Hamid, A. I., & Abdullah, J. M. (2018). Working Memory From the Psychological and Neurosciences Perspectives: A Review. *Frontiers in Psychology*, 9(1). https://doi.org/10.3389/fpsyg.2018.00401

Chun, M. M., Golomb, J. D., & Turk-Browne, N. B. (2011). A taxonomy of external and internal attention. *Annual review of psychology*, *62*, 73-101.

Cocchini, G., Logie, R. H., Sala, S. D., MacPherson, S. E., & Baddeley, A. D. (2002). Concurrent performance of two memory tasks: Evidence for domain-specific working memory systems. *Memory & Cognition*, 30(7), 1086–1095. https://doi.org/10.3758/bf03194326

Cowan, N. (1999). An embedded-processes model of working memory. In A. M. P. Shah (Ed.), *Models of working memory* (pp. 62-101). Cambridge, UK: Cambridge University Press.

Cowan, N. (2001). The magical number 4 in short-term memory: A reconsideration of mental storage capacity. *Behavioral And Brain Sciences*, *24*(1), 87-114. doi: 10.1017/s0140525x01003922

Cowan, N. (2005). Working Memory Capacity (1st ed.). *Psychology Press*. https://doi.org/10.4324/9780203342398

Cowan, N. (2010). The magical mystery four: How is working memory capacity limited, and why?. *Current directions in psychological science*, *19*(1), 51-57.

Cowan, N. (2011). The focus of attention as observed in visual working memory tasks: Making sense of competing claims. *Neuropsychologia*, *49*(6), 1401-1406.

Cowan, N. (2016). Working Memory Maturation: Can We Get at the Essence of Cognitive Growth? *Perspectives on Psychological Science*, 11(2), 239–264. https://doi.org/10.1177/1745691615621279

Criss, A. H., Malmberg, K. J., & Shiffrin, R. M. (2011). Output interference in recognition memory. *Journal of Memory and Language*, 64(4), 316–326. https://doi.org/10.1016/j.jml.2011.02.003

Del Gatto, C., Brunetti, R., & Delogu, F. (2015). Cross-modal and intra-modal binding between identity and location in spatial working memory: The identity of objects does not help recalling their locations. *Memory*, 24(5), 603–615. https://doi.org/10.1080/09658211.2015.1034137

Delogu, F., Gravina, M., Nijboer, T., & Postma, A. (2014). Binding "what" and "where" in auditory working memory: An asymmetrical association between sound identity and sound location. *Journal of Cognitive Psychology*, 26(7), 788–798. https://doi.org/10.1080/20445911.2014.959448

Delogu, F., & Lilla, C. C. (2017). Do you remember where sounds, pictures and words came from? the role of the stimulus format in object location memory. *Memory*, 25(10), 1340–1346. https://doi.org/10.1080/09658211.2017.1300668

Delvenne, J., & Bruyer, R. (2004). Does visual short-term memory store bound features? *Visual Cognition*, 11(1), 1–27. https://doi.org/10.1080/13506280344000167

Delvenne, J. F., & Bruyer, R. (2006). A configural effect in visual short-term memory for features from different parts of an object. *Quarterly journal of experimental psychology* (2006), 59(9), 1567–1580. https://doi.org/10.1080/17470210500256763

Delvenne, J.-F., Cleeremans, A., & Laloyaux, C. (2010). Feature bindings are maintained in visual short-term memory without sustained focused attention. *Experimental Psychology*, 57(2), 108–116. https://doi.org/10.1027/1618-3169/a000014

De Schrijver, S., & Barrouillet, P. (2017). Consolidation and restoration of memory traces in working memory. *Psychonomic Bulletin & Review*, 24(5), 1651–1657. https://doi.org/10.3758/s13423-017-1226-7

Diao, L., Qi, S., Xu, M., Li, Z., Ding, C., Chen, A., et al. (2016). Neural signature of reward-modulated unconscious inhibitory control. *Int. J. Psychophysiol.* 107, 1–8. doi: 10.1016/j.ijpsycho.2016.06.012

Dixon, R. A., Wahlin, A., Maitland, S. B., Hultsch, D. F., Hertzog, C., & Bäckman, L. (2004). Episodic memory change in late adulthood: Generalizability across samples and performance indices. *Memory & Cognition*, 32(5), 768–778. https://doi.org/10.3758/BF03195867

Ecker, U. K. H., Maybery, M., & Zimmer, H. D. (2013). Binding of intrinsic and extrinsic features in working memory. *Journal of Experimental Psychology: General*, 142(1), 218–234. https://doi.org/10.1037/a0028732

Elsley, J., & Parmentier, F. (2009). Short article: Is verbal–spatial binding in working memory impaired by a concurrent memory load?. *Quarterly Journal of Experimental Psychology*, 62(9), 1696-1705. https://doi.org/10.1080/17470210902811231

Engle, R. W., Tuholski, S. W., Laughlin, J. E., & Conway, A. R. A. (1999). Working memory, short-term memory, and general fluid intelligence: A latent-variable approach. *Journal of Experimental Psychology: General*, *128*(3), 309–331. https://doi.org/10.1037/0096-3445.128.3.309

