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Examining Motivating Factors Influencing Attention, Memory, and Metacognition

A dissertation submitted in partial satisfaction

of the requirements for the degree Doctor of Philosophy

in Psychology

by

Alexander Siegel

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ABSTRACT OF THE DISSERTATION

Examining Motivating Factors Influencing Attention, Memory, and Metacognition

by

Alexander Siegel

Doctor of Philosophy in Psychology

University of California, Los Angeles, 2020

Professor Alan Dan Castel, Chair

Visuospatial memory is an important cognitive process that allows us to remember the identity and location of objects in the environment. As the binding of visual and spatial features is required, visuospatial memory represents an attentionally-demanding form of associative memory (Chalfonte & Johnson, 1996). Further, substantial evidence has shown that older adults may have specific deficits in the remembering associations (Naveh-Benjamin, 2000). Despite this associative deficit, older adults and younger adults under conditions of divided attention have been shown to exhibit maintained memory selectivity – that is, despite remembering less information overall, they are still able to attend to and later remember high-value information. The current Dissertation investigates the underlying attention (Chapter 2), memory (Chapter 3), and metacognitive (Chapter 4) processes involved in this prioritization ability and how they change with age.

Chapter 2 examines how the ability to selectively remember high-value information in the visuospatial domain is affected in dual-task paradigms in which attention must be divided between multiple tasks. Evidence is provided of maintained prioritization when concurrent tasks draw from different processing resources, but impaired prioritization when they draw form overlapping processing resources, as evidenced by a lack of selectivity in intra-modal dual-task conditions. Chapter 3 explores how older adults' prioritization ability compares to younger adults in this demanding visuospatial associative memory context and how younger adults' strategies may change when negatively valued information is present. Results suggest that older adults maintain selectivity relative to younger adults, but still display deficits in memory for high-value information. Younger adults were also biased towards studying and remembering positive over negative locations, despite equivalent influence on their task goals. Finally, Chapter 4 studied the metacognitive processes underlying prioritization ability in younger and older adults, revealing a tradeoff in resources from prioritizing high-value information to accurately monitoring memory performance. The current Dissertation adds to our knowledge about people's ability to selectively remember important information, a crucial form of cognitive control, by casting further light upon the attentional, memorial, and metacognitive aspects involved in the prioritization of visuospatial information.

The dissertation of Alexander Siegel is approved.

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2020

DEDICATION

To my mom, dad, and sister, thank you for being by my side

when I need it most – it means the world.

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CHAPTERS IN EDITED BOOKS

1. **Siegel, A. L. M.,** Whatley, M. C., Hargis, M. B., & Castel, A. D. (in press). Changes in learning, memory, and metacognition in older adulthood. In A. Drolet & C. Yoon (Eds.), *The aging consumer: Perspectives from Psychology and Economics (2nd ed.).* New York, NY: Routledge.

2. Hargis, M. B., Whatley, M. C., **Siegel, A. L. M.,** & Castel, A. D. (in press). Motivated cognition and curiosity in the aging consumer. In A. Drolet & C. Yoon (Eds.), *The aging consumer: Perspectives from Psychology and Economics (2nd ed.).* New York, NY: Routledge.

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4. Knowlton, B. J., **Siegel, A. L. M.**, & Moody, T. D. (2017). Procedural learning in humans. In H. Eichenbaum (Ed.), *Memory systems, Vol. 3 of Learning and memory: A comprehensive reference, 2nd edition,* J. H. Byrne (ed.). pp. 295-312. Oxford, UK: Academic Press.

SELECTED PRESENTATIONS

1. **Siegel, A. L. M.**, Schwartz, S. T. & Castel, A. D. (2019, November). *Memory and metamemory for the location of items: The effects of information importance and encoding difficulty.* Poster presented at the Psychonomic Society's 60th Annual Meeting in Montreal, Canada.

2. **Siegel, A. L. M.**, & Castel, A. D. (2019, May). *Comparing automatic and strategic influences on emotional item-location binding in aging.* Poster presented at the UCLA Conference on Aging in Los Angeles, CA.

3. **Siegel, A. L. M.**, & Castel, A. D. (2019, February). *How attentional load affects memory for important visuospatial information.* Invited talk presented by A. L. M. Siegel to the CLAMDIG research group at the University of York, UK.

4. **Siegel, A. L. M**., & Castel, A. D. (2019, January). *Examining effects of information importance on visuospatial memory in old age.* Invited talk presented by A. L. M. Siegel to the Memory and Successful Ageing research group at the University of Leeds, UK.

5. **Siegel, A. L. M**., & Castel, A. D. (2018, November). *Memory for emotional objects in spatial locations: Effects of attentional load.* Poster presented at the Psychonomic Society's 59th Annual Meeting in New Orleans, LA.

6. **Siegel, A. L. M.,** Carone, B. J., Castel, A. D., & Drolet, A. (2018, May). *Clinically studied or clinically proven? False memory for print advertisements.* Poster presented at the 30th Association for Psychological Sciences (APS) Convention in San Francisco, CA.

7. **Siegel, A. L. M.,** & Castel, A. D. (2018, May). *Younger and older adults' predictions about memory and selectivity in a value-directed memory task.* Poster presented at the Cognitive Aging Conference in Atlanta, GA and at the UCLA Research Conference on Aging in Los Angeles, CA.

8. **Siegel, A. L. M.**, & Castel, A. D. (2018, April). *Remembering emotional objects and spatial locations: The role of value in binding.* Invited talk presented by A. D. Castel at the Society for Affective Science Conference in Los Angeles, CA.

CHAPTER 1: INTRODUCTION

Throughout daily life, we constantly rely on our ability to remember information in a variety of ways. Do you remember where you parked your car at work today? Can you recall the contents of your grocery list for this week? How about the date of your anniversary? These types of everyday tasks can be challenging and, despite our best efforts, we often fail to correctly remember information. Perhaps you search for your car where you parked it yesterday or you neglect to buy eggs at the market – or worse yet, you forget to buy an anniversary gift for your partner. Unsurprisingly, these failures to encode and later retrieve information from memory become more frequent with advancing age (Kester, Benjamin, Castel, & Craik, 2002), potentially leading to various practical issues among the older population, such as failing to take medication or forgetting where the doctor's office is located. This inability to remember information can have a detrimental impact on older adults' lives.

In addition to deficits in remembering verbal information like names or facts about the world, older adults often experience failures in remembering visuospatial information. The ability to remember this information is crucial to daily functioning, as we constantly encounter situations where we must remember information in particular locations – for instance, where we have placed our wallet when we return home after a long day at work. Like memory for verbal episodic information, our ability to remember visuospatial episodic information (e.g., *what* and *where* things are in our environment) declines consistently as we age (Jenkins, Myerson, Joerding, & Hale, 2000; Park et al., 2002). These declines are likely due to deficits in both individual visual and spatial component memory (e.g., Light & Zelinski, 1983; Vaughan & Hartman, 2010), as well as a deficit in binding identity and location information (Chalfonte & Johnson, 1996; Siegel & Castel, 2018b; Thomas, Bonura, Taylor, & Brunyé, 2012). This visuospatial binding deficit is illustrative of a more general associative memory deficit found in various other domains in older adulthood (Castel & Craik, 2003; Naveh-Benjamin, 2000).

In light of clear memory capacity deficits, older adults are able to use strategies to compensate for age-related memory deficits. The selection, optimization, and compensation model (SOC; Baltes & Baltes, 1990) posits that older adults, aware of their overall memory deficits, are able to selectively focus on a specific subset of information in an effort to alleviate those deficits. The model predicts that older adults select important information to focus cognitive resources towards in order to optimize potential gains and compensate for potential losses. Support for this model is provided by lab-based tasks in which older adults are able to selectively attend to and later remember information that is of high value, a process termed value-directed remembering (VDR; Castel, Benjamin, Craik, & Watkins, 2002). This ability to remain selective despite limits on overall memory has been demonstrated in a variety of different contexts, including when information is visuospatial in nature (Siegel & Castel, 2018a).

Importantly, memory selectivity in this context is dependent upon the strategic allocation of attention during the encoding period, as participants must allocate attention towards high-value and away from low-value information in order to fulfill task-related goals (Castel, 2008). Attentional control may also be a particularly critical component when the binding visual and spatial information is required, as theories of visual search suggest that the serial allocation of focused attention is necessary when searching for and remembering conjunctions of features (Treisman & Gelade, 1980; Treisman & Sato, 1990). The crucial role of attention in VDR tasks is highlighted by studies that examine divided attention at encoding (Middlebrooks, Kerr, & Castel, 2017; Siegel & Castel, 2018b) and varying presentation formats (Ariel, Dunlosky, & Bailey, 2009; Brown & Brockmole, 2010; Middlebrooks & Castel, 2018).

Metacognition, the ability to monitor and control our cognitive processes, is a crucial aspect of daily functioning. Metamemory, the metacognitive processes associated with memory, allows us to assess memory quality or strength and adjust our behavior to regulate our memories. For example, when learning information for an upcoming exam, it is imperative for a successful student to accurately evaluate their knowledge of the material (e.g., "How well do I know this piece of information?") and adjust their behavior to account for this evaluation (e.g., "I do not know it that well, so I need to study this information in more depth"). Metacognitive functioning is also critical in old age when memory errors may be more frequent. For example, older adults must remember which medications they have taken in a given day and must be able to adjust their behavior in order to account for this assessment (e.g., "I forgot to take my blood pressure medication earlier, so I must do so now"). As such, it is important for younger and older adults to accurately monitor their memory performance and subsequently control their behaviors to maximize this performance.

Effective metacognitive functioning may become more important as we age due to an increase in the frequency of episodic memory errors (Hertzog & Dixon, 1994). Thus, the ability to monitor when information will be later remembered or forgotten may be a particularly important skill for older adults. In contrast to well-documented episodic memory deficits that occur with advancing age (for a review, see Hess, 2005; Zacks & Hasher, 2006), metacognitive processes associated with memory may experience little to no age-related decline in some circumstances (Castel, Middlebrooks, & McGillivray, 2016; Hertzog & Dunlosky, 2011). Various metamemory studies utilizing judgments of learning (JOLs) to examine how well participants can assess whether information will be later recalled have found negligible differences in JOL accuracy between younger and older adults (Hertzog, Sinclair, & Dunlosky, 2010; Hines, Touron, & Hertzog, 2009). Additional work has shown that older adults are equally as accurate as younger adults in determining when and how much information they may have forgotten between initial encoding and retrieval (Halamish, McGillivray, & Castel, 2011). As such, older adults in some circumstances may rely on their intact metacognitive abilities to mitigate memory declines.

This Dissertation explores motivating factors influencing attention, memory, and metacognition in both younger and older adults. Naturally, these cognitive processes are intricately interlinked: what we pay attention to influences what we remember, what we remember influences how we monitor and control our memory, how we monitor our memory performance influences what we pay attention to, etc. As such, while the following chapters are subdivided by and primarily interested in each of these separate components, it would be silly to suggest that they explore these processes individually and independently. Rather, the main focus of the discussion will center around each of these cognitive processes and the experiments conducted will focus on the relevant mechanisms with the acknowledgement that attentional, memorial, and metacognitive processes are all likely at play in all of the presented tasks. With that in mind, Chapter 2 discusses the attentional mechanisms responsible for binding information in memory and how this ability is influenced by different types of attentionally-demanding secondary tasks in younger adults. Chapter 3 examines how younger and older adults can prioritize information in memory dependent the information importance and how memory strategies may change in the face of negatively valued information. Finally, Chapter 4 focuses on younger and older adults' metacognitive abilities to further examine whether, despite marked declines in capacity, older adults can successfully engage in metacognitive monitoring and control to offset such declines.

CHAPTER 2: THE CRITICAL ROLE OF ATTENTION IN MEMORIAL BINDING

Portions of the introductory comments and Experiment 1 are taken from Siegel & Castel (2018a)

As is well established, attention and memory are closely connected cognitive processes. Generally, our ability to selectively focus our attention on particular stimuli in the environment increases the likelihood that the information will undergo perceptual processing and enter working memory. Further processing of that information (e.g., rehearsal) influences whether that information will be stored in long-term memory. Unattended information, on the other hand, is much less likely to enter working memory and conscious awareness. As such, what we pay attention to is likely to influence what we later remember (for a review, see Fougnie, 2008). With regards to visuospatial memory, attention may be particularly crucial when binding multiple visual features. By examining how attention is allocated in an environment with multiple visual stimuli, prior work has been able to examine how attention may influence our ability to bind and later remember visuospatial information.

The mechanism underlying visuospatial binding impairments in old age may be informed by theories of visual attention. The feature integration theory (FIT; Treisman & Gelade, 1980; Treisman & Sato, 1990) posits that there are two stages when conducting visual search: the pre-attentive stage and focused attention stage. When searching for an object within an array, the pre-attentive stage is parallel and automatic, which is sufficient when identifying single features of an object. However, when searching for conjunctions of features, the focused attention stage is required in which features are combined in a serial and effortful process. The feature integration theory asserts that attention acts like a “glue” which integrates the independent features of an object into a coherent whole (Figure 2.1).

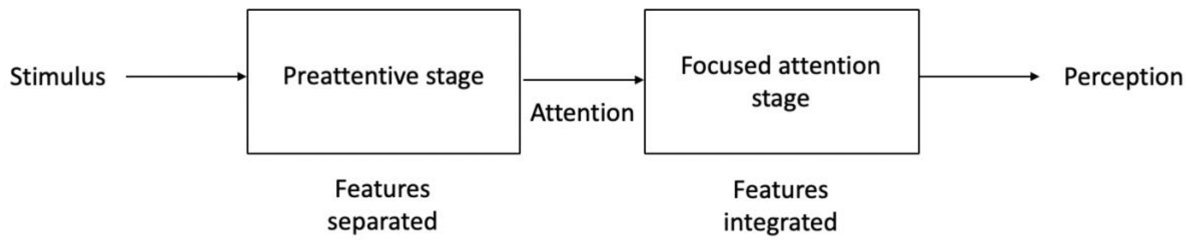

Figure 2.1. Stimulus perception as posited by feature integration theory. A stimulus is observed in the environment and individual features can be detected in the pre-attentive stage. However, to bind multiple features of a stimulus, the focused attention stage is required. Attention is the "glue" that acts to bind those multiple features into a coherent whole.

Interpreted in the context of visuospatial memory, the binding of object identity and location information into a solitary unit in memory may be more cognitively demanding than memory for single feature memory (i.e., identity *or* location) due to the serial and effortful allocation of attention that is required. This may lead to disproportionate visuospatial binding deficits in older adults who tend to have impairments in attentional and processing resources (Castel & Craik, 2003; Craik & Byrd, 1982).

Empirical work has attempted to extend this theory to the domain of visuospatial memory with mixed results. Generally, in these tasks, attentional resources are taxed at encoding by the presence of a secondary task unrelated to the visuospatial binding task (e.g., backwards counting). While some studies have demonstrated that the introduction of a secondary task to divide attention during encoding leads to less accurate visuospatial binding (e.g., Brown & Brockmole, 2010; Feng, Pratt, & Spence, 2012; Fougnie & Marois, 2009; Wheeler & Treisman, 2002; Zokaie, Heider, & Husain, 2014), other work has not found a disproportionate effect of increased attentional load on binding as compared to memory for single visual features (e.g., Allen, Baddeley, & Hitch, 2006; Allen, Hitch, Mate, & Baddeley, 2012; Baddeley, Allen, & Hitch, 2011; Johnson, Hollingworth, & Luck, 2008; Ueno, Allen, Baddeley, Hitch, & Saito, 2011). It is important to note that the role of attentional impairments in associative binding deficits has been called into question (Naveh-Benjamin & Smyth, 2016; Smyth & Naveh-Benjamin, 2016). However, the aforementioned studies utilized verbal, not visual materials to assess the role of attention in associative memory. While attention may not be crucial to the binding of verbal information, it is likely that visuospatial binding does require significant attentional resources. As it currently stands, there is not definitive evidence as to whether diminished attentional resources during encoding influences later memory by disrupting feature binding, memory for individual features, or both. What does seem clear, however, is that taxing attentional resources during encoding results in less accurate visuospatial memory indicating that attention is involved in this process, at least in some capacity.

Chapter 2 explores how younger adults bind information in visuospatial memory and how manipulating the amount of attentional load during encoding influences this binding ability. Differing types of secondary tasks are used to divide attention during encoding to determine the effects of cross-modal and intra-modal attentional load on the ability to selectively prioritize information. Further, by varying the amount of available attentional resources, we provide evidence of automatic and strategic influences of information importance. Thus, Chapter 2 serves to investigate the critical role of attention in memorial binding and how attention can be automatically captured and strategically directed in different circumstances.

Experiment 1: The Role of Attention in Remembering Important Item-Location Associations

Many of us have encountered a situation where, after returning home from a long day at work, we are unable to locate where we have placed our wallet or car keys. This ability (or inability) to remember the identity and location of items is a form of visuospatial memory. Successful visuospatial memory is dependent on the accurate binding of the "what" and "where" features of an item. That is, it is not sufficient to remember what your wallet looks like (visual information) or its potential locations (spatial information), but rather the link between the item and location (e.g., my wallet is on top of my nightstand). As in other forms of episodic memory, errors in visuospatial memory (e.g., a misplaced wallet) may become more frequent with advancing age (Brockmole & Logie, 2013; Park et al., 2002), the presence of neurodegenerative disorders like Alzheimer's disease (Iachini, Iavarone, Senese, Ruotolo, & Ruggiero, 2009; Sahakian et al., 1988), and in situations in which we are distracted (Feng et al., 2012; Fougnie & Marois, 2009).

Of particular interest in the current study was how visuospatial memory ability may be affected by divided attention at encoding, especially when task-relevant goals must be pursued. Prior work demonstrates that, in the presence of an abundance of information, participants are able to selectively attend to and later remember what is most important (e.g., Castel, 2008; Castel et al., 2002; Stefanidi, Ellis, & Brewer, 2018). Given limitations on memory capacity, this represents an efficient strategy to remember information that may be the most useful during recall. Importantly, the ability to be selective (that is, to remember what is valuable) may be dependent upon how attention is allocated during encoding (Castel, 2008). That is, during the encoding period, participants must deliberately focus on high-value (and away from low-value) information to increase the likelihood of later remembering the valuable information. This is supported by research demonstrating that participants with attentional impairments like attention-deficit/hyperactivity disorder and Alzheimer's disease exhibit suboptimal selectivity relative to healthy controls (Castel, Balota, & McCabe, 2009; Castel, Lee, Humphreys, & Moore, 2011). As such, the availability of attentional resources during encoding likely influences subsequent memory selectivity during retrieval.

The ability to selectively allocate attention during encoding may also depend on the format in which information is encountered. Various studies have found that participants are less effective in executing goal-relevant study strategies for sequentially presented, as compared to simultaneously presented information (Ariel et al., 2009; Dunlosky & Thiede, 2004; Middlebrooks & Castel, 2018; Robison & Unsworth, 2017). For sequentially presented information, participants must maintain information in working memory while making item-by-item decisions in line with the task goal. For simultaneously presented information, no such maintenance of information in working memory is necessary as all information is available for the duration of the encoding period. Participants may be more effective in strategically allocating attention during encoding for simultaneously presented information, as they may have more cognitive resources available. Prior work utilizing the same paradigm as the current study has found that both younger and older adults were able to selectively attend to and remember high-value visuospatial associations, regardless of presentation format (Siegel & Castel, 2018b). Both younger and older adults became more selective with continued task experience when information was sequentially presented, while they were consistently selective throughout the task for simultaneously presented information. These results further supported the notion that the execution of value-based study strategies may be inherently more difficult for sequentially, relative to simultaneously, presented information, especially when items and locations must be associated in memory.

As it currently stands, the literature suggests that participants are able to engage in selective study-strategies to optimize their performance related to task goals in both a verbal (Castel, 2008; Castel et al., 2002; Stefanidi et al., 2018) and visuospatial (Siegel & Castel, 2018b) memory context. These value-based study strategies appear to be more effectively implemented when information is encountered in a simultaneous presentation format which may be due to decreased attentional load and strain on working memory resources during encoding relative to a sequential presentation of information (Ariel et al., 2009; Dunlosky & Thiede, 2004; Middlebrooks & Castel, 2018; Robison & Unsworth, 2017; Siegel & Castel, 2018b). While some work has shown that an increase in attentional load during encoding may disrupt the binding of visual and spatial information (Brown & Brockmole, 2010; Elsley & Parmentier, 2009), it may not affect participants' ability to execute value-based study strategies (Middlebrooks et al., 2017), although these factors have not been studied in conjunction. Further, while the division of attentional resources during encoding may not hinder the implementation of value-based study strategies for single pieces of verbal information (Middlebrooks et al., 2017), it may have differential effects when the cognitive load is already high, as in the case of visuospatial binding. Deficits in strategy execution in a visuospatial binding context are most likely to be present when information is sequentially presented, as this represents an additional stressor on cognitive resources. Thus, the current study sought to examine how these factors (presentation format and secondary tasks during encoding) may interact to affect value-directed remembering in a cognitively demanding visuospatial binding paradigm.

The Current Study

The purpose of the current study was to examine how visuospatial memory and selectivity may vary under conditions that differentially strain attentional resources. In a 2 (presentation format: simultaneous, sequential) x 2 (attention: full, divided) between-subjects design, we examined memory and selectivity using a visuospatial value-directed remembering paradigm (Castel, 2008; Castel et al., 2002; Siegel & Castel, 2018b) while manipulating encoding conditions through differing presentation formats and the presence or absence of a secondary tone discrimination task. The current study addresses an important theoretical issue as to whether these factors interact to produce a compounded effect on attentional resources, or whether they would independently influence participants' visuospatial memory and selectivity.

Participants may be more selective under conditions that tax attentional resources less (i.e., simultaneous presentation, full attention) than those that may have a greater strain on attentional resources (i.e., sequential presentation, divided attention), consistent with prior findings (Ariel et al., 2009; Dunlosky, Ariel, & Thiede, 2011; Dunlosky & Thiede, 2004; Middlebrooks & Castel, 2018; Robison & Unsworth, 2017; Siegel & Castel, 2018b). It may also be the case that the combination of these factors produces compounded effects. That is, participants in the condition with the greatest hypothesized strain on attentional resources (i.e., sequential-divided attention) may exhibit the poorest memory performance and selectivity, while the condition with the least hypothesized strain (i.e., simultaneous-full attention) may exhibit the best memory performance and selectivity. Some work has found that participants are able to maintain selectivity in a variety of divided attention conditions (Middlebrooks et al., 2017). In this case, we would expect consistent selectivity regardless of the level of strain on attentional resources during encoding. However, in contrast to the present study, Middlebrooks and colleagues (2017) used verbal materials (i.e., word lists) and did not require any association of information in memory. In the context of the current task where stimuli are item-location associations, attentional resources may be stressed to a greater degree, which may lead to lower subsequent selectivity, especially in the sequential presentation format. In fact, prior work in the visual working memory domain examining how numerical reward values may influence participants' visual working memory has found that participants were able to prioritize high- over low-priority visual objects (Hu, Hitch, Baddeley, Zhang, & Allen, 2014). However, the addition of increasingly demanding concurrent secondary tasks reduced or eliminated this ability to prioritize the encoding of high-priority information, highlighting the important role of the executive control of attention during the encoding of visual information of differing importance (Hu, Allen, Baddeley, & Hitch, 2016). As such, there may exist differences in how participants encode visuospatial and verbal information of differing value due to differential strain on attentional resources, which may be especially pronounced in the presence of a cognitively demanding secondary task.

A unique benefit of the current design is that it allows for the investigation of a spatial resolution measure by examining the pattern of errors produced by participants. By analyzing participants' spatial relocation errors (i.e., how far participants misplaced an item from its target location), we were able to examine gist-based visuospatial memory in the absence of an exact memory trace. The binding of items with a wider range of locations (i.e., not exclusively the target location) represented a coarser measure of visuospatial memory in the current task. Using this measure, we investigated whether gist-based visuospatial memory accuracy differed as a function of information importance between these different encoding conditions. Prior work has found that younger adults' gist-based visuospatial memory was influenced by information importance only when adequate attentional resources were available during encoding (i.e., for simultaneously presented information), but not under more taxing encoding conditions (i.e., sequentially presented information; Siegel & Castel, 2018b). In the context of the current study, we expected that gist-based visuospatial memory may be moderated by the value of information under less demanding encoding conditions, whereas this may not have been the case when attentional resources were more strained during the study period.

Finally, it is important to note that we examined memory selectivity across of series of eight trials (referred to as "grid numbers" in the current study). The inclusion of multiple trials was motivated by prior research that has consistently demonstrated that participants may not optimally execute a value-based study strategy on the first trial, but increase their selectivity towards high-value information with continued task experience (Castel, 2008; Middlebrooks et al., 2017; Siegel & Castel, 2018b). So, if only one trial is completed, it may appear as if participants are not selective in their memory performance, remembering a similar proportion of low- and high-value information. However, with repeated trials and feedback on their performance, participants are able to assess their own performance and modify their strategy use in order to improve their performance on the task. As such, the utilization of multiple trials is critical when examining how participants may optimize their strategies on goal-directed tasks (Ariel, 2013; Castel, 2008; Nelson & Narens, 1990; Wong et al., 2019).

Method

Participants

The participants in this study were 96 University of California, Los Angeles undergraduate students ranging in age from 18 to 25 years (73 females, M_{age} = 20.13 years, SD_{age}

= 1.43). Participants had completed an average of 14.10 years of education (*SD* = 1.02) when they completed the study and received partial course credit for participation.

Materials

The materials in this study consisted of eight unique 5 x 5 grids containing ten items each presented on a computer screen (see Figure 2.2 for an example grid). The grids were approximately 15 x 15 cm on the screen (17.06° visual angle) and contained 25 cells, each of which was approximately 3 x 3 cm in size (3.44° visual angle). Within each of ten randomly chosen cells was an item selected from a normed picture database (Snodgrass & Vanderwart, 1980). The items used were 80 black and white line drawings of everyday household items (e.g., a key, a camera, and an iron). On the computer screen, items were approximately 2 x 2 cm in size (2.29° visual angle).

To form a grid, ten items were randomly selected from the pool and randomly placed in the cells of the grid with the constraint that no more than two items be present in any row or column of the grid (to reduce the likelihood of the item arbitrarily forming spatial patterns that may aid memory). Items were then randomly paired with point values ranging from 1 point (lowest value) to 10 points (highest value) indicated by the numerical value placed in the top left portion of each item-containing cell. Each value was used once per grid. This process was repeated to form eight unique grids for each participant. While one participant may have been presented with an iron paired with the 7-point value in the top left cell of the second grid, a different participant could encounter that same item paired with the 4-point value in the bottom right cell of the sixth grid. As such, each participant was presented with a different set of eight completely randomized grids.

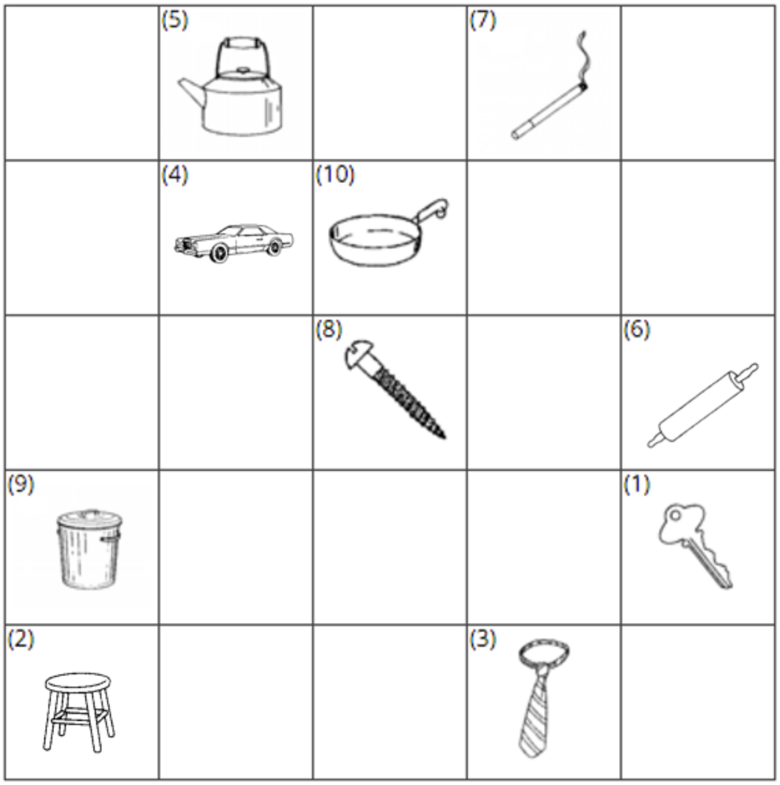

Figure 2.2. An example grid that participants may have been presented with during the study phase. Items were everyday household objects taken from a normed picture database. Information importance was indicated by the numerical value in the top left corner of each item-containing cell. In the simultaneous conditions, information was presented as shown in the figure. In the sequential conditions, items were presented one at a time.

Procedure

Participants were randomly assigned to one of four between-subjects encoding conditions: simultaneous presentation format/full attention (Sim-FA), simultaneous presentation format/divided attention (Sim-DA), sequential presentation format/full attention (Seq-FA), or sequential/divided attention (Seq-DA).

All participants were instructed that they would be presented with ten items placed within a 5 x 5 grid and would be later tested on that information. Participants were further instructed that each item would be paired with a point value from 1 to 10 indicated by a number in the top left portion of each item-containing cell. The participants' goal was to maximize their point score (a summation of the points associated with correctly remembered information) on each grid. Participants in the simultaneous conditions were shown all ten items concurrently for a total of 30s. Participants in the sequential conditions were shown items one at a time, each for 3s (totaling 30s for the ten items) and were presented randomly with regards to their location in the grid and their associated point value. Participants were told that after they studied the information within the grid, they would immediately be shown the items underneath a blank grid and be asked to place each item in its previously presented location by first clicking on the item and then the cell in which they wanted to place it. If participants were unsure of an item's location, they were asked to guess, as they would not be penalized for incorrectly placed items. Participants were given an unlimited duration to complete this testing phase and were required to place all ten items before advancing to the next grid. After participants placed all ten items, they were given feedback on their performance in terms of the items that they correctly placed, the number of points they received (out of 55 possible), and the percentage of points they received. After receiving feedback, participants repeated this procedure with unique grids for seven further study-test cycles (for a total of eight grids).

Participants in the divided attention conditions also completed a tone discrimination task during the study period. Participants were instructed that during the study phase they would hear a series of tones. Tones were presented auditorily through headphones and were one of two pitches: low pitch (400 Hz) and high pitch (900 Hz). Each tone was played for a duration of 1s and the order of presentation was random for each participant with the constraint that no pitch was played more than three times consecutively. Participants completed a 1-back tone discrimination task such that they were required to determine whether the most current tone they heard was the “same” or “different” than the tone immediately preceding it. The corresponding keys were labeled as such on the keyboard. Before each study-test cycle, a blank grid appeared on the screen and the first tone was played. Participants were instructed that they were not required to respond to this first tone. After 3s, the first item (in the Seq-DA) or all ten items (in the Sim-DA) appeared along with the second tone. Participants then had to make their first decision (“same” or “different” than the first tone). After that, the remaining tones were played in 3s intervals, totaling 11 tones by the end of the study period (one preceding the presentation of items and ten during item presentation). In the Seq-DA condition, tones were played for the first second of each item’s 3s presentation duration. For both conditions, participants were required to make their tone discrimination response within a 3s window before the following tone was played. Participants were able to change their response within that 3s interval and their final response was used in later analyses.

After finishing the experimental task, participants also completed a modified operation span (OSpan) task (Oswald, McAbee, Redick, & Hambrick, 2015) as a measure of working memory capacity. This measure was included examine whether participants’ visuospatial memory performance and/or selectivity may vary with working memory capacity. However, we found no significant differences in terms of the amount of information recalled or participants’ selectivity as a function of OSpan, consistent with prior studies examining memory selectivity (Castel et al., 2009; Cohen, Rissman, Suthana, Castel, & Knowlton, 2014, 2016; Middlebrooks et al., 2017) and discussion of these results is not included in the current study.