Fan, J., McCandliss, B. D., Sommer, T., Raz, A., & Posner, M. I. (2002). Testing the Efficiency and Independence of Attentional Networks. *Journal of Cognitive Neuroscience,* 14(3), 340–347. https://doi.org/10.1162/089892902317361886

Farrell, S. (2008). Multiple roles for time in short-term memory: Evidence from serial recall of order and timing. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, 34(1), 128–145. https://doi.org/10.1037/0278-7393.34.1.128

Faul, F., Erdfelder, E., Buchner, A., & Lang, A.-G. (2009). Statistical power analyses using G*Power 3.1: Tests for correlation and regression analyses. *Behavior Research Methods*, 41(4), 1149-1160. https://doi.org/10.3758/BRM.41.4.1149

Fougnie, D. (2008). The relationship between attention and working memory. *New research on short-term memory*, 1, 45.

Fougnie, D., & Alvarez, G. A. (2011). Object features fail independently in visual working memory: Evidence for a probabilistic feature-store model. *Journal of Vision*, *11*(12), 3–3. https://doi.org/10.1167/11.12.3

Fougnie, D., Cormiea, S. M., & Alvarez, G. A. (2013). Object-based benefits without object-based representations. *Journal of Experimental Psychology: General*, *142*(3), 621–626. https://doi.org/10.1037/a0030300

Fougnie, D., & Marois, R. (2009). Attentive tracking disrupts feature binding in visual working memory. *Visual Cognition*, 17(1-2), 48–66. https://doi.org/10.1080/13506280802281337

Gagné, N., & Franzen, L. (2023). How to Run Behavioural Experiments Online: Best Practice Suggestions for Cognitive Psychology and Neuroscience. *Swiss Psychology Open*, 3(1): 1, pp. 1–21. DOI: https://doi.org/10.5334/spo.34

Gajewski, D. A., & Brockmole, J. R. (2006). Feature bindings endure without attention: Evidence from an explicit recall task. *Psychonomic Bulletin & Review*, 13(4), 581–587. https://doi.org/10.3758/bf03193966

Gao, Z., Wu, F., Qiu, F., He, K., Yang, Y., & Shen, M. (2017). Bindings in working memory: The role of object-based attention. *Attention, Perception, & Psychophysics,* 79(2), 533–552. https://doi.org/10.3758/s13414-016-1227-z

Gathercole, S. E., Alloway, T. P., Willis, C., & Adams, A. M. (2006). Working memory in children with reading disabilities. *Journal of experimental child psychology*, 93(3), 265-281.

Gathercole, S. E., Brown, L., & Pickering, S. J. (2003). Working memory assessments at school entry as longitudinal predictors of National Curriculum attainment levels. *Educational and Child Psychology*, *20*(3), 109-122.

Gathercole, S. E., Alloway, T. P., Willis, C., & Adams, A. M. (2006). Working memory in children with reading disabilities. *Journal of experimental child psychology*, *93*(3), 265-281.

Gathercole, S. E., Pickering, S. J., Ambridge, B., & Wearing, H. (2004). The structure of working memory from 4 to 15 years of age. *Developmental Psychology*, 40(2), 177-190.

Germine, L., Nakayama, K., Duchaine, B. C., Chabris, C. F., Chatterjee, G., & Wilmer, J. B. (2012). Is the web as good as the lab? Comparable performance from web and lab in cognitive/ perceptual experiments. *Psychonomic Bulletin & Review*, 19(5), 847–857. https://doi.org/10.3758/s13423-012-0296-9

Gonthier, C. (2021). Charting the diversity of strategic processes in visuospatial short-term memory. *Perspectives on Psychological Science*, 16(2), 294-318. https://doi.org/10.1177/1745691620950697.

Gray, S., Green, S., Alt, M., Hogan, T., Kuo, T., Brinkley, S., & Cowan, N. (2017). The structure of working memory in young children and its relation to intelligence. *Journal of Memory and Language*, *92*, 183-201.

Greene, N. R., Chism, S., & Naveh-Benjamin, M. (2021). Levels of specificity in episodic memory: Insights from response accuracy and subjective confidence ratings in older adults and in younger adults under full or divided attention. *Journal of Experimental Psychology: General, 151(4), 804*. https://doi.org/10.1037/xge0001113

Griffin, I. C., & Nobre, A. C. (2003). Orienting Attention to Locations in Internal Representations. *Journal of Cognitive Neuroscience*, 15(8), 1176–1194. https://doi.org/10.1162/089892903322598139

Grogan, J. P., Randhawa, G., Kim, M., & Manohar, S. G. (2022). Motivation improves working memory by two processes: Prioritisation and retrieval thresholds. *Cognitive Psychology*, 135, 101472. https://doi.org/10.1016/j.cogpsych.2022.101472

Gruber, M. J., & Otten, L. J. (2010). Voluntary control over prestimulus activity related to encoding. *Journal of Neuroscience*, 30(29), 9793–9800. https://doi.org/10.1523/JNEUROSCI.0915-10.2010