Results

Given the nature of the data, we first analyzed tone discrimination, overall item-location recall accuracy, and spatial relocation errors using analyses of variance (ANOVA). Then, in order to examine the effects of item value and task experience on these measures, we used hierarchical linear modeling (HLM). Explained in more detail at the beginning of the Memory Selectivity section, HLM is a powerful technique that allowed us to examine the relationship between our variables (i.e., the relationship between item value and recall probability for any given item, and how each encoding condition and task experience may have changed this probability). This technique has been used in prior work as a useful analytical approach (Middlebrooks et al., 2017; Siegel & Castel, 2018b). However, it does not provide any comparison directly examining mean condition differences (e.g., differences in the overall averages between encoding conditions). In contrast, a mean-based analytic technique (e.g., ANOVA) is unable to detect any direct relationships between item value and recall probability but is able to determine whether there were differences between encoding conditions on average. As such, the utilization of these analyses in conjunction allowed us to appropriately examine differences in overall recall (using analyses of variance) and differences in selectivity between conditions (using HLM).

Tone Discrimination

Tone discrimination performance for the two divided attention conditions is depicted in Figure 2.3. Tone discrimination performance was analyzed to ensure that participants' attention was adequately divided during encoding. Firstly, we examined each participants' tone discrimination performance individually to ensure that participants were not simply ignoring the auditory task in order to focus on the visuospatial memory task. We initially set an inclusion criterion such that, to be included in the analyses, participants had to (a) have responded on at least 50% of tones and (b) have tone discrimination accuracy greater than 50% averaged across all eight grids. This criterion excluded two participants (one from the Sim-DA condition and one from the Seq-DA condition) resulting in 94 participants across the four conditions. However, the exclusion of these two participants did not result in any change in the pattern of results described in the results section below when including all 96 participants. Therefore, we decided to include all 96 participants that we collected in the following analyses.

To determine whether tone discrimination accuracy during encoding varied as a function of presentation format or across grids, we conducted a 2 (Presentation format: simultaneous, sequential) x 8 (Grid: 1, 2, ..., 8) repeated-measures analysis of variance (ANOVA) which revealed a significant main effect of grid, $F(7, 322) = 12.72$, $p < .001$, $\eta_2 = .21$. Follow-up comparisons using Tukey HSD tests indicated that tone discrimination accuracy was significantly lower on Grid 1 ($M = .47$, $SD = .30$), than on Grids 2-8 ($M_{G2\text{-}8} = .69$, $SD_{G2\text{-}8} = .22$), adjusted *p*s < .001. There were no other significant comparisons between grids. There was also no main effect of presentation format, $F(1, 46) = 0.10$, $p = .75$, $\eta_2 = .002$, and no interaction, $F(7, 322) = 1.24$, $p = .28$, $\eta_2 = .02$. Finally, to determine whether performance differed from chance (i.e., 50%) throughout the task, we conducted one-sample t-tests on tone discrimination performance for Grid 1 and Grids 2-8 collapsing across presentation format conditions. The analyses revealed that while tone discrimination performance on Grid 1 was not significantly different than chance performance, $t(47) = 0.72$, $p = .48$, it was significantly greater than chance on Grids 2-8, $t(47) = 7.47$, $p < .001$. These results suggest that there was no difference in tone accuracy between presentation conditions and that participants' performance was consistently above chance after the first grid.

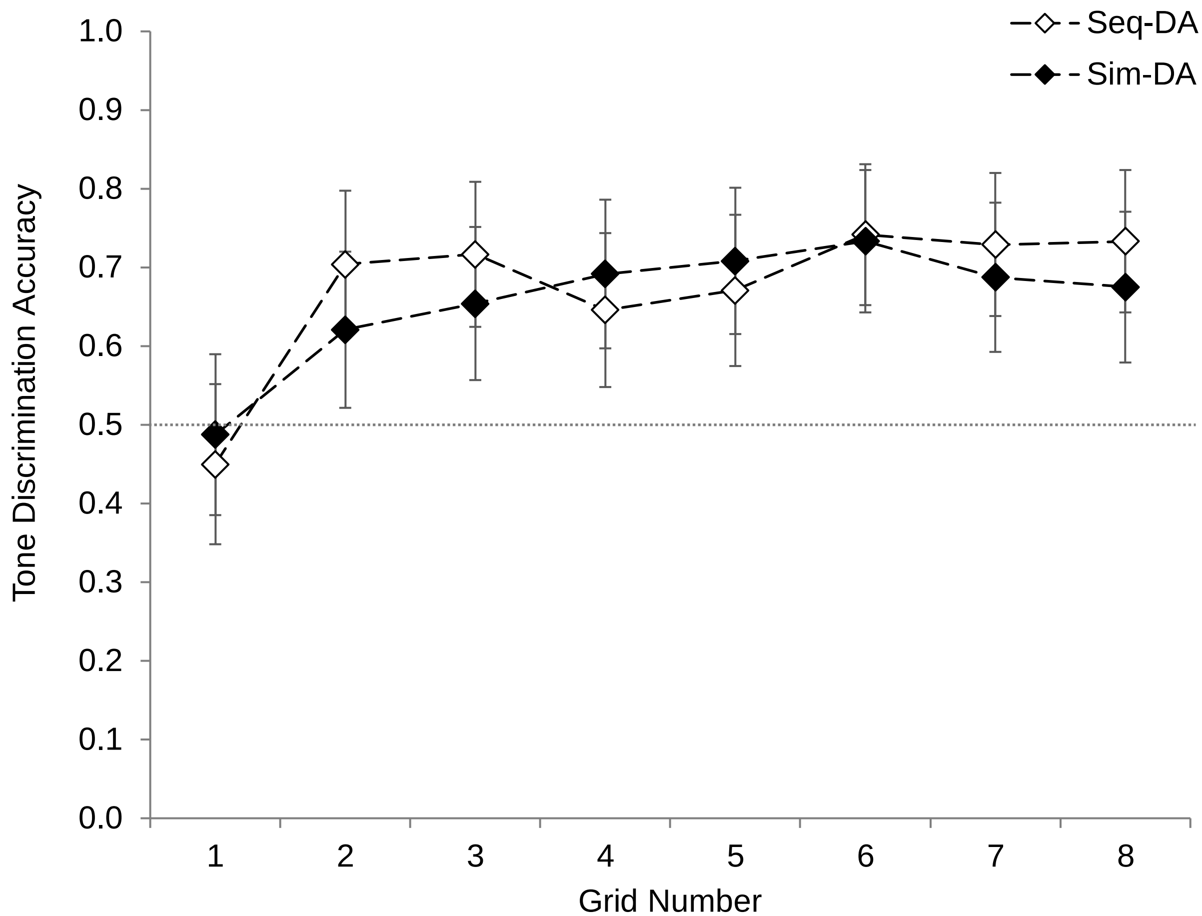

Figure 2.3. Tone discrimination performance in the divided attention conditions across grids. *Note*: Dotted line indicates chance performance of 50%. Error bars represent ±1 standard error. Sim: simultaneous presentation format, Seq: sequential presentation format.

Overall Item-Location Recall

We first examined item-location recall accuracy without regard to item value across the task using a 2 (Presentation format: simultaneous, sequential) x 2 (Attention: full, divided) x 8 (Grid: 1, 2, ..., 8) repeated-measures ANOVA on item-location recall accuracy. There was a main effect of presentation format, $F(1, 92) = 17.60$, $p < .001$, $\eta_2 = .11$, such that participants had higher item-location recall accuracy in the simultaneous ($M = .56$, $SD = 2.77$) relative to the sequential presentation format (*M* = .44, *SD* = .24). There was also a significant main effect of attention, $F(1, 92) = 54.06$, $p < .001$, $\eta^2 = .33$, such that participants had higher item-location recall accuracy in the full (*M* = .61, *SD* = .25) relative to the divided attention condition (*M* = .39, *SD* = .23). In addition, the ANOVA revealed a main effect of grid, $F(7, 644) = 4.22$, $p < .001$, $\eta^2 = .04$. Follow-up comparisons using Tukey HSD tests indicated that participants had higher item-location recall accuracy on Grid 8 (*M* = .57, *SD* = .26) relative to Grid 1 (*M* = .46, *SD* = .32), $t(94) = 4.38$, $p < .001$, and Grid 2 (*M* = .45, *SD* = .26), $t(94) = 4.53$, $p < .001$. No other follow-up comparisons were significant.

Finally, we found a significant interaction between attention and grid, $F(7, 644) = 11.96$, $p < .001$, $\eta^2 = .11$. To decompose this interaction, we conducted one-way ANOVAs analyzing item-location recall across grids for each attention condition. For the full attention conditions, we found a main effect of grid, $F(7, 329) = 2.80$, $p < .01$. Follow-up comparisons using Tukey HSD tests indicated that participants in the full attention conditions had significantly higher item-location accuracy on Grid 1 (*M* = .70, *SD* = .21) relative to Grid 5 (*M* = .59, *SD* = .25), $t(94) = 3.17$, $p = .04$, Grid 6 (*M* = .56, *SD* = .27), $t(94) = 3.80$, $p = .004$, and Grid 7 (*M* = .57, *SD* = .24), $t(94) = 3.40$, $p = .02$. No other follow-up comparisons were significant. For the divided attention conditions, we also found a main effect of grid, $F(7, 329) = 12.62$, $p < .001$. Follow-up comparisons using Tukey HSD tests indicated that item-location recall accuracy was lower on Grid 1 (*M* = .21, *SD* = .20) than Grids 3-8 ($M_{G3\text{-}8} = .44$, $SD_{G3\text{-}8} = .23$), *p*s < .001, and lower on Grid 2 (*M* = .30, *SD* = .17) than Grids 5-8 ($M_{G5\text{-}8} = .47$, $SD_{G5\text{-}8} = .23$), *p*s < .01. No other follow-up comparisons were significant. There were no other significant interactions.

Memory Selectivity

Item-location recall accuracy as a function of item-value, encoding condition, and grid number is depicted in Figure 2.4. In order to compare selectivity between groups and across grids, we used hierarchical linear modeling (HLM) to analyze item-location recall accuracy as a function of item value. HLM has been used in previous studies investigating memory selectivity (Castel, Murayama, Friedman, McGillivray, & Link, 2013; Middlebrooks & Castel, 2018; Middlebrooks et al., 2016, 2017; Raudenbush & Bryk, 2002). The post-hoc binning of items into low, medium, and high value groups may not accurately reflect participants' valuations of to-be-learned stimuli (e.g., Participant 1 may consider items with values 6-10 to be of "high" value, while Participant 2 may only consider items with values 8-10 as such). In contrast, HLM treats item value as a continuous variable, allowing for a more precise investigation of the relationship between item-location recall accuracy and item value. Further, by first clustering data within each participant and then examining possible condition differences, HLM accounts for both within- and between-subject differences in strategy use, the latter of which would not be evident when conducting standard analyses of variance. Thus, HLM allows for a more fine-grained analysis of participants' value-based strategies.

In a two-level HLM, item-location recall accuracy (using a Bernoulli distribution, 0 = not recalled, 1 = recalled; level 1 = items; level 2 = participants) was modeled as a function of item value, grid number, and the interaction between those two variables. Item value and grid number were entered into the model as group-mean centered variables (with item value anchored at the mean value of 5.5 and grid number anchored at the mean value of 4.5). The encoding conditions (0 = Sim-FA, 1 = Sim-DA, 2 = Seq-FA, 3 = Seq-DA) were included as level-2 predictors. In this

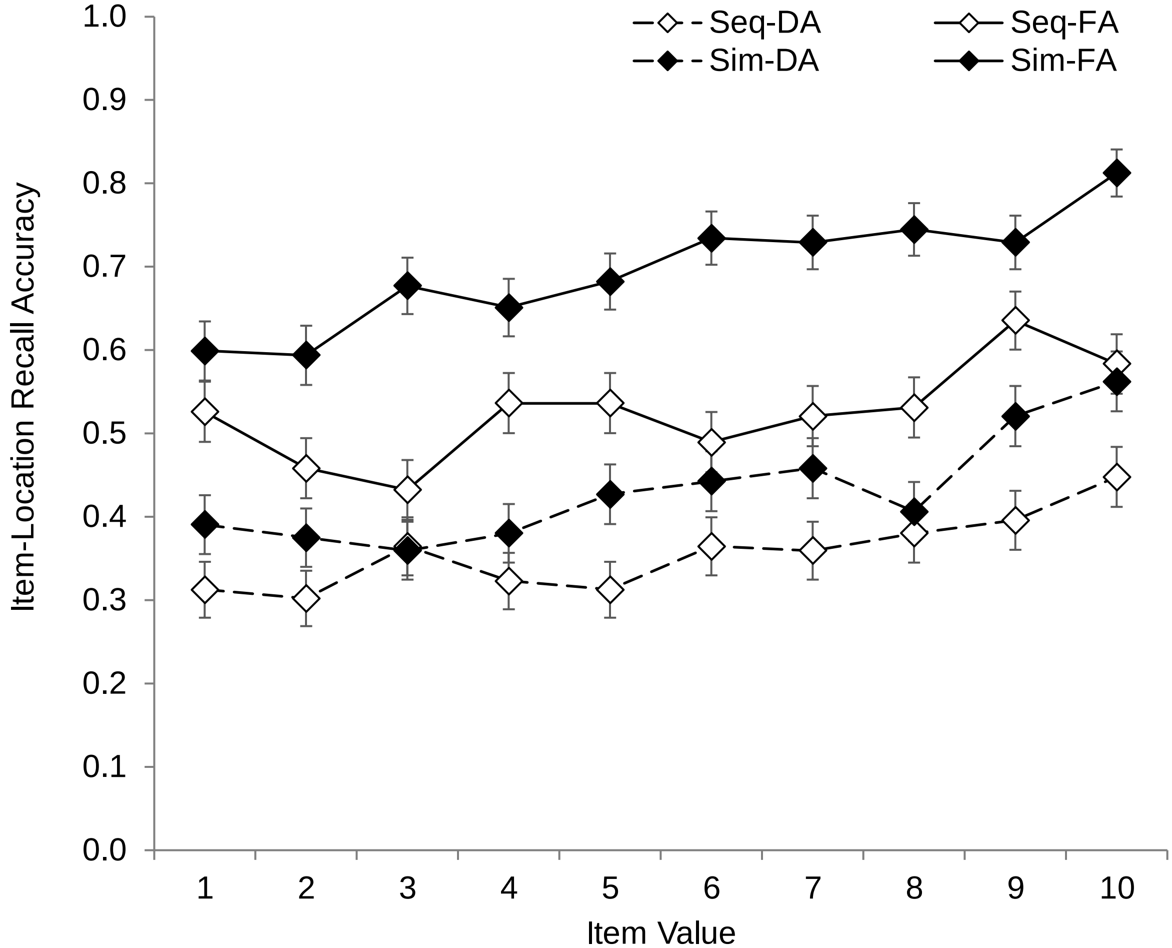

Figure 2.4. Item-location recall accuracy as a function of presentation format, attention, and item value averaged across grids. Error bars represent ±1 standard error. *Sim*: simultaneous presentation format, *Seq*: sequential presentation format, *FA*: full attention, *DA*: divided attention.

analysis, participants in the Sim-FA condition were treated as the comparison group, while Comparison 1 compared Sim-FA and Sim-DA, Comparison 2 compared Sim-FA and Seq-FA, and Comparison 3 compared Sim-FA and Seq-DA.

Table 2.1 presents the tested model and estimated regression coefficients in the current study. Regression coefficients (β) obtained from HLM can be interpreted via their exponential (Raudenbush & Bryk, 2002) – that is, the Exp(β) represents the effect of the independent variable on the odds ratio of correct item placement (the probability of successful item-location recall accuracy divided by the unsuccessful recall probability). An Exp(β) value greater than one indicates a positive effect of a predictor, while an Exp(β) value less than one indicates a negative effect of a predictor.

Firstly, there was a significant effect of value on item-location recall accuracy for participants in the Sim-FA condition, $\beta_{10} = 0.10$, $p = .001$. This effect was consistent across the other encoding conditions (*p*s > .19). This indicates that for each increase in item value, participants were $e_{0.10} = 1.11$ times more likely to correctly place that item. Further, participants were $e_{0.10*10} = 2.84$ times more likely to successfully place a 10-point, as compared to a 1-point item. Thus, as item value increased, participants in all conditions were more likely to have accurate item-location recall accuracy.

Secondly there was no significant effect of grid number for participants in the Sim-FA condition, $\beta_{20} = -0.04$, $p = .34$. While this lack of grid number effect was consistent for Comparison 2 comparing Sim-FA and Seq-FA condition ($p = .83$), there was a significant difference for Comparison 1 comparing Sim-FA and Sim-DA and Comparison 3 comparing Sim-FA and Seq-DA (*p*s < .001). To calculate the simple slopes for the Sim-DA and Seq-DA conditions, the β_{20} and β_{21}/β_{23} coefficients were added ($\beta_{\text{Sim-DA}} = 0.19$, $\beta_{\text{Seq-DA}} = 0.15$). To determine the significance of these slopes, the model was adjusted to treat Sim-DA as the comparison group and then adjusted again to include Seq-DA as the comparison group. This method was used throughout the rest of this study to calculate the significance of simple slopes.

For the Sim-DA condition, grid number was a significant predictor of item-location recall accuracy, $\beta_{Sim\text{-}DA} = 0.19$, $p < .001$, such that for each increase in grid number, participants were $e^{0.19} = 1.21$ times more likely to successfully place an item and were $e^{0.19*8} = 4.57$ times more likely to successfully place an item on Grid 8, as compared to Grid 1. Similarly, participants in the Seq-DA condition, grid number was also a significant predictor of item-location recall accuracy, $\beta_{Seq\text{-}DA} = 0.15$, $p < .001$, such that for each increase in grid number participants were $e^{0.15} = 1.16$ times more likely to successfully place an item and were $e^{0.15*10} = 3.32$ times more likely to successfully place an item on Grid 8, as compared to Grid 1. Taken together, these results indicate that participants in the divided attention conditions had higher item-location recall accuracy with continued task experience, while those in the full attention conditions maintained a consistent level of accuracy throughout the task.

Finally, for the Sim-FA condition, there was not a significant value x grid number interaction, $\beta_{30,} = -0.003$, $p = .72$. This was not significantly different for either the Sim-DA or Seq-FA conditions (*p*s > .82). However, there was a marginally significant difference between Sim-FA and Seq-DA as indicated by Comparison 3, $\beta_{33} = 0.02$, $p = .08$. Analyzing the simple slope of the Seq-DA condition revealed that there was in fact a significant value x grid number interaction for that group, $\beta_{Seq\text{-}DA} = 0.02$, $p = .04$. This indicates that while participants in the other three conditions were consistently selective throughout the task, participants in the Seq-DA condition became more selective with continued task experience.

Bayesian Analysis

We conducted a Bayesian analysis to address potential issues of statistical power related to the lack of value-based differences in precise item-location recall found between encoding conditions. Bayesian null hypothesis testing has been used to determine the likelihood of null effects in previous value-directed remembering research (e.g., Middlebrooks et al., 2017; Siegel & Castel, 2018b). We computed a Bayes factor (BF_{10}) to determine the likelihood of the null effect of value on memory performance between encoding conditions. Computing Bayes factors allows one to compare the probability of obtaining the results under the null hypothesis (i.e., no difference between encoding conditions) with the probability of obtaining the results under the alternative hypothesis (i.e., true differences in the effect of value on memory performance between encoding conditions; Jarosz & Wiley, 2014).

Comparing Bayes factors within the HLM framework can be difficult (Lorch & Myers, 1990; Murayama, Sakaki, Yan, & Smith, 2014). So, we conducted a simpler two-step procedure that has been used in previous value-directed remembering studies (Middlebrooks et al., 2017; Siegel & Castel, 2018b). First, using logistic regression, item-location recall accuracy was regressed on item value within each grid for each participant. Then, a 4 (Encoding condition: Sim-DA, Sim-FA, Seq-DA, Seq-FA) x 8 (Grids: 1, 2, ..., 8) repeated-measures Bayesian ANOVA was conducted on the obtained slopes using default priors. The computed Bayes factor ($BF_{10} = .059$) for encoding condition indicated that the null hypothesis was $1/.059 = 16.95$ times as likely to be true than the alternative hypothesis. This represents "strong" evidence (as determined by norms set by Kass and Raftery, 1995) that the lack of difference between encoding conditions likely reflects a similar effect of value on memory performance for these groups, rather than a lack of statistical power to detect an existing difference.

Spatial Resolution

A unique benefit of the current design is that, in addition to correctly recalled information, we were able to analyze the pattern of errors produced by participants in each condition and determine whether these errors varied systematically as a function of item value or grid number. The usage of items placed within grids enabled us to examine participants' spatial resolution (i.e., not only if a participant misplaced an item, but the magnitude of that error) by calculating the distance between a participant's erroneous placement of an item and the item's previously presented (target) location. The inclusion of this spatial resolution measure allowed us to draw conclusions about participants' visuospatial gist memory, which may be by influenced in different manners by varying degrees of attentional resources and presentation formats. Further, gist-based visuospatial memory may be influenced by information importance in that participants may have smaller errors for higher value information, which would represent another form of memory selectivity that is not apparent when solely examining correct and incorrect item placement.

Spatial resolution was analyzed using spatial relocation error (SRE) scores. A visual depiction of SREs is shown in Figure 2.5. SREs were calculated in the following manner. For each incorrectly placed item, the coordinates of the erroneous placement were compared to the coordinates of that item's previously presented location. In the context of the 5 x 5 grids used in the current study, coordinates were of the form (row, column) and ranged from (1, 1) indicating the cell in the top left corner of the grid to (5, 5) indicating the cell in the bottom right corner. Row and column differences were calculated by subtracting the incorrect row value from the correct row value and the incorrect column value from the correct column value. The absolute value of the row difference and column difference scores were calculated and the SRE was determined by the larger of these two values. Essentially, SREs represent the minimum number of "steps" (either vertical, horizontal, or diagonal) between an incorrectly placed item and the

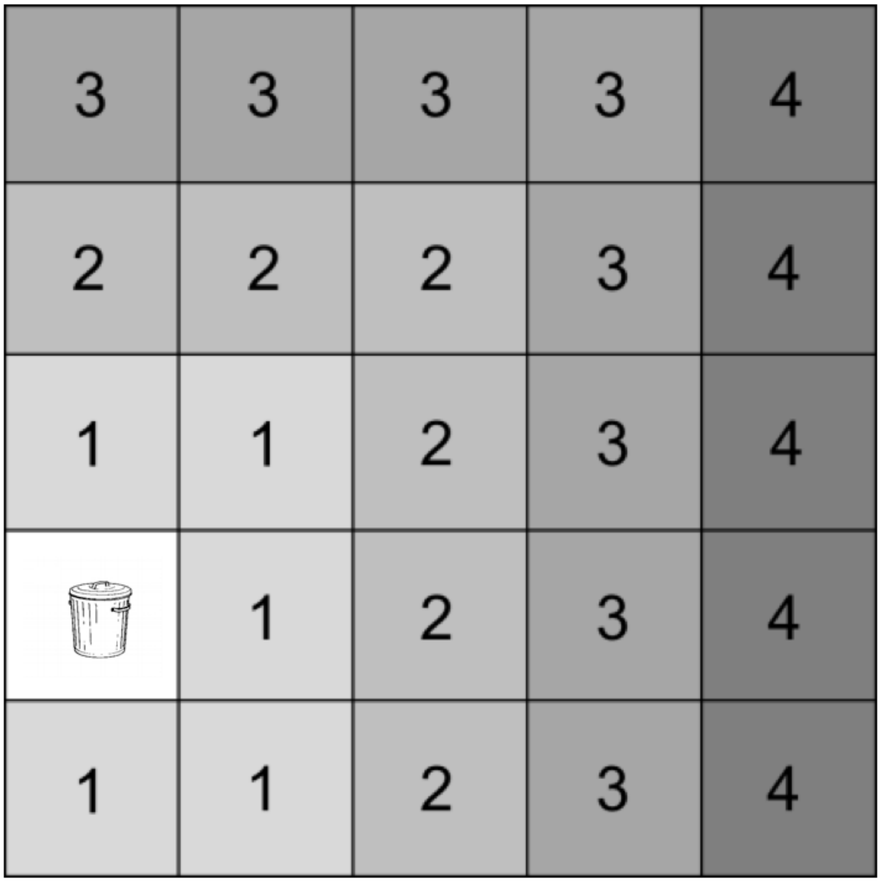

Figure 2.5. An example of relocation error scores relative to an item's correct location. Relocation error represents the number of "steps" from an incorrectly placed item to the previously presented location. Depending on the target location, the relocation error score ranged from 1 (*directly adjacent to the previously presented location*) to 4 (*distance of four steps from correct placement*). Lighter shades indicate a misplaced item closer to the target cell resulting in a small relocation error score. Darker shades indicate a misplaced item farther from the target cell resulting in a large relocation error score.

target location. Dependent upon an item's previously presented location, SREs could range from 1 (directly adjacent to the correct cell) to 4 (four steps away from the correct cell). While certain locations had a maximum SRE of 3 (e.g., a cell in the center of the grid) and others a maximum of 4 (e.g., a cell in the corner of a grid), these differences were likely evenly distributed across item value and grid number due to the random assignment of value to items and random placement of items within grids for each participant. SREs were used as the dependent variable in the following analyses.

First, we compared SREs across grids and between conditions, without regard to item value. In order to avoid excluding participants from analyses who did not receive an SRE score on at least one grid (due to perfect item-location recall accuracy), we averaged participants' data into grid quartiles resulting in four SREs for each participant (Grids 1-2, Grids 3-4, Grids 5-6, and Grids 7-8). After averaging, six participants were still excluded from the following analyses due to perfect item-location recall accuracy on at least one grid quartile (after exclusion, $n_{Sim\text{-}FA}$ = 20, $n_{Sim\text{-}DA}$ = 22, $n_{Seq\text{-}FA}$ = 24, $n_{Seq\text{-}DA}$ = 24). We conducted a 2 (Presentation format: sequential, simultaneous) x 2 (Attention: full, divided) x 4 (Grid quartiles: 1-2, 3-4, 5-6, 7-8) repeated-measures ANOVA on participants' SREs and found a main effect of presentation format, $F(1, 86) = 12.07$, $p = .001$, $\eta^2 = .10$, such that participants in the sequential conditions had significantly higher SREs ($M = 1.91$, $SD = 0.29$), as compared to the simultaneous conditions ($M = 1.70$, $SD = 0.29$). There was also a main effect of attention, $F(1, 86) = 16.50$, $p < .001$, $\eta^2 = .16$, such that participants in the divided attention conditions ($M = 1.93$, $SD = 0.29$) had significantly higher SREs than those in the full attention conditions ($M = 1.68$, $SD = 0.29$).

In addition to main effects, we also observed several interactions. There was a significant interaction between presentation format and attention, $F(1, 86) = 4.94$, $p = .03$, $\eta^2 = .04$. To decompose this interaction, for each attention condition, we conducted independent samples t-tests to compare SREs between presentation formats. For the full attention condition, participants in the sequential presentation format ($M = 1.84$, $SD = 0.35$) had significantly higher SREs than those in the simultaneous presentation format (*M* = 1.51, *SD* = 0.32), $t(42) = 3.28$, $p = .002$. However, for the divided attention condition, there was no difference in SREs between the sequential (*M* = 1.97, *SD* = 0.20) and simultaneous (*M* = 1.89, *SD* = 0.23) presentation formats, $t(44) = 1.30$, $p = .20$. There was also an interaction between presentation format and grid quartiles, $F(3, 84) = 3.11$, $p = .03$, $\eta^2 = .03$. Follow-up one-way ANOVAs comparing SREs across grid quartiles for each presentation format revealed no main effect of grid for either sequentially or simultaneously presented information (*p*s > .12).

To examine spatial resolution as a function of the value of information, we conducted a two-level HLM using SREs as the dependent variable. We applied the same model used on item-location recall accuracy by modeling SREs as a function of item value, grid number and the interaction of these two variables (the output variable, however, was not coded as a Bernoulli distribution, but rather a continuous one from 1 to 4 to reflect the range of SRE scores). The obtained regression coefficients are presented in Table 2.1 and participants' SREs with regard to item value and grid number are shown in Figure 2.6. There was a significant effect of value on SREs for the Sim-FA group, $\beta_{10} = -0.04$, $p < .001$. However, the regression coefficients from the other conditions revealed that there were significant differences between the Sim-FA and Sim-DA conditions, $\beta_{11} = 0.03$, $p = .05$, the Sim-FA and Seq-FA conditions, $\beta_{12} = 0.05$, $p = .01$, and the Sim-FA and Seq-DA conditions, $\beta_{13} = 0.03$, $p = .04$. Further analyses confirmed there was no significant effect of value on SREs for the Sim-DA ($\beta_{Sim\text{-}DA} = -0.01$, $p = .18$), Seq-FA ($\beta_{Seq\text{-}FA} = 0.0003$, $p = .98$) or Seq-DA ($\beta_{Seq\text{-}DA} = -0.01$, $p = .14$) conditions. These results indicate that participants in the Sim-FA condition placed higher value items closer to the correct location, while participants in the other three conditions did not misplace items with regard to item value.

There was no significant effect of grid number on SREs for the Sim-FA condition, $\beta_{20} =$

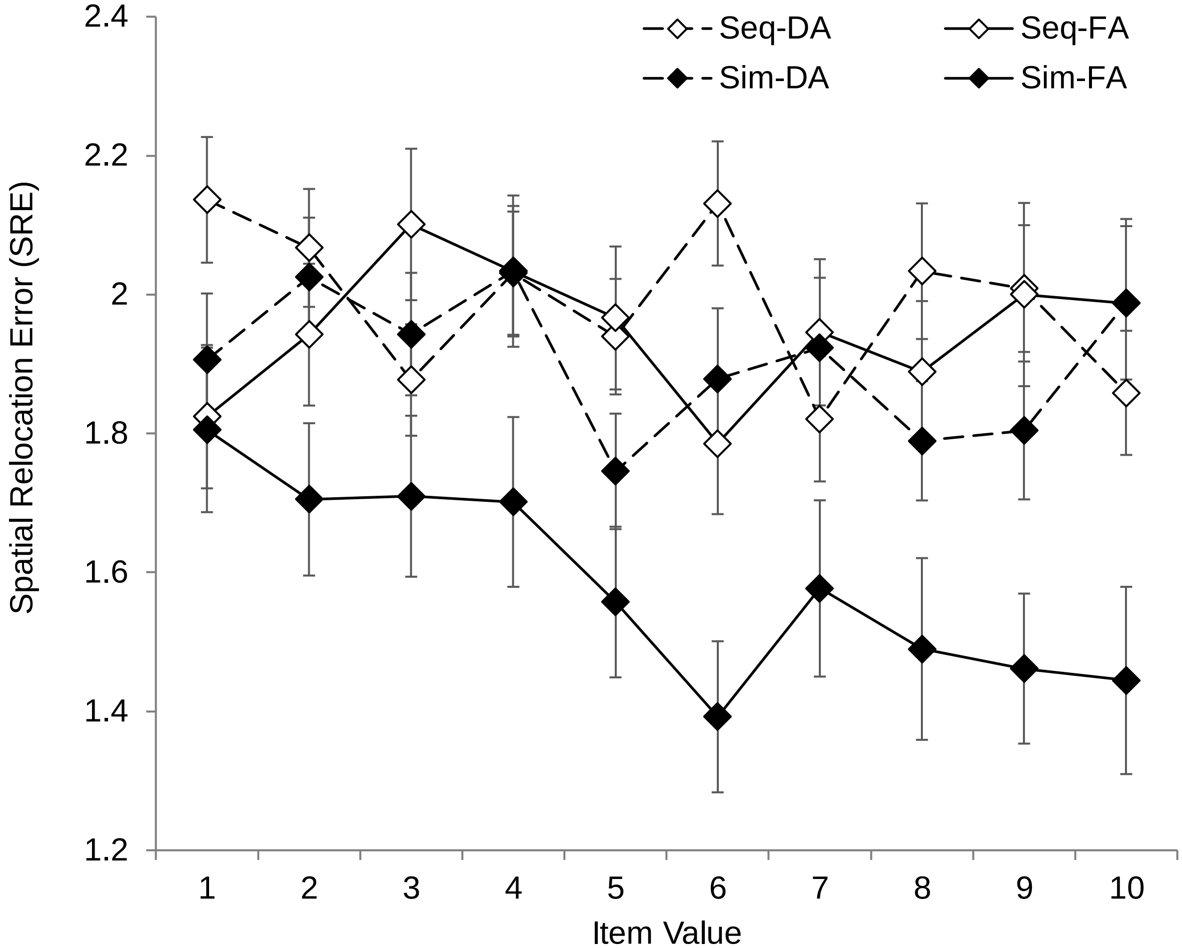

Figure 2.6. Mean relocation error as a function of presentation format, attention, and item value averaged across grids. Error bars represent ±1 standard error. *Sim*: simultaneous presentation format, *Seq*: sequential presentation format, *FA*: full attention, *DA*: divided attention.