Guazzo, F., Allen, R. J., Baddeley, A. D., & Della Sala, S. (2020). Unimodal and crossmodal working memory binding is not differentially affected by age or Alzheimer's disease. *Neuropsychology*. https://doi.org/10.1037/neu0000622

Gunseli, E., van Moorselaar, D., Meeter, M., & Olivers, C. N. L. (2015). The reliability of retro-cues determines the fate of noncued visual working memory representations. *Psychonomic Bulletin & Review*, 22(5), 1334–1341. https://doi.org/10.3758/s13423-014-0796-x

Hanley, J. R., & Bakopoulou, E. (2003). Irrelevant speech, articulatory suppression, and phonological similarity: A test of the phonological loop model and the feature model. *Psychonomic Bulletin & Review*, 10(2), 435–444. https://doi.org/10.3758/bf03196503

Hardwicke, T. E., & Wagenmakers, E. J. (2023). Reducing bias, increasing transparency and calibrating confidence with preregistration. *Nature Human Behaviour*, 7(1), 15-26. https://doi.org/10.1038/s41562-022-01497-2

Hartshorne, J. K. (2008). Visual working memory capacity and proactive interference. *PloS One*, 3(7), e2716. https://doi.org/10.1371/journal.pone.0002716

Hay, D. C., Smyth, M. M., Hitch, G. J., & Horton, N. J. (2007). Serial position effects in short term visual memory: A SIMPLE explanation?. *Memory & Cognition*, *35*(1), 176-190.

Henrich, J., Heine, S. J., & Norenzayan, A. (2010). Most people are not WEIRD. *Nature*, 466(7302), 29–29. https://doi.org/10.1038/466029a

Henry, L., & MacLean, M. (2003). Relationships between working memory, expressive vocabulary and arithmetical reasoning in children with and without intellectual disabilities. *Educational and Child Psychology*, *20*(3), 51-63.

Hitch, G. J., Hu, Y., Allen, R. J., & Baddeley, A. D. (2018). Competition for the focus of attention in visual working memory: perceptual recency versus executive control. *Annals of the New York Academy of Sciences, 1424*(1), 64-75. https://doi.org/10.1111/nyas.13631

Hitch, G. J., Allen, R. J., & Baddeley, A. D. (2020). Attention and binding in visual working memory: Two forms of attention and two kinds of buffer storage. *Attention, Perception, & Psychophysics*, 82(1), 280-293.

Hitch, G. J., Fastame, M. C., & Flude, B. (2005). How is the serial order of a verbal sequence coded: Some comparisons between models. *Memory*, 13, 247–258. doi:10.1080/09658210344000314.

Hollingworth, A., Richard, A. M., & Luck, S. J. (2008). Understanding the Function of Visual Short-Term Memory: Transsaccadic Memory, Object Correspondence, and Gaze Correction*. Journal of Experimental Psychology. General*, 137(1), 163–181. https://doi.org/10.1037/0096-3445.137.1.163

Hu, Y., Hitch, G. J., Baddeley, A. D., Zhang, M., & Allen, R. J. (2014). Executive and perceptual attention play different roles in visual working memory: Evidence from suffix and strategy effects. *Journal of Experimental Psychology: Human Perception and Performance*, *40*, 1665–1678. https://doi.org/10.1037/a0037163

Hu, Y., Allen, R. J., Baddeley, A. D., & Hitch, G. J. (2016). Executive control of stimulus driven and goal-directed attention in visual working memory. *Attention, Perception, & Psychophysics*, *78*(7), 2164-2175.

Hurlstone, M. J., Hitch, G. J., & Baddeley, A. D. (2014). Memory for serial order across domains: An overview of the literature and directions for future research. *Psychological Bulletin*, 140(2), 339–373. https://doi.org/10.1037/a0034221

Infanti, E., Hickey, C., & Turatto, M. (2015). Reward associations impact both iconic and visual working memory. *Vision research, 107*, 22-29. doi.org/10.1016/j.visres.2014.11.008

James, W. (1890). The principles of psychology. New York, NY: Holt, Rinehart & Winston

Jiang, Y., Olson, I. R., & Chun, M. M. (2000). Organization of visual short-term memory. *Journal of Experimental Psychology: Learning, Memory, and Cognition,* 26(3), 683–702. https://doi.org/10.1037/0278-7393.26.3.683

Johnson, A.J., & Allen, R.J. (2023) Intentional and incidental odour-colour binding in working memory. *Memory*, 92-107. https://doi.org/10.1080/09658211.2022.2124273

Johnston, J. C., McCann, R. S., & Remington, R. W. (1995). Chronometric evidence for two types of attention. *Psychological Science*, 6(6), 365–369.