0.004, p = .85. This was consistent for both the Seq-FA and Seq-DA conditions (ps > .20). However, there was a marginal difference between Sim-FA and Sim-DA conditions, β_{21} = -0.04, p = .05. A follow-up analysis revealed that there was a significant effect of grid number on SREs for the Sim-DA condition ($\beta_{\text{Sim-DA}}$ = -0.03, p < .001). For the Sim-DA condition, the magnitude of participants' SREs decreased with task experience. For the other three conditions, the SREs produced by participants were of a similar magnitude throughout the task. Finally, there was no interaction between value and grid number on SREs for the Sim-FA condition, $\beta_{30} = -0.004$, $p = .38$. This was also consistent for the three other conditions (ps > .14). Thus, the previously described effects of value on SREs for each encoding condition were consistent throughout the task.

In sum, the results demonstrate that participants in the sequential and divided attention conditions were less accurate in their item-location recall than those in the simultaneous and full attention conditions, respectively. While participants in all four encoding conditions were equally selective in terms of correctly recalled information, only those in the condition with the lowest cognitive load (i.e., Sim-FA) exhibited errors that were sensitive to item value, misplacing high-value items closer to the target location than low-value items. So, while no differences in selectivity were present between encoding conditions in terms of precise item-location memory, analyses of the errors produced by participants did indicate an interaction between the availability of attentional resources during encoding and participants' gist-based visuospatial memory.

Discussion

The current study examined how participants' visuospatial memory and selectivity would be affected by differentially stressing attentional demands through varying presentation formats and the presence or absence of a secondary task during encoding. We found that both sequentially presented information and divided attention led to less accurate visuospatial memory than simultaneously presented information and full attention, respectively. This was reflected in not only the items that were correctly placed by participants, but also the distance by which items were misplaced – that is, when participants in the simultaneous and full attention conditions inaccurately placed an item, it was placed closer to the target location. Further, all participants were equally selective in terms of the information they correctly remembered, despite overall deficits for sequential and divided attention conditions. Differences emerged, however, when examining gist-based visuospatial memory. Only the Sim-FA condition's errors were influenced by the value of information, placing high value information closer to the target location, while the other conditions exhibited a more random pattern of errors.

The results obtained in the current study demonstrate greater visuospatial memory ability for simultaneously, as compared to sequentially, presented information (e.g., Blalock & Clegg, 2010; Lecerf & de Ribaupierre, 2005; Siegel & Castel, 2018b) and full, as compared to divided, attention at encoding (e.g., Brown & Brockmole, 2010; Feng et al., 2012; Fougnie & Marois, 2009). Further, participants in the divided attention conditions recalled more information overall with increased task experience, consistent with prior findings (Middlebrooks et al., 2017), suggesting that, as they received feedback, participants in those conditions refined their strategy in order to recall more information on later grids. We also found further evidence that participants can selectively engage in value-based study strategies related to task goals even under attention-demanding conditions, such as when information is presented sequentially (Middlebrooks & Castel, 2018; Siegel & Castel, 2018b) and the presence of a secondary task during encoding (Middlebrooks et al., 2017). This was particularly notable for participants in the Seq-DA condition, whose attentional resources were thought to be the most depleted due to the necessity of binding sequentially presented items and locations while performing the tone discrimination task. Participants in this condition required adequate task experience to reach maximum selectivity, consistent with prior findings (Castel, McGillivray, & Friedman, 2012; Middlebrooks & Castel, 2018; Siegel & Castel, 2018b).

On the surface, this lack of detrimental effects of divided attention on selectivity (at least in terms of precise item-location recall) may appear to be inconsistent with prior work that has found that the ability to prioritize information in visual working memory is impaired by cognitively demanding secondary tasks (Hu et al., 2014, 2016). However, it is important to note that the prior research did not use the same value structure (i.e., a continuous series of point values) as the current study – rather, participants were instructed to prioritize the first or last item presented in a series of items. Taxing attentional resources may have a more detrimental effect on high-value information in Hu and colleagues' (2014, 2016) paradigm, where the value structure is dichotomous (i.e., a single item is prioritized over other items). If that single high-value item is not remembered, then participants' ability to selectively encode high-priority information is considered impaired. In the current study, where the value structure is continuous, the effects of a secondary task during encoding may be more dispersed over a range of values, rather than one high-value item in particular. As such, these apparent differences in the effects of attentional load on visuospatial memory may be due to the differences in value structure of the task, rather than participants' ability to remember visuospatial information of differing importance.

When examining the current results there appears to be little evidence that presentation format and attention during encoding interact to influence visuospatial memory and selectivity. However, the inclusion of analyses examining the spatial resolution of errors produced by participants suggests there may in fact be a combined effect of these factors. As previously described, only participants in the Sim-FA condition's errors were influenced by information importance, while the other conditions' errors in visuospatial memory did not vary as a function of item value. These results are consistent with prior findings investigating visuospatial memory and selectivity, such that gist-based visuospatial memory was only influenced by the value of information when adequate resources were available during encoding (Siegel & Castel, 2018b).

One potential explanation for the superiority of the Sim-FA condition in this regard is the ability to engage in relational processing. Prior research investigating the representation of information in visuospatial memory suggests that visuospatial information is organized based on a global spatial configuration when encoding in a simultaneous manner (Jiang, Olson, & Chun, 2000). That is, each item is encoded and represented relative to the other items in the array, which has been shown to later enhance visuospatial memory (Lilienthal, Hale, & Myerson, 2014; Taylor, Thomas, Artuso, & Eastman, 2014). In contrast, when information is encoded in a sequential manner in which items are presented in isolation, visuospatial representations may shift to a more local, item-specific organization (Blalock & Clegg, 2010; Jaswal & Logie, 2011). In the context of the current study, participants in the Sim-FA condition may have been able to rely upon relational processing during encoding to enhance visuospatial memory. This may have especially true for information of high value, as participants likely allocated a significant amount of study time toward such items. This may have enhanced these participants' precise item-location (e.g., remembering that the key is in the top left corner) and gist-based (e.g., remembering that the iron is somewhere below key in the left side of the grid) visuospatial memory. On the other hand, the presence of a secondary task during encoding may have attenuated Sim-DA participants' ability to engage in relational processing leading to less accurate visuospatial memory overall and errors that were not sensitive to item value. Similarly, participants in both sequential conditions may not have engaged in relational processing at all, which may have led to lower precise item-location memory and gist-based visuospatial memory that was not affected by item value. So, the ability to engage in global/relational processing during encoding may explain the observed differences in precise and gist-based visuospatial memory. It is important to note, however, that the results are not direct evidence of relational processing during encoding as this represents only one potential explanation for the obtained results. It is entirely possible that the errors produced by participants were individual item-location errors reflecting a lack of spatial precision for particular items not dependent upon any form of relational processing. Future research should consider systematically (rather than randomly, as in the current study) varying the location of items in order to determine whether the pattern of errors produced by participants was due to relational processing or more random item-location errors.

Finally, these results also help to clarify the role of attention in visuospatial binding. Currently, a debate in the literature exists as to whether attention is particularly crucial when binding multiple visual features of an object (e.g., Brown & Brockmole, 2010; Feng et al., 2012; Wheeler & Treisman, 2002) or whether increasing attentional load equally affects individual component memory for single features and memory for feature bindings (e.g., Allen et al., 2006, 2014; Baddeley et al., 2011; Ueno et al., 2011). Given the design of the current study, we cannot make any direct comparison between item (individual identity or location feature memory) and associative memory. As we were specifically interested in the binding mechanism underlying visuospatial memory and the effect of information importance and cognitive load on this mechanism, the current design only tested memory for item-location associations. As such, we cannot determine whether value directly (i.e., an exclusive memory "boost" to high-value item-location pairs) or indirectly (i.e., a "boost" to individual visual or spatial component memory leading to better overall memory for high-value item-location pairs) affects visuospatial binding. However, as performance in the current study was dependent upon associative memory for item-location pairs, the observed effects of value demonstrate that information importance is influencing visuospatial binding in some manner.

With this limitation in mind, the results suggest that attentional control is a crucial aspect of the feature binding process in visuospatial memory, at least when the maintenance and execution of goal-related strategies is required. It is likely that successful performance on this task required two different forms of attention. First, a bottom-up form of visual attention was necessary in order to bind the visual and spatial features of items within the grid array (i.e., associating a particular item to a particular location). Secondly, a top-down form of strategic attention was required for participants to maintain and execute task-related goals (i.e., maximizing their point score by attending to high-value information). This bottom-up attention was disrupted when attention was divided (resulting in lower overall visuospatial memory accuracy), adding further support that bottom-up attention is crucial in the binding of multiple visual features of an object, consistent with predictions made by the FIT (Treisman & Gelade, 1980; Treisman & Sato, 1990). However, results also suggest that these deficits in visuospatial binding may be reduced when participants are given multiple trials to optimize their study strategies. This secondary top-down attention may have facilitated the bottom-up attention needed to bind visuospatial features by guiding participants' focus towards high-value information. By learning to strategically allocate attention, participants were able to successfully bind visuospatial information in the event that this bottom-up attention failed to accurately do so. As such, it is likely that the role of attention in this visuospatial memory selectivity paradigm is two-fold by 1) facilitating the binding of multiple visual features into a coherent unit and 2) enabling the execution of goal-related strategies in order to optimize performance.

The current study examined how differentially stressing attentional resources during encoding would affect performance on an attention-demanding visuospatial memory and selectivity task. Despite lower overall memory accuracy, participants in the most cognitively demanding conditions maintained their selectivity towards high-value information, suggesting that factors that influence attentional resources may not impair participants' ability to implement value-based study strategies. When adequate attentional resources were available during encoding, participants may have been able to rely on relational processing to form gist-based item-location memory traces that were moderated by information importance. When attentional resources were stressed to a greater degree, however, engagement in relational processing may have been attenuated or eliminated and participants' gist-based visuospatial memory was no longer influenced by the value of information. In sum, while participants were able to compensate for overall memory deficits by selectively focusing on high-value information when attentional resources were taxed, impairments in gist-based visuospatial memory were still observed, highlighting the role of attention in visuospatial binding and the execution of optimal value-based study strategies during encoding.

Experiment 2: Selective Memory Disrupted in Intra-Modal Dual-Task Encoding Conditions

The ability to prioritize information in attention and memory is a skill that is crucial to daily life given the wealth of information with which we are constantly inundated. We cannot truly pay attention to and/or remember everything we experience as cognitive resources are limited in nature. Given these natural limitations, it is adaptive to identify a subset of information that is most important on which to focus these limited resources in order to subsequently increase the likelihood of remembering that information at the expense of less important information. For instance, it may be more important to remember where we have placed our wallet or car keys when we return home after a long day at work relative to our pen or coat. This ability to selectively encode and retrieve information as a function of its importance, termed value-directed remembering (VDR), has been extensively studied (e.g., Castel, 2008; Castel et al., 2002) and represents a crucial form of goal-oriented cognitive control, as attentional resources must be distributed in a top-down manner (at least partially) to a particular subset of information in order to maximize goal-related memory ability.

In general, the effect of information importance on memory is robust under a variety of different conditions; maintained prioritization in memory is found in cognitively healthy older adults (Castel et al., 2002; Siegel & Castel, 2018a, 2019), younger adults under dual-task conditions (Middlebrooks et al., 2017; Siegel & Castel, 2018b), individuals with lower working memory capacity (Hayes et al., 2013; Robison & Unsworth, 2017) and even, to some extent, children with and without attention-deficit/hyperactivity disorder (ADHD; Castel, Humphreys, et al., 2011; Castel, Lee, et al., 2011) and older adults with Alzheimer's disease (Castel et al., 2009; Wong et al., 2019). Further, this prioritization ability has been demonstrated in recognition (Adcock et al., 2006; Elliott & Brewer, 2019; Elliott et al., 2020; Gruber & Otten, 2010; Gruber et al., 2016; Hennessee et al., 2017; Hennessee et al., 2019; Sandry et al., 2014; Spaniol et al., 2013), cued recall (Griffin et al., 2019; Schwartz et al., 2020; Wolosin et al., 2012), and free recall memory paradigms (Allen & Ueno, 2018; Atkinson et al., 2018; Castel et al., 2002; Cohen et al., 2017; Nguyen et al., 2019; Stefanidi et al., 2018), as well as with more naturalistic, real-world materials like severe medication interactions (Friedman et al., 2015; Hargis & Castel, 2018), potentially life-threatening allergies (Middlebrooks, McGillivray, et al., 2016), and important faces (DeLozier & Rhodes, 2015; Hargis & Castel, 2017). Behavioral and eye-tracking work suggests that the effect of value on memory is a result of both automatic, bottom-up and strategic, top-down control processes, with value automatically and involuntarily capturing attention (Anderson, 2013; Roper et al., 2014; Sali et al., 2014) and explicitly directing controlled, goal-oriented attention (Ariel & Castel, 2014; for a review, see Chelazzi et al., 2013; Ludwig & Gilchrist, 2002, 2003). Neuroimaging work reveals similar findings demonstrating that neural activity occurs in typical reward processing regions like the ventral tegmental area (VTA) and the nucleus accumbens (NAcc) as well as frontotemporal regions involved in executive functioning like the left inferior frontal gyrus and left posterior lateral temporal cortex (Adcock et al., 2006; Carter et al., 2009; Cohen et al., 2014, 2016).

Effective cognitive control may be particularly critical for maximizing selectivity in the context of visual-spatial information. The ability to remember the identity and location of items (like the location of your wallet) is a form of visual-spatial memory which relies on the accurate binding of the "what" and "where" features of an item (Chalfonte & Johnson, 1996; Thomas et al., 2012). That is, it is not sufficient to remember what your wallet looks like (visual information) or its potential locations (spatial information), but rather the link between the item and location (e.g., my wallet is on top of my nightstand). As informed by theories of visual search (e.g., feature integration theory; Treisman & Gelade, 1980; Treisman & Sato, 1990), the binding of object identity and location information into a solitary unit in memory may be more cognitively demanding than memory for single feature memory (i.e., identity *or* location) due to the serial and effortful allocation of attention that is required during encoding. As such, selective encoding in the visual-spatial memory domain may be particularly resource intensive, as attention is required to both bind items to locations and differentially study information according to its value.

However, despite the cognitively demanding nature of visual-spatial binding, prior work has indicated that participants can selectivity attend to and remember high-value over low-value item-location information, even under dual-task conditions (Siegel & Castel, 2018a, 2018b). In previous work utilizing a visual-spatial VDR task (Siegel & Castel, 2018b), participants were presented with items of differing value within a grid array and were asked to prioritize high-value over low-value items for a later item relocation test. Half of the participants studied items while completing a concurrent auditory tone discrimination task in which 1-back same/different decisions were made about low and high pitch tones. While overall memory performance was significantly worsened relative to full attention conditions with no secondary encoding task, selectivity was maintained with participants recalling an equivalent proportion of high-value relative to low-value item-locations. This lack of effect of a secondary task on prioritization ability was also found in a verbal memory context (i.e., words paired with point values) in which various auditory tone tasks taxed cognitive resources to differing degrees during encoding (Middlebrooks et al., 2017). Other work, however, has found that selective encoding can be impaired in some circumstances (Elliott & Brewer, 2019), with results indicating that random number generation, but not articulatory suppression (i.e., repeating the same digit), impairs selectivity in a remember/know recognition paradigm. As such, the extent to which dividing attentional resources during encoding impacts value-directed cognitive control processes remains equivocal.

Considered alongside the results from Middlebrooks et al. (2017), the results of Siegel and Castel (2018b) indicate that participants can maintain memory selectivity in both verbal and visual-spatial recall memory domains and under various levels of cognitive load during encoding. Despite cognitively demanding auditory distractor tasks resulting in lower overall memory performance, participants were still able to selectively study and remember information according to its value, suggesting that efficient cognitive control and strategizing during encoding may be relatively unimpaired by increased cognitive load. At the center of this maintained prioritization is participants' ability to successfully direct attention to high-value information in order to increase the likelihood of recall. Evidently, tying up some attentional resources does not detract from participants' ability to direct the remaining resources towards items of their choosing. In other words, these divided attention tasks are not interfering with participants' selective attention towards the visual-spatial or verbal primary task. The goal of the current study, then, is to determine if there is some form of secondary task that would not only draw resources away from the primary visual-spatial memory task, but also interfere with the ability to direct attention within that primary task. The current study examines whether secondary tasks that draw upon the same attentional resources used in the primary task may result in an impaired ability to direct attention during encoding and thus impair selectivity where secondary tasks have not done so (Middlebrooks et al., 2017; Siegel & Castel, 2018b).

Central to the proposed hypotheses in the current study is the idea of modality-specific pools of attention. While a debate existed between the existence of one central, amodal "pool" of attention (Kahneman, 1973; Taylor et al., 1967) and theories suggesting the presence of modality-specific attentional pools (i.e., one pool for visual attention, one for auditory attention, etc.; Navon & Gopher, 1979; Pashler, 1989; Treisman & Davies, 1973; Wickens, 1980, 1984), there has been strong empirical support for the latter (Allport et al., 1972; cf. Arnell & Jolicoeur, 1999; Duncan et al., 1997; Hein et al., 2006; Martens et al., 2010; McLeod, 1977; Parkes & Coleman, 1990; Rees et al., 2001; Rollins & Hendricks, 1980; Soto-Faraco & Spence, 2002; Van der Burg et al., 2013 for empirical work supporting the central, amodal view of attentional resources). Anecdotally, in the real world many people drive a car while listening to the radio with relative ease; however, few can (or should) drive and read a book or text message at the same time without experiencing major difficulties. Multiple resources theory (Wickens, 1980, 1984) would suggest that these two tasks can be completed simultaneously with little impairment in performance on either task because driving relies on visual attention and listening to the radio upon auditory attention. However, when two tasks draw upon the same pool of resources (e.g., reading and driving), this pool is drained more rapidly, and decrements can be observed in one or both of the tasks.

More recent work has suggested that whether or not a task draws upon the same attentional pool may depend on whether the task involves spatial attention (i.e., attending to a location in space). This work has shown that binding in visual-spatial memory may recruit partially shared resources between vision and audition via verbal rehearsal (Wahn & König, 2015, 2017), that visual and spatial working memory may rely on similar, but separable processing resources (Logie, 1995; Vergauwe et al., 2009), and that verbal and spatial resources may be functionally and neurocognitively distinct (Polson & Friedman, 1988). As such, attentional allocation across sensory modalities and the extent to which secondary tasks prove detrimental to one's ability to selectively allocate attention to the primary task may also depend on whether the task requires the use of spatial resources.

The current study sought to clarify the conditions (if any) in which the ability to prioritize in attention and memory, an important form of cognitive control, may be compromised by testing predictions made by multiple resources theory – that is, whether tasks requiring overlapping modality-specific resources may interfere with selective memory for high-value information. While it is important to study how divided attentional resources may influence our ability to remember information in general, it is also important to understand how it influences our ability to *selectively* attend to and encode important subsets of information in memory. The main goal of the current study, then, was to determine whether cognitive control in the form of selective encoding may be impaired when a secondary task requires the use of overlapping attentional resources, potentially diminishing the extent to which resources could be devoted to the primary memory task.

Experiment 2a

As found in previous work (e.g., Middlebrooks et al., 2017; Siegel & Castel, 2018b), participants are able to maintain selectivity despite increasingly cognitively demanding secondary tasks. However, the secondary tasks utilized in these experiments required only the use of auditory attentional resources with no visual or spatial component present. If attentional resources are indeed modality-specific, then it is of little surprise that these secondary tasks do not hinder participants' ability to selectively remember high-value information. The goal of Experiment 2a was to determine whether an audio-spatial secondary task would succeed in impairing selectivity during the completion of a visual-spatial primary task. We hypothesized that the addition of a secondary audio-nonspatial task (as used in prior work; Middlebrooks et al., 2017; Siegel & Castel, 2018b) would reduce memory performance, but result in equivalent selectivity to a full attention control group with no secondary task during encoding. However, we expected that the addition of a secondary audio-*spatial* task would draw upon the shared attentional resources as the primary visual-spatial task (i.e., spatial attentional resources), consistent with multiple resources theory (Wickens, 1980, 1984), and result in both decreased memory performance *and* selectivity relative to the control group.

To test these hypotheses, three between-subjects encoding conditions were utilized: a control condition with no secondary distractor task, an audio-nonspatial divided attention condition, and an audio-spatial divided attention condition. Participants in each of the three conditions completed eight trials of the visual-spatial selectivity task used in previous work (Siegel & Castel, 2018a, 2018b) in which participants were asked to remember the location of items paired with points values indicating their importance placed in random locations in a grid. During the study phase, the audio-nonspatial and audio-spatial conditions were asked to also complete a secondary auditory distractor task. While participants in the audio-nonspatial condition made 1-back same/different judgments about low-pitched and high-pitched tones during encoding (with no spatial component), the audio-spatial group were required to make same/different judgments about the auditory channel or side on which the tone was played. That is, for these participants the tones during the task were played in either the left channel or the right channel and participants had to judge whether the most recent tone played was in the same channel (e.g., left-left) or a different channel (right-left) than the tone just prior. Thus, to be successful on this secondary task required the usage of audio-spatial resources during encoding.

Method

Participants

The participants in Experiment 2a were 72 University of California, Los Angeles (UCLA) undergraduate students (51 females, M_{age} = 20.08 years, SD_{age} = 2.00, age range: 18-31). The highest level of education reported by participants was 63% some college, 15% associate degree, 13% high school graduate, and 10% bachelor's degree. All participants participated for course credit and reported normal or corrected-to-normal vision.

Sample size was based on prior work investigating similar research questions (e.g., Allen & Ueno, 2018; Middlebrooks et al., 2017; Siegel & Castel, 2018b). To determine the post-hoc sensitivity of our analyses of variance with the given sample sizes, we used the G*Power program (Faul et al., 2007). When including the relevant parameters (three between-subjects' groups and eight within-subjects measures) and a power level of 0.95, the resultant effect size was Cohen's f = .16, suggesting that this is the smallest effect that we could have reliably detected with the current sample size. Converting this Cohen's f to eta-squared results in η_2 = .024 (Cohen, 1988). In both experiments, all significant findings had effect sizes surpassed this value, suggesting that our sample size provided adequate power to detect significant differences in the current study.

Materials

Similar to prior work (Siegel & Castel, 2018a, 2018b), the materials in this study consisted of eight unique 5 × 5 grids containing ten items each presented on a computer screen. The grids were approximately 15 × 15 cm on the screen (17.06° visual angle) and contained 25 cells, each of which was approximately 3 × 3 cm in size (3.44° visual angle). Within each of ten randomly chosen cells was an item selected from a normed picture database (Snodgrass & Vanderwart, 1980). The items used were 80 black and white line drawings of everyday household items (e.g., a key, a camera, and an iron). On the computer screen, items were approximately 2 × 2 cm in size (2.29° visual angle). To form a grid, ten items were randomly selected from the 80-item pool and randomly placed in the cells of the grid with the constraint that no more than two items be present in any row or column of the grid (to reduce the likelihood of the item arbitrarily forming spatial patterns that may aid memory). Items were then randomly paired with point values ranging from 1 point (lowest value) to 10 points (highest value) indicated by the numerical value placed in the top left portion of each item-containing cell. Each value was used once per grid. This process was repeated to form eight unique grids for each participant. For example, while one participant may have been presented with an iron paired with the 7-point value in the top left cell of the second grid, a different participant could encounter that same item paired with the 4-point value in the bottom right cell of the sixth grid. As such, each participant was presented with a different set of eight completely randomized grids.

Procedure

Participants were randomly assigned to one of three between-subjects encoding conditions: full attention (FA), audio-nonspatial divided attention (ANS), or audio-spatial divided attention (AS). All participants were instructed that they would be presented with ten items placed within a 5 × 5 grid and would be later tested on that information. Participants were further instructed that each item would be paired with a point value from 1 to 10 indicated by a number in the top left portion of each item-containing cell. The participants were told that their goal was to maximize their point score (a summation of the points associated with correctly remembered information) on each grid. Participants were shown items one at a time, each for 3 s (totaling 30 s for the ten items) which were presented randomly with regard to their location in the grid and their associated point value. Participants were told that after they studied the information within the grid, they would immediately be shown the items underneath a blank grid and be asked to place each item in its previously presented location by first clicking on the item and then the cell in which they wanted to place it. If participants were unsure of an item’s location, they were asked to guess, as they would not be penalized for incorrectly placed items. Participants were given an unlimited duration to complete this testing phase and were required to place all ten items before advancing to the next trial. After participants placed all ten items, they were given feedback on their performance in terms of the items that they correctly placed, the number of points they received (out of 55 possible), and the percentage of points they received. After receiving feedback, participants repeated this procedure with unique grids for seven further study-test cycles (for a total of eight trials).

Participants in the divided attention conditions also completed tone distractor tasks during the study period (Figure 2.7). Participants were instructed that they would hear a series of tones during the study phase. Tones were presented auditorily through headphones worn by the participants throughout the duration of the experiment. In the ANS condition, tones were one of two pitches: low pitch (400 Hz) and high pitch (900 Hz). In the AS condition, all tones were 650 Hz (the average of the low and high pitch frequencies used in the ANS condition) but were either played only in the right auditory channel or the left auditory channel. In both conditions, each tone was played for a duration of 1 s and the order of presentation was random for each participant with the constraint that no pitch (ANS) or side (AS) was played more than three times consecutively. Participants completed a 1-back tone discrimination task such that they were required to determine whether the most current tone they heard was the "same" or "different" than the tone immediately preceding it. For example, in the ANS condition, a "same" response was required when two consecutive tones were high pitch, while in the AS condition a "same" response was required when two consecutive tones were played in the left channel. The corresponding keys for "same" and "different" were labeled as such on the keyboard.

Before each study-test cycle, a blank grid appeared on the screen and the first tone was played. Participants were instructed that they were not required to respond to this first tone. After 3 s, the first item appeared along with the second tone. Participants then had to make their first decision ("same" or "different" than the first tone). After that, the remaining tones were played

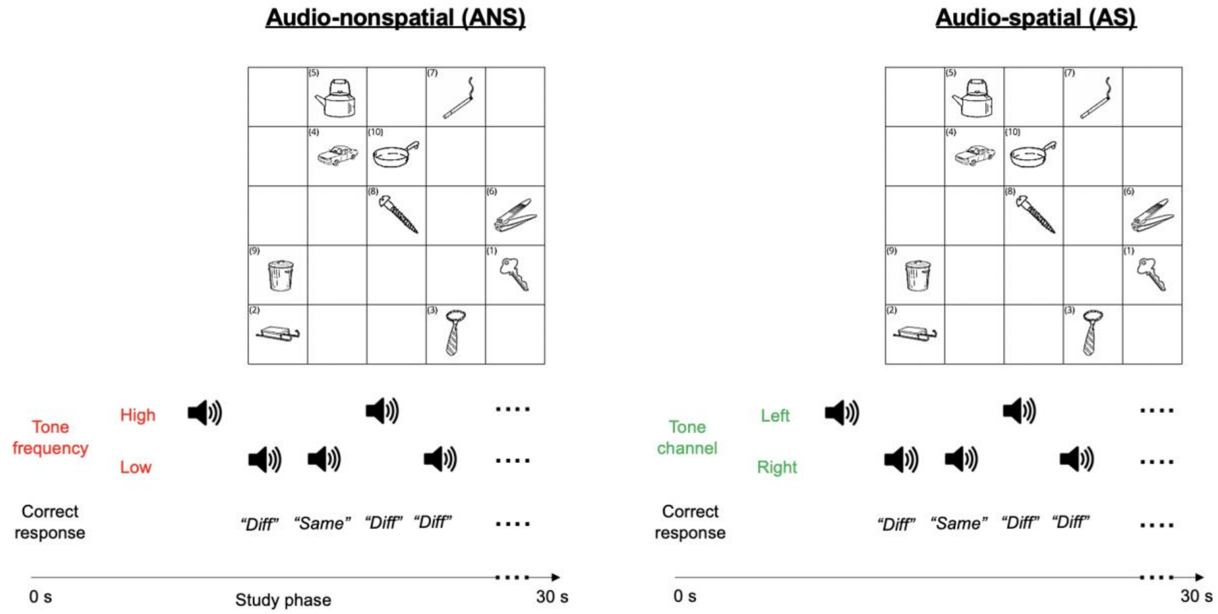

Figure 2.7. Schematic of the study phase in Experiment 2a for the divided attention conditions. In the audio-nonspatial condition (left), participants made 1-back same/different judgments on tones of high/low frequency. In the audio-spatial condition (right), participants made 1-back same/different judgments on tones in the left/right channel. In both conditions, participants made a total of 10 judgments during the study phase of each trial before advancing to the relocation test.

in 3-s intervals, totaling 11 tones by the end of the study period (one preceding the presentation of items and ten during item presentation). The tones were played for the first second of each item's 3-s presentation duration. For both conditions, participants were required to make their tone discrimination response within the 3-s window before the following tone was played. Participants were able to change their response within that 3 s interval and their final response was used in later analyses. To encourage participants to equivalently divide their effort between the two tasks, feedback on tone distractor task performance (i.e., the number of correct tone decisions out of ten possible) was presented along with the primary grid task feedback after each trial. Please note, for the divided attention conditions, we set an inclusion criterion based on tone distractor task performance such that, to be included in the study, participants had to (i) have responded to at least 50% of tones and (ii) have tone discrimination accuracy greater than 50% averaged across all eight grids, similar to prior work (Siegel & Castel, 2018b). Participants were excluded from the study if they did not fulfill either (i) or (ii) and data were collected until there were 24 participants in each divided attention condition that satisfied these criteria.

Results

In this task, memory performance was analyzed using a distance to target location (DTL) measure. As the current study utilized grids containing items of differing value, the materials allowed for a unique, fine-grained exploration of memory accuracy. Compared to studies in which memory performance is measured in a binary manner (i.e., an item is either recalled or not recalled), the grids utilized in the current study permitted a more detailed analysis of participants' memory as a function of value in each encoding condition (i.e., the *degree* to which an item's location was correctly recalled). All of the following analyses were also conducted using binary recall (0 = not correctly replaced, 1 = correctly replaced) as the dependent measure which resulted in a consistent pattern of findings. Given that the DTL measure may represent a more precise measure of memory performance by capturing both verbatim item-location memory and gist-based memory (Siegel & Castel, 2018a, 2018b), we report the following analyses using DTL as the outcome measure.

The DTL measure depicted in Figure 2.8 was calculated for each item placed by participants. A DTL score of 0 indicated an item was correctly placed in its previously presented location, while a score of 1 indicated that an item was misplaced by one cell from the target location (either horizontally, vertically, or diagonally), a score of 2 indicated an item was misplaced two cells from the target location, and so on. DTL scores could range from 0 (correctly placed in the target location) to 4 (four cells away from the target cell). While certain locations had a maximum DTL of 3 (e.g., a cell in the center of the grid) and others a maximum of 4 (e.g., a cell in the corner of a grid), these differences were likely evenly distributed across items and trials due to the random placement of items within grids and across trials for each participant. DTL scores were used as the dependent variable in the following analyses. In all such analyses, smaller DTL scores indicate closer placement to the target cell (and more accurate memory performance), while larger DTL scores indicate farther placement from the target cell (and less accurate memory performance).