Jolicœur, P., & Dell'Acqua, R. (1998). The Demonstration of Short-Term Consolidation. *Cognitive Psychology,* 36(2), 138–202. https://doi.org/10.1006/cogp.1998.0684

Jones, D., Farrand, P., Stuart, G., & Morris, N. (1995). Functional equivalence of verbal and spatial information in serial short-term memory. *Journal of Experimental Psychology: Learning, Memory, and Cognition,* 21, 1008–1018. doi:10.1037/0278-7393.21.4.1008

Jun, E., Hsieh, G., & Reinecke, K. (2017). Types of motivation affect study selection, attention, and dropouts in online experiments. *Proceedings of the ACM on Human- Computer Interaction*, 1(CSCW), 1–15. DOI: https://doi. org/10.1145/3134691

Kane, M. J., & Engle, R. W. (2002). The role of prefrontal cortex in working-memory capacity, executive attention, and general fluid intelligence: An individual-differences perspective. *Psychonomic Bulletin & Review*, 9(4), 637–671. https://doi.org/10.3758/bf03196323

Karlsen, P., Allen, R., Baddeley, A., & Hitch, G. (2010). Binding across space and time in visual working memory. *Memory & Cognition*, 38(3), 292-303. doi: 10.3758/mc.38.3.292

Katsuki, F., & Constantinidis, C. (2014). Bottom-up and top-down attention: different processes and overlapping neural systems. *The Neuroscientist*, 20(5), 509–521. https://doi.org/10.1177/1073858413514136

Klatt, L.-I., Getzmann, S., Begau, A., & Schneider, D. (2020). A dual mechanism underlying retroactive shifts of auditory spatial attention: dissociating target- and distractor-related modulations of alpha lateralization. *Scientific Reports*, 10(1). https://doi.org/10.1038/s41598-020-70004-2

Klyszejko, Z., Rahmati, M., & Curtis, C. E. (2014). Attentional priority determines working memory precision. *Vision research, 105*, 70-76.

Kovacs, O., & Harris, I. M. (2019). The role of location in visual feature binding. *Attention, Perception, & Psychophysics*, *81*(5), 1551–1563. https://doi.org/10.3758/s13414-018-01638-8

Kyllingsbaek, S., & Bundesen, C. (2009). Changing change detection: Improving the reliability of measures of visual short-term memory capacity. *Psychonomic Bulletin & Review*, 16(6), 1000–1010. https://doi.org/10.3758/pbr.16.6.1000

Langerock, N., Vergauwe, E., & Barrouillet, P. (2014). The maintenance of cross-domain associations in the episodic buffer. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, 40(4), 1096–1109. https://doi.org/10.1037/a0035783

Lepsien, J., & Nobre, A. C. (2007). Attentional modulation of object representations in working memory. *Cerebral cortex*, 17(9), 2072-2083. https://doi.org/10.1093/cercor/bhl116

Lisman, J. E., & Grace, A. A. (2005). The hippocampal-VTA loop: controlling the entry of information into long-term memory. *Neuron*, 46(5), 703-713. https://doi.org/10.1016/j.neuron.2005.05.002.

Locke, J. (1841). An Essay Concerning Human Understanding.

Logie, R. H. (1995). Visuo-spatial working memory Hove. *UK: Lawrence Erlbaum Associates Ltd.*

Logie, R. H. (1996). The seven ages of working memory. *Working Memory and Human Cognition, 31–65.*

Logie, R. H. (2011). The Functional Organization and Capacity Limits of Working Memory. *Current Directions in Psychological Science*, 20(4), 240–245. https://doi.org/10.1177/0963721411415340

Logie, R. H., & Cowan, N. (2015). Perspectives on working memory: introduction to the special issue. *Memory & Cognition*, 43(3), 315–324. https://doi.org/10.3758/s13421-015-0510-x

Luck, S., & Vogel, E. (1997). The capacity of visual working memory for features and conjunctions. *Nature*, *390*(6657), 279-281. doi: 10.1038/36846

Luck, S. J., & Vecera, S. P. (2002). Attention. Stevens' handbook of experimental psychology, 1, 235-286.

Lytle, M. N., Hammer, R., & Booth, J. R. (2020). A neuroimaging dataset on working memory and reward processing in children with and without ADHD. *Data in Brief*, *31*, 105801. doi:https://doi.org/10.1016/j.dib.2020.105801

Makovski, T., Sussman, R., & Jiang, Y. V. (2008). Orienting attention in visual working memory reduces interference from memory probes. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, 34(2), 369–380. https://doi.org/10.1037/0278-7393.34.2.369

Makovski, T., Watson, L.M., Koutstaal, W. and Jiang, Y.V. (2010). Method matters: Systematic effects of testing procedure on visual working memory sensitivity. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, 36(6), pp.1466–1479. doi:https://doi.org/10.1037/a0020851.

Marshall, C. M., & Nation, K. (2003). Individual differences in semantic and structural errors in children's memory for sentences. *Educational and Child Psychology*, *20*(3), 7–18. https://doi.org/10.53841/bpsecp.2003.20.3.7

Mangun, G. R., & Hillyard, S. A. (1991). Modulations of sensory-evoked brain potentials indicate changes in perceptual processing during visual-spatial priming. *Journal of Experimental Psychology: Human Perception and Performance,* 17(4), 1057–1074. https://doi.org/10.1037/0096-1523.17.4.1057

Marshall, C. M., & Nation, K. (2003). Individual differences in semantic and structural errors in children's memory for sentences. *Educational and Child Psychology*, *20*(3), 7-18.