Given the multifaceted nature of these data, we used a conjunction of statistical analyses to examine memory performance. First, we examined participants' tone distractor performance across trials to ensure that participants were adequately attempting the secondary tone task. We next examined overall memory performance between encoding conditions across the multiple trials without regard to item value using analyses of variance (ANOVAs) on DTL scores. Then, we examined memory performance as a function of item value and trial, using these measures as predictors of DTL in a multilevel regression model. As such, this allowed us to appropriately examine differences in overall memory (using analyses of variance) and differences in the effects of value between encoding conditions (using multilevel modeling).

Tone Distractor Accuracy

To examine how participants in the divided attention conditions performed on the auditory tone distractor task, we conducted a 2 (Encoding condition: *ANS*, *AS*) × 8 (Trial: *1, 2, ...,*

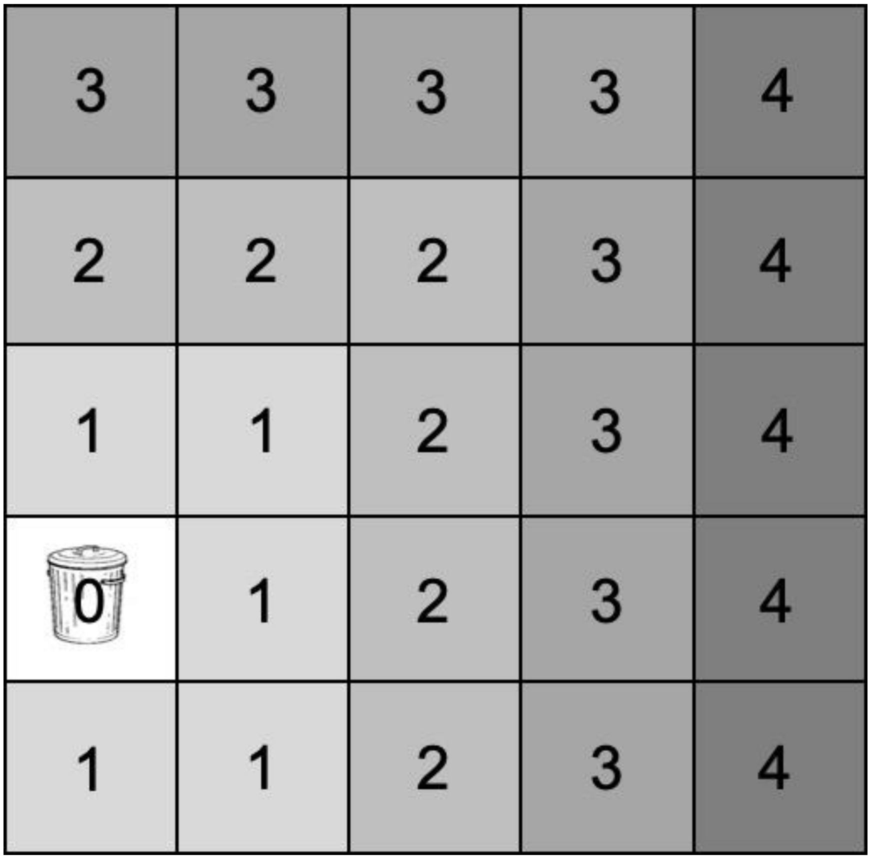

Figure 2.8. An example of distance to target location (DTL) scores relative to an item's correct location. DTL represents the number of "steps" from an incorrectly placed item to the previously presented location. Depending on the target location, the DTL score ranged from 0 (correctly placed in the target location) to 4 (distance of four horizontal, vertical, or diagonal steps from target location). Lighter shades indicate placement closer to the target cell resulting in a small DTL score. Darker shades indicate placement farther from the target cell resulting in a larger DTL score.

8) mixed-subjects ANOVA on tone distractor accuracy (i.e., the proportion of tones out of 10 to which a correct same/different judgment was made). In this and all following ANOVAs in the current study, in the case of sphericity violations, Greenhouse-Geisser corrections were used. There was no main effect of encoding condition such that there was no difference in accuracy between the ANS condition (M = .78, SD = .08) and the AS condition (M = .80, SD = .13), F(1, 46) = 0.66, p = .42, η^2 = .01. There was a main effect of trial, F(7, 322) = 9.92, p < .001, η^2 = .17, with Bonferroni-corrected paired-samples t-tests indicating lower tone distractor performance on Trial 1 relative to Trials 3-8, ps < .02, and no other significant comparisons, ps > .09. There was no interaction between encoding condition and trial, F(7, 322) = 1.92, p = .07, η^2 = .03.

To determine whether performance differed from chance (i.e., 50%) throughout the task, we conducted one-sample t-tests on tone distractor accuracy for Trial 1, Trial 2, and the average of Trials 3-8 (due to the previously described significant differences) collapsing across encoding conditions. These analyses revealed that tone discrimination accuracy was higher than chance on Trial 1 (M = .64, SD = .26), t(47) = 3.90, p < .001, Trial 2 (M = .74, SD = .20), t(47) = 8.29, p < .001, and Trials 3-8 (M = .83, SD = .12), t(47) = 18.73, p < .001. These results indicate that participants in both divided attention conditions were equivalently accurate on the tone distractor task, performance increased after Trial 2, and performance was consistently above chance throughout the experiment.

Overall Memory Accuracy

Memory performance on the visual-spatial grid task was measured using the previously described DTL measure (ranging from 0 to 4) depicted in Figure 2.9, with lower values indicating an item was relocated closer to the target location and higher values indicating an item was relocated farther form the target location. We conducted a 3 (Encoding condition: *ANS*, *AS*, *FA*) × 8 (Trial: *1*, *2*, ..., *8*) mixed-subjects ANOVA on DTL scores. There was a main effect of encoding condition, F(2, 69) = 22.85, p < .001, η^2 = .40, with Bonferroni-corrected independent-samples *t*-tests indicating significantly lower DTL scores in the FA condition ($M = 0.83$, $SD = .40$) relative to the ANS condition ($M = 1.42$, $SD = .31$), $t(46) = 6.14$, $p < .001$, and AS condition ($M = 1.36$, $SD = .25$), $t(46) = 5.52$, $p < .001$. There was no difference in DTL scores between the ANS and AS conditions, $t(46) = 0.62$, $p > .99$.

Further, there was a main effect of trial, $F(7, 483) = 2.66$, $p = .01$, $\eta^2 = .03$, but also a significant interaction between encoding condition and trial on DTL scores, $F(14, 483) = 4.67$, $p < .001$, $\eta^2 = .12$. To decompose this interaction, we conducted three separate Bonferroni-corrected repeated-measures ANOVAs examining DTL scores across trials within each encoding condition. In the ANS and FA conditions, there was no main effect of trial, $F(7, 161) = 1.30$, $p = .26$, $\eta^2 = .05$, and $F(7, 161) = 2.28$, $p = .09$, $\eta^2 = .09$, respectively. In the AS condition, however, there was a main effect of trial, $F(7, 161) = 9.55$, $p < .001$, $\eta^2 = .29$, with follow-up paired-samples *t*-tests indicating higher DTL scores on Trial 1 relative to all subsequent trials, *p*s < .004, and no other significant comparisons, *p*s > .99. As such, these results show that participants in the divided attention conditions had less accurate memory performance compared to participants in the full attention condition, but the type of divided attention (ANS or AS) did not result in different overall memory accuracy. In addition, participants in the AS condition improved their memory performance from Trial 1 to Trial 2 and were consistent thereafter, whereas the ANS and FA conditions were consistent in their degree of overall memory accuracy throughout the task.

Memory Selectivity

Average DTL scores, as a function of item-value and encoding condition, are depicted in Figure 2.9. In order to compare selectivity between conditions and across trials, we used multilevel modeling/hierarchical linear modeling (HLM), which has been used in many previous

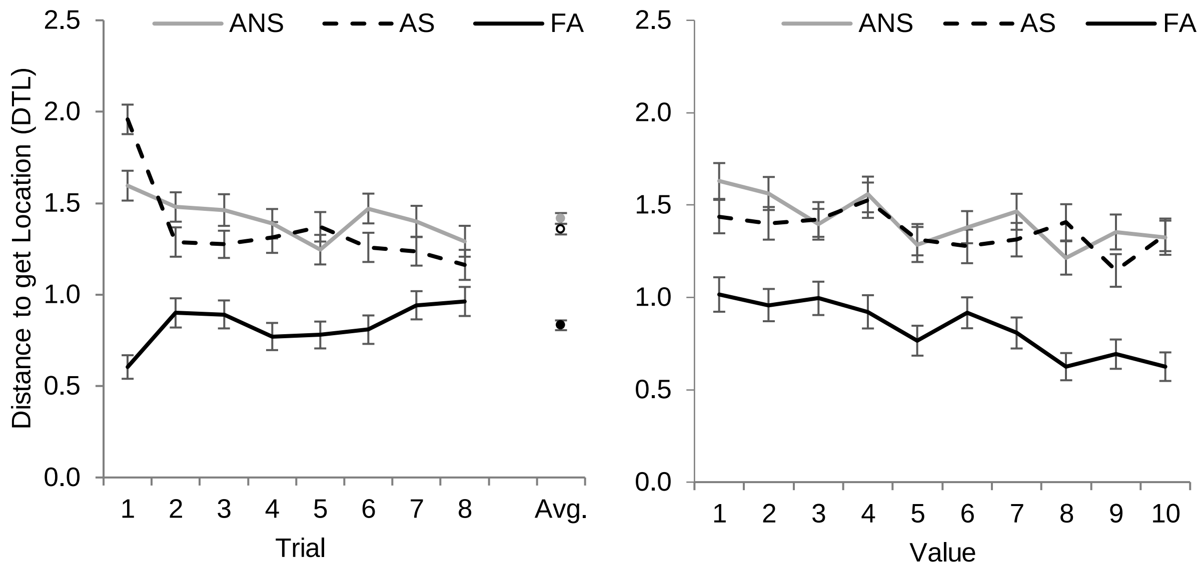

Figure 2.9. Distance to target location (DTL) between encoding conditions as a function of trial (left) and item value (right) in Experiment 2a. Smaller values indicate placement closer to the target location and larger values indicate placement farther from target location. Error bars represent ±1 standard error of the mean.

studies investigating memory selectivity (Castel et al., 2013; Middlebrooks & Castel, 2018; Middlebrooks et al., 2016, 2017; Raudenbush & Bryk, 2002; Siegel & Castel, 2018a, 2018b, 2019). We first considered analyzing the data in an ANOVA framework using different value "bins" (i.e., low, high, and medium value) as levels of a categorical predictor. However, the post-hoc binning of items may not accurately reflect each individual participants' valuations of to-be-learned stimuli (e.g., Participant 1 may consider items with values 6-10 to be of "high" value, while Participant 2 with a lower capacity may only consider items with values 8-10 as such). In contrast, HLM treats item value as a continuous variable in a regression framework, allowing for a more precise investigation of the relationship between relocation accuracy and item value. Further, by first clustering data within each participant and then examining possible condition differences, HLM accounts for both within- and between-subject differences in strategy use, the latter of which would not be evident when conducting standard analyses of variance or simple linear regressions. Thus, HLM allows for a more precise analysis of participants' unique value-based strategies.

In a two-level HLM (level 1 = items; level 2 = participants), DTL was modeled as a function of item value, trial, and the interaction between those two variables. Item value and trial were entered into the model as group-mean centered variables (with item value anchored at the mean value of 5.5 and trial anchored at the mean value of 4.5). The encoding conditions (ANS, AS, FA) were included as dummy-coded level-2 predictors. In this analysis, participants in the ANS condition were treated as the comparison group, while Comparison 1 compared ANS and AS, and Comparison 2 compared ANS and FA.

Table 2.2 presents the tested model and estimated regression coefficients in the current study. Firstly, the HLM indicated that there was a negative effect of item value on DTL scores for the ANS group, $\beta_{10} = -.03$, $p = .02$. This effect was consistent for the other encoding conditions as indicated by the lack of significance of the comparison coefficients, $\beta_{11} = -.01$, $p = .49$, $\beta_{12} = .01$, $p = .53$. As such, for all three encoding conditions, as item value increased, items were relocated closer to the target location. Secondly, there was also a significantly negative effect of list in the ANS condition, $\beta_{20} = -.03$, $p = .04$, indicating that DTL scores in this condition became smaller across lists. This effect was not significantly different for the AS condition, $\beta_{22} = -.04$, $p = .07$, but was significantly more positive for the FA condition, $\beta_{21} = .06$, $p = .01$. Reconducting the analysis using the FA condition as the comparison group to calculate the simple slope indicated that there was a positive effect of list on DTL scores in that condition, $\beta = .03$ $p = .049$, suggesting an increase in DTL scores across trials. Finally, returning to the original HLM, there was no interaction between value and trial in the ANS condition, $\beta_{30} = -.003$, $p = .52$, which did not significantly differ for the FA condition, $\beta_{31} = -.0003$, $p = .96$, or the AS condition, $\beta_{32} = .001$, $p = .90$, suggesting that the relationship between value and DTL scores was consistent across trials in each encoding condition. In sum, the HLM indicated that all three encoding conditions were equivalently selective in their memory and that those in the AS and ANS condition became more accurate with increasing task experience while participants in the FA condition became less accurate.

Discussion

To summarize the results, there were very few differences in performance between the non-spatial and spatial divided attention conditions. Participants in both conditions had equivalent tone distractor accuracy and overall DTL magnitudes and increased their memory performance across trials. Crucially, while participants in both conditions had less accurate performance than those in the control condition, there were no differences in selectivity between participants in the control condition and in the divided attention conditions, or between those in the divided attention conditions themselves as evidenced by multilevel modeling analyses. Given these results, it is clear that the addition of a secondary task during encoding that involved an auditory spatial component did not hinder participants' ability to prioritize information in visual-spatial memory, contrary to our initial theoretically motivated hypotheses.

Experiment 2b

The results of Experiment 2a and previously published work (cf. Elliott & Brewer, 2019; Middlebrooks et al., 2017; Siegel & Castel, 2018b) demonstrate that selectivity is maintained under conditions of auditory-nonspatial and auditory-spatial divided attention in both verbal and visual-spatial memory domains. However, while the AS condition certainly involved a spatial component (i.e., judging between tones played in left channel versus right channel), it was not truly sharing the exact same processing resources as the primary task which requires *visual*-spatial, not *audio*-spatial resources. Perhaps, then, selectivity may be impaired when the secondary task is truly intra-modal, sharing the exact same processing resources as the primary task, which as indicated by previous work in the visual search domain may interfere with cognitive control processes (Burnham et al., 2014; Kim et al., 2005; Lin & Yeh, 2014). Experiment 2b sought to determine whether intra-modal divided attention may produce deficits in memory prioritization where cross-modal divided attention did not. It stands to reason that tasks that require the same processing and attentional resources during encoding may draw upon the same attentional pool, limiting the resources that can be devoted to either task and diminishing participants' ability to selectively study information. However, on the other hand, this limitation in resources may only produce deficits in memory accuracy, and not impairments in selectivity similar to prior cross-modal divided attention findings. As such, Experiment 2b compared how visual-spatial selectivity may be affected in new conditions of cross-modal (e.g., visual-nonspatial) and intra-modal (i.e., visual-spatial) divided attention. Further, as compared to Experiment 2a in which objects were presented sequentially, objects in Experiment 2b were presented simultaneously (i.e., all at the same time) to allow for higher recall and more effective strategy implementation, as indicated by prior work (Ariel et al., 2009; Middlebrooks & Castel, 2018; Schwartz et al., 2020; Siegel & Castel, 2018a, 2018b). In Experiment 2a, overall recall accuracy (i.e., the proportion of items correctly replaced in the exact previous location) was relatively low in the divided attention conditions (M_{ANS} = .32, M_{AS} = .34), so this change was made to ensure that any observed differences in selectivity would be due to the nature of the divided attention task and not the difficulty of the presentation format.