Martinussen, R., Hayden, J., Hogg-Johnson, S., & Tannock, R. (2005). A meta-analysis of working memory impairments in children with attention deficit/hyperactivity disorder. *Journal of the American Academy of Child and Adolescent Psychiatry*, 44(4), 377–384. https://doi.org/10.1097/01.chi.0000153228.72591.73

Mayes, A., Montaldi, D., & Migo, E. (2007). Associative memory and the medial temporal lobes. *Trends in Cognitive Sciences*, 11(3), 126–135. https://doi.org/10.1016/j.tics.2006.12.003

Milner, B. (1996). Amnesia following operation on the temporal lobes. *Neurocase,* 2(4), 259u298. https://doi.org/10.1093/neucas/2.4.259-u

Morey, C. C., & Bieler, M. (2013). Visual short-term memory always requires general attention. *Psychonomic Bulletin & Review*, 20(1), 163–170. https://doi.org/10.3758/s13423-012-0313-z

Morey, C. C., Cowan, N., Morey, R. D., & Rouder, J. N. (2011). Flexible attention allocation to visual and auditory working memory tasks: Manipulating reward induces a trade-off. *Attention, Perception, & Psychophysics*, *73*(2), 458-472.

Murdock, B. B., & Anderson, R. E. (1975). Encoding, storage, and retrieval of item information. In *Information processing and cognition* (pp. 145-194). Routledge.

Murty, V. P., & Adcock, R. A. (2014). Enriched encoding: reward motivation organizes cortical networks for hippocampal detection of unexpected events. *Cerebral Cortex* , *24*(8), 2160–2168. https://doi.org/10.1093/cercor/bht063

Myers, N. E., Stokes, M. G., & Nobre, A. C. (2017). Prioritizing Information during Working Memory: Beyond Sustained Internal Attention. *Trends in cognitive sciences,* 21(6), 449–461. https://doi.org/10.1016/j.tics.2017.03.010

Naveh-Benjamin, M., Cowan, N., Kilb, A., & Chen, Z. (2007). Age-related differences in immediate serial recall: Dissociating chunk formation and capacity. *Memory & Cognition*, 35(4), 724–737. https://doi.org/10.3758/bf03193310

Norman, D. A., & Waugh, N. C. (1968). Stimulus and response interference in recognition-memory experiments. *Journal of Experimental Psychology*, 78(4, Pt.1), 551–559. https://doi.org/10.1037/h0026637

Oberauer, K. (2002). Access to information in working memory: Exploring the focus of attention. *Journal Of Experimental Psychology: Learning, Memory, And Cognition*, *28*(3), 411-421. doi: 10.1037/0278-7393.28.3.411

Oberauer, K. (2009). Design for a Working Memory. *Psychology of Learning and Motivation,* 51:45-100. DOI: https://doi.org/10.1016/S0079-7421(09)51002-X

Oberauer, K. (2013). The focus of attention in working memory—from metaphors to mechanisms. *Frontiers in Human Neuroscience*, 7. https://doi.org/10.3389/fnhum.2013.00673

Oberauer, K., & Hein, L. (2012). Attention to Information in Working Memory. *Current Directions in Psychological Science,* 21(3), 164–169. https://doi.org/10.1177/0963721412444727

Oberauer, K., & Kliegl, R. (2006). A formal model of city limits in working memory. *Journal of memory and language*, *55*(4), 601-626.

Olivetti Belardinelli, M., Sestieri, C., Di Matteo, R., Delogu, F., Del Gratta, C., Ferretti, A., & Romani, G. L. (2004). Audio-visual crossmodal interactions in environmental perception: an fMRI investigation. *Cognitive Processing*, *5*, 167-174. https://doi.org/10.1007/s10339-004-0024-0

Olson, I. R., & Marshuetz, C. (2005). Remembering “what” brings along “where” in visual working memory. *Perception & Psychophysics*, 67(2), 185–194. https://doi.org/10.3758/bf03206483

Osman, A., & Moore, C. M. (1993). The locus of dual-task interference: psychological refractory effects on movement-related brain potentials. *Journal of Experimental Psychology: Human Perception and Performance,* 19(6), 1292.

Parmentier, F. B. R., & Jones, D. M. (2000). Functional characteristics of auditory temporal–spatial memory: Evidence from serial order errors*. Journal of Experimental Psychology: Learning, Memory, and Cognition,* 26, 222–238. doi:10.1037/0278-7393.26.1.222

Parra, M. A., Fabi, K., Luzzi, S., Cubelli, R., Hernandez Valdez, M., & Della Sala, S. (2015). Relational and conjunctive binding functions dissociate in short-term memory. *Neurocase*, *21*(1), 56-66

Pashler, H. (1994). Dual-task interference in simple tasks: Data and theory. *Psychological Bulletin*, 116(2), 220–244. https://doi.org/10.1037/0033-2909.116.2.220

Paulsen, D. J., Hallquist, M. N., Geier, C. F., & Luna, B. (2015). Effects of incentives, age, and behavior on brain activation during inhibitory control: a longitudinal fMRI study. *Developmental cognitive neuroscience*, *11*, 105-115. doi:https://doi.org/10.1016/j.dcn.2014.09.003.

Pertzov, Y., Bays, P. M., Joseph, S., & Husain, M. (2013). Rapid forgetting prevented by retrospective attention cues.*Journal of Experimental Psychology: Human Perception and Performance,* 39(5), 1224–1231. https://doi.org/10.1037/a0030947

Pertzov, Y., & Husain, M. (2014). The privileged role of location in visual working memory. *Attention, Perception, & Psychophysics*, 76(7), 1914–1924. https://doi.org/10.3758/s13414-013-0541-y

Pinto, Y., van der Leij, A. R., Sligte, I. G., Lamme, V. A. F., & Scholte, H. S. (2013). Bottom-up and top-down attention are independent. *Journal of Vision,* 13(3), 16. https://doi.org/10.1167/13.3.16

Portrat, S., Camos, V., & Barrouillet, P. (2009). Working memory in children: A time-constrained functioning similar to adults. *Journal of Experimental Child Psychology,* 102(3), 368–374. https://doi.org/10.1016/j.jecp.2008.05.005

Posner, M. I., & Petersen, S. E. (1990). The Attention System of the Human Brain. *Annual Review of Neuroscience*, 13(1), 25–42. https://doi.org/10.1146/annurev.ne.13.030190.000325

Roe, D., Allen, R. J., Elsley, J., Miles, C., & Johnson, A. J. (2024). Working memory prioritisation effects in tactile immediate serial recall. *Quarterly Journal of Experimental Psychology,* 0(0). https://doi.org/10.1177/17470218241231283.

Reips, U.-D. (2021). Web-Based Research in Psychology. *Zeitschrift für Psychologie*, 229(4), pp.198–213. doi:https://doi.org/10.1027/2151-2604/a000475.

Rensink, R. A. (2002). Change detection. *Annual review of psychology*, 53(1), 245-277.

Rerko, L., & Oberauer, K. (2013). Focused, unfocused, and defocused information in working memory. *Journal of Experimental Psychology: Learning, Memory, and Cognition,* 39(4), 1075–1096. https://doi.org/10.1037/a0031172

Rouder, J. N., Morey, R. D., Morey, C. C., & Cowan, N. (2011). How to measure working memory capacity in the change detection paradigm. *Psychonomic Bulletin & Review,* 18(2), 324–330. https://doi.org/10.3758/s13423-011-0055-3

Ryan, A. D., & Campbell, K. L. (2021). The ironic effect of older adults' increased task motivation: Implications for neurocognitive aging. *Psychonomic Bulletin & Review*. Advance online publication. https://doi.org/10.3758/s13423-021-01963-4

Salamé, P., & Baddeley, A. (1982). Disruption of short-term memory by unattended speech: Implications for the structure of working memory. *Journal of Verbal Learning and Verbal Behavior*, 21(2), 150–164. https://doi.org/10.1016/s0022-5371(82)90521-7

Salamé, P., & Baddeley, A. (1986). Phonological factors in STM: Similarity and the unattended speech effect. *Bulletin of the Psychonomic Society*, 24(4), 263–265. https://doi.org/10.3758/bf03330135b

Sander, M. C., Werkle-Bergner, M., & Lindenberger, U. (2011). Binding and strategic selection in working memory: A lifespan dissociation. *Psychology and Aging*, 26(3), 612–624. https://doi.org/10.1037/a0023055

Sandry, J., Schwark, J., & MacDonald, J. (2014). Flexibility within working memory and the focus of attention for sequential verbal information does not depend on active maintenance. *Memory & Cognition*, *42*(7), 1130-1142. doi: 10.3758/s13421-014-0422-1

Sandry, J., & Ricker, T. (2020). Prioritization within visual working memory reflects a flexible focus of attention. *Attention, Perception, & Psychophysics*, *82*(6), 2985-3004. doi:10.3758/s13414-020-02049-4

Sandry, J., Zuppichini, M. D., & Ricker, T. J. (2020). Attentional flexibility and prioritization improves long-term memory. *Acta Psychologica*, 208, 103104. https://doi.org/10.1016/j.actpsy.2020.103104

Schneegans, S., & Bays, P. M. (2017). Neural Architecture for Feature Binding in Visual Working Memory. *The Journal of Neuroscience*, *37*(14), 3913–3925. https://doi.org/10.1523/jneurosci.3493-16.2017

Schneegans, S., & Bays, P. M. (2019). New perspectives on binding in visual working memory. *British Journal of Psychology*, *110*(2), 207-244. https://doi.org/10.1111/bjop.12345

Schneegans, S., Harrison, W. and Bays, P. (2021). Location-independent feature binding in visual working memory for sequentially presented objects. Attention, Stores: A Neuropsychological Study. *Quarterly Journal of Experimental Psychology*, 22(2), 261–273. https://doi.org/10.1080/00335557043000203

Schneegans, S., McMaster, J. M. V., & Bays, P. M. (2022). Role of time in binding features in visual working memory. *Psychological Review*. https://doi.org/10.1037/rev0000331

Schulman, A. I. (1974). The Declining course of recognition memory. *Memory & Cognition*, 2(1), 14–18. https://doi.org/10.3758/bf03197485

Scoville, W. B., & Milner, B. (1957). Loss of recent memory after bilateral hippocampal lesions*. Journal of Neurology, Neurosurgery & Psychiatry*, 20, 11–21. https://doi.org/10.1136/jnnp.20.1.11

Seli, P., O'Neill, K., Carriere, J. S., Smilek, D., Beaty, R. E., & Schacter, D. L. (2021). Mind-Wandering across the age gap: Age-related differences in mind-wandering are partially attributed to age-related differences in motivation. *The Journals of Gerontology*. Series B, 76(7), 1264–1271. https://doi.org/10.1093/geronb/gbaa031

Shallice, T., & Warrington, E. K. (1970). Independent Functioning of Verbal Memory. *Neuropsychologia*, *49*(6), 1597- 1604. doi: 10.1016/j.neuropsychologia.2010.11.030

Shigemune, Y., Abe, N., Suzuki, M., Ueno, A., Mori, E., Tashiro, M., … Fujii, T. (2010). Effects of emotion and reward motivation on neural correlates of episodic memory encoding: a PET study. *Neuroscience Research*, *67*(1), 72–79. https://doi.org/10.1016/j.neures.2010.01.003

Shimi, A., Nobre, A. C., Astle, D., & Scerif, G. (2014). Orienting Attention Within Visual Short-Term Memory: Development and Mechanisms. *Child Development*, 85(2), 578–592. https://doi.org/10.1111/cdev.12150

Souza, A. S., Rerko, L., & Oberauer, K. (2015). Refreshing memory traces: thinking of an item improves retrieval from visual working memory. *Annals of the New York Academy of Sciences,* 1339(1), 20–31. https://doi.org/10.1111/nyas.12603

Souza, A. S., & Oberauer, K. (2016). In search of the focus of attention in working memory: 13 years of the retro-cue effect. *Attention, Perception & Psychophysics,* 78(7), 1839–1860. https://doi.org/10.3758/s13414-016-1108-5

Souza, A. S., Vergauwe, E., & Oberauer, K. (2018). Where to attend next: guiding refreshing of visual, spatial, and verbal representations in working memory. *Annals of the New York Academy of Sciences,* 1424(1), 76–90. https://doi.org/10.1111/nyas.13621

Sperling, G. (1960). The information available in brief visual presentations. *Psychological Monographs: General and Applied*, 74(11), 1–29. https://doi.org/10.1037/h0093759

Theeuwes, J. (2018). Visual Selection: Usually Fast and Automatic; Seldom Slow and Volitional. *Journal of Cognition*, *1*(1), 29. https://doi.org/10.5334/joc.13

Treisman, A. M., & Gelade, G. (1980). A feature-integration theory of attention. *Cognitive Psychology*, 12(1), 97–136. https://doi.org/10.1016/0010-0285(80)90005-5

Treisman, A., & Zhang, W. (2006). Location and binding in visual working memory. *Memory & Cognition*, *34*(8), 1704–1719. https://doi.org/10.3758/bf03195932

Tremblay, S., Guérard, K., Parmentier, F. B. R., Nicholls, A. P., & Jones, D. M. (2006). A spatial modality effect in serial memory. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, 32, 1208– 1215. doi:10.1037/0278-7393.32.5.1208

Triplett, N. (1898). The Dynamogenic Factors in Pacemaking and Competition. *The American Journal of Psychology*, 9(4), pp.507–533. doi:https://doi.org/10.2307/1412188.

Ueno, T., Mate, J., Allen, R. J., Hitch, G. J., & Baddeley, A. D. (2011). What goes through the gate? Exploring interference with visual feature binding. *Neuropsychologia*, 49(6), 1597–1604. https://doi.org/10.1016/j.neuropsychologia.2010.11.030

Unsworth, N., & Engle, R. W. (2007). The nature of individual differences in working memory capacity: active maintenance in primary memory and controlled search from secondary memory. *Psychological review*, *114*(1), 104.

Uittenhove, K., Jeanneret, S., & Vergauwe, E. (2022). From lab-based to web-based behavioural research: Who you test is more important than how you test. Preprint]. *PsyArXiv*. https://doi. org/10.31234/osf. io/uy4kb.

van den Berg R, Zou Q, Li Y, Ma WJ (2023) No effect of monetary reward in a visual working memory task. *PLoS ONE* 18(1): e0280257. https://doi.org/10.1371/journal. pone.0280257

Van de Weijer-Bergsma, E., Kroesbergen, E. H., Prast, E. J., & Van Luit, J. E. H. (2014). Validity and reliability of an online visual–spatial working memory task for self-reliant administration in school-aged children. *Behavior Research Methods*, *47*(3), 708–719. https://doi.org/10.3758/s13428-014-0469-8

van Geldorp, B., Parra, M. A., & Kessels, R. P. (2015). Cognitive and neuropsychological underpinnings of relational and conjunctive working memory binding across age. *Memory,* 23(8), 1112-1122.

Vergauwe, E., & Cowan, N. (2015). Attending to items in working memory: evidence that refreshing and memory search are closely related. *Psychonomic Bulletin & Review*, 22(4), 1001–1006. https://doi.org/10.3758/s13423-014-0755-6

Vergauwe, E., Langerock, N., & Barrouillet, P. (2014). Maintaining information in visual working memory: Memory for bindings and memory for features are equally disrupted by increased attentional demands. *Canadian Journal of Experimental Psychology / Revue Canadienne de Psychologie Expérimentale*, 68(3), 158–162. https://doi.org/10.1037/cep0000025

Vogel, E. K., Woodman, G. F., & Luck, S. J. (2001). Storage of features, conjunctions, and objects in visual working memory. *Journal of Experimental Psychology: Human Perception and Performance,* 27(1), 92–114. https://doi.org/10.1037/0096-1523.27.1.92

Vogel, E., Woodman, G., & Luck, S. (2005). Pushing around the Locus of Selection: Evidence for the Flexible-selection Hypothesis. *Journal Of Cognitive Neuroscience*, 17(12), 1907-1922. doi: 10.1162/089892905775008599

Walker, P., & Cuthbert, L. (1998). Remembering visual feature conjunctions: Visual memory for shape-colour associations is object-based. *Visual Cognition*, 5(4), 409–455. https://doi.org/10.1080/713756794

Walker, P., & Moylan, K. (1994). The enhanced representation of surface texture consequent on the loss of sight. *Neuropsychologia*, 32(3), 289–297. https://doi.org/10.1016/0028-3932(94)90132-5.

Waugh, N. C., & Norman, D. A. (1965). Primary memory. *Psychological review*, 72(2), 89.

Wheeler, M., & Treisman, A. (2002). Binding in short-term visual memory. *Journal Of Experimental Psychology: General*, *131*(1), 48-64. doi: 10.1037/0096-3445.131.1.48

Wilton, R. N. (1989). The Structure of Memory: Evidence concerning the Recall of Surface and Background Colour of Shapes. *The Quarterly Journal of Experimental Psychology Section A*, 41(3), 579-598. https://doi.org/10.1080/14640748908402383

Wittmann, B.C., Schott, B.H., Guderian, S., Frey, J.U., Heinze, H.J. and Düzel, E. (2005). Reward-related fMRI activation of dopaminergic midbrain is associated with enhanced hippocampus-dependent long-term memory formation. *e-Neuroforum*, 11(2). doi:https://doi.org/10.1515/nf-2005-0205.

Woodman, G. F., Vogel, E. K., & Luck, S. J. (2012). Flexibility in visual working memory: Accurate change detection in the face of irrelevant variations in position. *Visual Cognition*, *20*(1), 1–28. https://doi.org/10.1080/13506285.2011.630694

Xu, S., Qi, S., Duan, H., Zhang, J., Akioma, M., Gao, F., ... & Yuan, Z. (2022). Task Difficulty Regulates How Conscious and Unconscious Monetary Rewards

Boost the Performance of Working Memory: An Event-Related Potential Study. *Frontiers in Systems Neuroscience*, *15*, 716961. doi:https://doi.org/10.3389/fnsys.2021.716961.

Xu, Y. (2002a). Encoding colour and shape from different parts of an object in visual short-term memory. *Perception and Psychophysics*, 64, 1260–1280.

Xu, Y. (2002b). Limitations of object-based feature encoding in visual short-term memory. *Journal of Experimental Psychology: Human Perception and Performance*, 28, 458–468.

Yantis, S. (2000). Goal-directed and stimulus-driven determinants of attentional control. *Attention and performance*, *18*, 73-103.

Yantis, S., Anderson, B. A., Wampler, E. K., & Laurent, P. A. (2012). Reward and attentional control in visual search. *The influence of attention, learning, and motivation on visual search*, 91-116.

Yeh, Y.-Y., Yang, C.-T., & Chiu, Y.-C. (2005). Binding or prioritization: The role of selective attention in visual short-term memory. *Visual Cognition*, 12(5), 759–799. https://doi.org/10.1080/13506280444000490

Yetano, A., & Royo, S. (2017). Keeping Citizens Engaged: A Comparison Between Online and Offline Participants. *Administration and Society,* 49(3), 394–422. DOI: https:// doi.org/10.1177/0095399715581625

Yin, X., Havelka, J., & Allen, R. J. (2021). The effect of value on long-term associative memory. *Quarterly Journal of Experimental Psychology*, *74*(12), 2033-2045.

Zajonc, R.B. (1965). Social Facilitation. *Science*, 149(3681), pp.269–274. doi:https://doi.org/10.1126/science.149.3681.269.

Zheng, W., Geng, J., Zhang, D., Zhang, J., & Qiao, J. (2022). Task difficulty rather than reward method modulates the reward boosts in visual working memory. *Journal of Vision, 22*(11):1, 1–8, https://doi.org/10.1167/jov.22.11.1.

Zokaei, N., Heider, M., & Husain, M. (2014). Attention is Required for Maintenance of Feature Binding in Visual Working Memory. *Quarterly Journal of Experimental Psychology,* 67(6), 1191–1213. https://doi.org/10.1080/17470218.2013.852232