Method

Participants

The participants in Experiment 2b were 72 UCLA undergraduate students (50 females, M_{age} = 20.71 years, SD_{age} = 1.65, age range: 18-28). The highest level of education reported by participants was 64% some college, 18% bachelor's degree, 10% associate degree, and 8% high school graduate. All participants participated for course credit and reported normal or corrected-to-normal vision. None of the participants had participated in Experiment 2a.

Materials and Procedure

The primary memory task used in the current experiment was the previously described visual-spatial VDR task used in Experiment 2a. Grids contained 10 everyday objects placed in randomly selected locations in a 5 × 5 grid. The objects were randomly assigned a point value ranging from 1-10 and participants were directed to maximize their point score (a summation of points associated with correctly placed objects). Participants had 18 s to study the grid with objects simultaneously presented for the whole study time. Study time was reduced from Experiment 2a as pilot data indicated that performance was potentially approaching ceiling when given 30 s to study simultaneously presented objects. After studying, participants were given an item-relocation test in which they were asked to replace items in their previously presented locations. They were then given feedback on their total score and completed a total of eight unique study-test cycles. The type of divided attention task during encoding differed between-subjects. While we attempted to mirror the auditory 1-back tone distractor task used in Experiment 2a as closely as possible, some changes were necessary to incorporate visual distractors.

In Experiment 2b, participants were randomly assigned to one of three between-subjects conditions: full attention (FA), visual-nonspatial divided attention (VNS), or visual-spatial divided attention (VS; $n = 24$ per condition). Participants in the FA condition completed the task without any secondary distractor during encoding, studying the objects in locations for 18 s followed by the relocation test. Participants in the VNS condition were required to complete a 1-back color discrimination task while studying the objects in the grid. As depicted in Figure 2.10, before presentation of the study grid, a square the exact same dimensions as the to-be-presented grid would appear in the center of the screen. This square was colored, in the red-green-blue (RGB) color format, a shade of grey with the following characteristics (R = 128, G = 128, B = 128). This grey square was presented for 3 s, followed by the study grid with the simultaneously presented objects, which appeared in place of the grey square. Participants studied the objects in their locations for 3 s, after which a second grey square appeared in place of the grid, and participants were required to make their first judgement: *is this shade of grey the same or different than the shade of grey that preceded it?* For different shades, the color was modified from the previous shade such that it was ± (R = 51, G = 51, B = 51) darker or lighter. Participants were required to make this judgment within the 3 s that the grey square was present on the screen and could change their response within that time frame only with their final response used in later analyses. After the 3 s elapsed, the same study grid would appear with the same objects in the same locations for a duration of 3 s, at which point the third grey square appeared and participants had to make their second judgment: is this shade of grey the same or different than the second grey square? This process repeated such that participants studied the

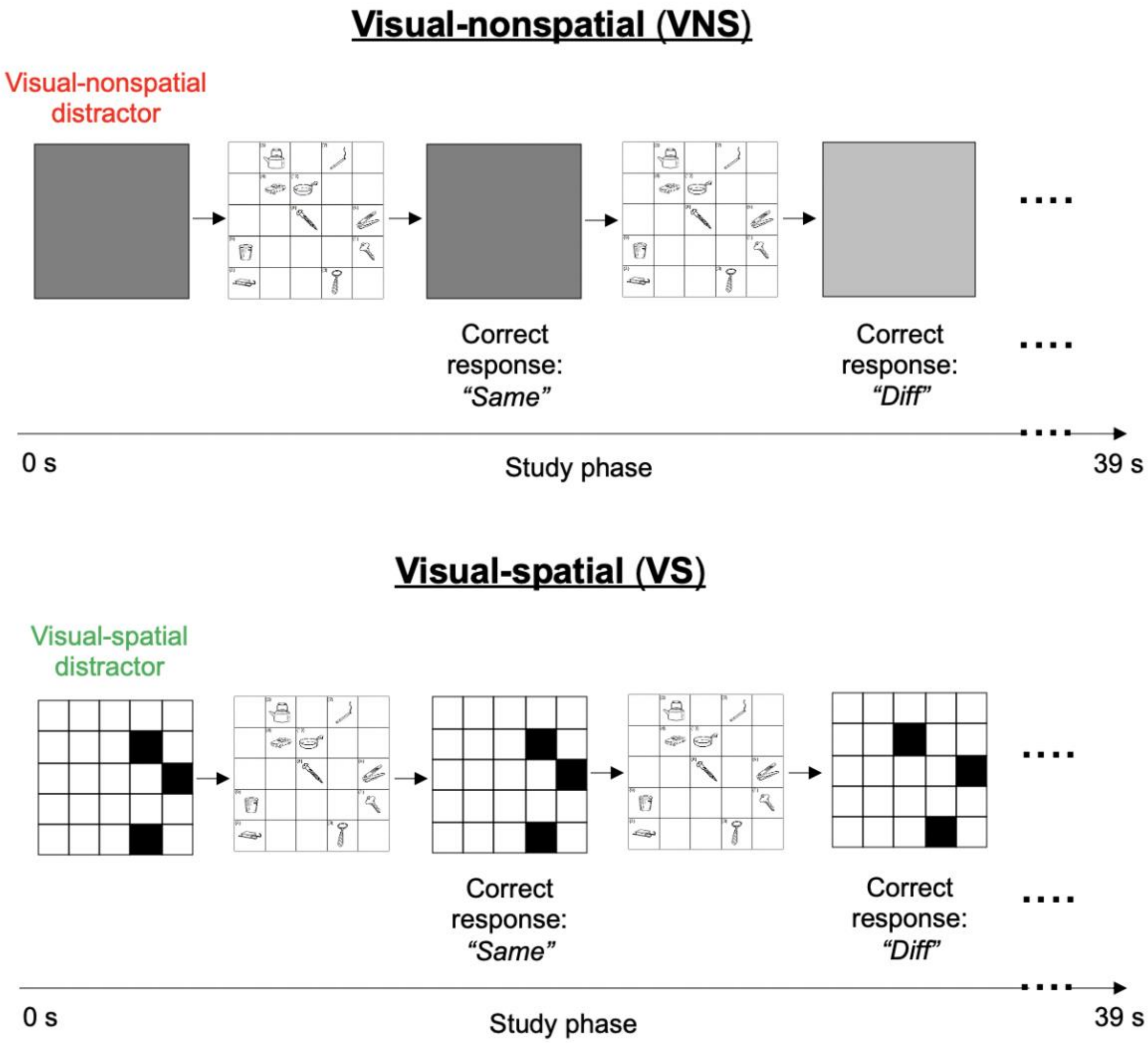

Figure 2.10. Schematic of the study phase in Experiment 2b for the divided attention conditions. In the visual-nonspatial condition (top), participants made 1-back same/different judgments on shades of grey. In the visual-spatial condition (bottom), participants made 1-back same/different judgments on patterns of filled in cells. In both conditions, participants made a total of 6 judgments during the study phase of each trial before advancing to the relocation test.

objects in the grid for a total of 18 s and made a total of six color judgments on the seven presented grey squares (one preceding the presentation of items and six during object presentation). So, the study period was a total of 39 s in length (3 s for the first grey square, 18 s for the following 6 grey squares, and 18 s for the study grid) alternating between the grey squares and objects in locations. On each trial, there were a total of three correct "same" decisions and three correct "different" decisions in a randomized order. After the sixth and final study grid presentation, a brief visual mask was shown and the object relocation test began. In both conditions, the corresponding keys for "same" and "different" were labeled as such on the keyboard.

The VS condition followed the same general procedure, but with different stimuli alternating with the study grid. In this condition, participants completed the 1-back visual pattern discrimination task shown in Figure 2.10. Prior to presentation of the objects, the grid appeared with three randomly selected cells filled in black. Participants viewed this pattern for 3 s at which point it disappeared and the objects immediately appeared in their randomly selected cells for another 3 s. Then, a second pattern of three black squares appeared for 3 s at which point participants were required to make their first same/different judgment: was this pattern of filled in cells the same or different than the previously presented pattern? For different patterns, one of the cells was randomly selected to be offset one cell either vertically, horizontally, or diagonally from its location in the previous pattern, while the other two filled cells remained the same. After making this judgment the objects reappeared for another 3 s followed by the third pattern and second same/different judgment. Again, this process repeated such participants studied the items in the grid for a total of 18 s and made a total of six pattern judgments on the seven presented patterns (one preceding the presentation of items and six during item presentation) with a total study period of 39 s alternating between the patterns and objects in locations. Similar to the VNS condition, on each trial, there were a total of three correct "same" decisions and three correct "different" decisions in a randomized order. After the sixth and final study grid presentation, a brief visual mask was shown and the object relocation test began. Participants were given feedback on their same/different judgment performance (i.e., the number and proportion out of six to which they correctly responded) along with their object/grid memory performance during the feedback phase in order to encourage equivalent participation in the tasks.

Finally, similar to Experiment 2a, we set an inclusion criterion based on the visual distractor tasks in the divided attention conditions. Participants were excluded from the study if they did not (i) respond on at least 50% of visual distractor judgments or (ii) have visual distractor accuracy greater than 50% across trials. Data was collected until there were 24 participants in each divided attention condition that satisfied these criteria.

Results

The same analytical approach used in Experiment 2a was again applied in Experiment 2b. We first analyzed visual distractor accuracy in the divided attention conditions, then examined overall visual-spatial grid memory accuracy between encoding conditions, and finally analyzed memory selectivity between encoding conditions using HLM.

Visual Distractor Accuracy

To examine how the divided attention conditions performed on the visual distractor task, we conducted a 2 (Encoding condition: *VNS, VS*) × 8 (Trial: *1, 2, ...,* 8) mixed-subjects ANOVA on visual distractor accuracy (i.e., the proportion of distractor decisions out of 6 to which a correct same/different judgment was made). There was no main effect of encoding condition, $F(1, 46) = 1.03$, $p = .32$, $\eta^2 = .02$, such that distractor accuracy was not significantly different between the VNS ($M = .67$, $SD = .11$) and the VS ($M = .64$, $SD = .09$) conditions. There was a main effect of trial, $F(7, 322) = 14.76$, $p < .001$, $\eta^2 = .24$, with follow-up Bonferroni-corrected paired-samples *t*-tests indicating visual distractor accuracy on Trial 1 (M = .36, SD = .28) was significantly lower than all subsequent trials ($M_{T2\text{-}8}$ = .69, SD = .10), *p*s < .001, and no other significant comparisons, *p*s > .99. There was no significant interaction between encoding condition and trial, $F(7, 322) = 0.37$, $p = .92$, $\eta^2 = .01$.

To determine whether performance differed from chance (i.e., 50%) at any point throughout the task, we conducted one-sample *t*-tests on tone discrimination performance for Trial 1 and the average of Trials 2-8 (due to the previously described significant differences) collapsing across encoding conditions. These analyses revealed that tone discrimination accuracy was lower than chance on Trial 1, $t(47) = 3.42$, $p = .001$, but significant higher than chance on Trials 2-8, $t(47) = 13.04$, $p < .001$. These results indicate that there was no difference in visual distractor accuracy between encoding conditions and that participants' performance was consistently above chance from the second trial onward.

Overall Memory Accuracy

Memory performance on the visual-spatial grid task was measured using the DTL measure (ranging from 0 to 4) depicted in Figure 2.11. We conducted a 3 (Encoding condition: *VNS*, *VS*, *FA*) × 8 (Trial: *1, 2, ..., 8*) mixed-subjects ANOVA on DTL scores. There was a main effect of encoding condition, $F(2, 69) = 8.30$, $p < .001$, $\eta^2 = .19$, with Bonferroni-corrected independent-samples *t*-tests indicating that DTL scores were lower in the FA condition (M = 0.54, SD = 0.37) than in the VNS condition (M = 0.88, SD = 0.37), $t(46) = 3.29$, $p = .01$, and the VS condition (M = 0.92, SD = 0.33), $t(46) = 3.73$, $p = .001$. There was no significant difference between the VNS and VS conditions, $t(46) = 0.44$, $p > .99$. There was a significant main effect of trial, $F(7, 483) = 8.72$, $p < .001$, $\eta^2 = .11$, but also a significant interaction between encoding condition and trial, $F(14, 483) = 1.96$, $p = .02$, $\eta^2 = .05$. To decompose this interaction, we

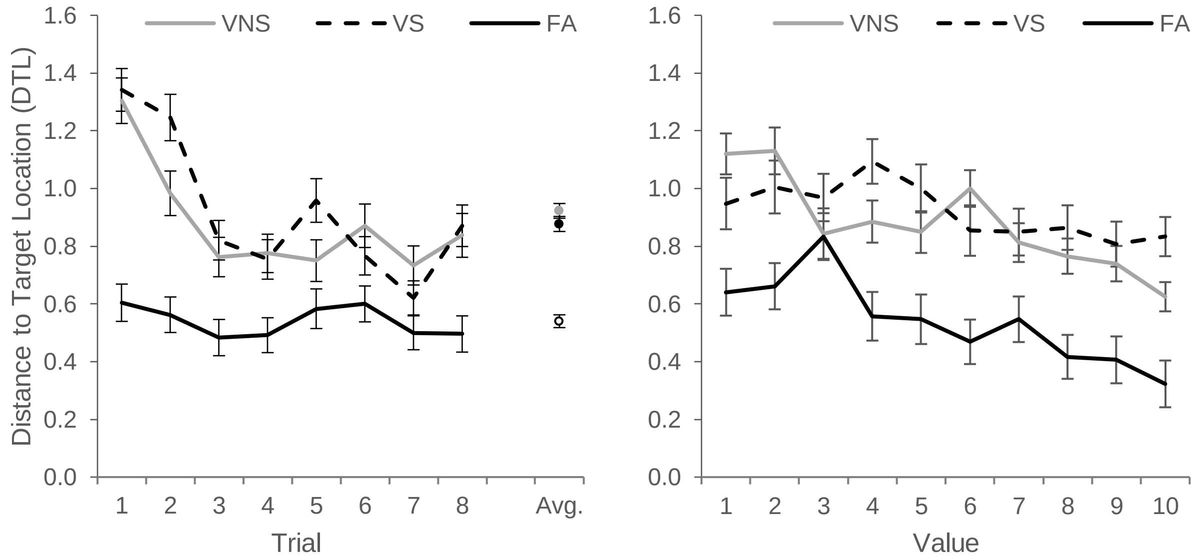

Figure 2.11. Distance to target location (DTL) between encoding conditions as a function of trial (left) and item value (right) in Experiment 2b. Smaller values indicate placement closer to the target location and larger values indicate placement farther from target location. Error bars represent ±1 standard error of the mean.

conducted Bonferroni-corrected repeated-measures ANOVAs examining the effect of trial on DTL scores within each encoding condition. In the VNS condition, there was a main effect of trial, $F(7, 161) = 3.91$, $p < .001$, $\eta_2 = .15$, with follow-up paired-samples *t*-tests indicating higher DTL scores on Trial 1 relative to Trials 5 and 7, *p*s < .05, and no other significant comparisons, *p*s > .10. In the VS condition, there was also a main effect of trial, $F(7, 161) = 8.12$, $p < .001$, $\eta_2 = .26$, with follow-up paired-samples t-tests indicating higher DTL scores on Trial 1 relative to Trials 4, 6, and 7, *p*s < .03, and higher DTL scores on Trial 2 relative to Trials 4, 6, 7, and 8, *p*s < .03, and no other significant comparisons, *p*s > .05. Finally, in the FA condition, there was no main effect of trial, $F(7, 161) = 0.39$, $p = .91$, $\eta_2 = .02$. Overall, memory accuracy was significantly higher in the FA relative to both divided attention conditions, and the divided attention conditions became more accurate on later trials.

Memory Selectivity

In a two-level HLM (level 1 = items; level 2 = participants), DTL scores were modeled as a function of item value, trial, and the interaction between those two variables. Similar to Experiment 2a, item value and trial were entered into the model as group-mean centered variables (with item value anchored at the mean value of 5.5 and trial anchored at the mean value of 4.5). The encoding conditions (0 = VNS, 1 = VS, 2 = FA) were included as level-2 predictors. In this analysis, participants in the VNS condition were treated as the comparison group, while Comparison 1 compared VNS and VS, and Comparison 2 compared VNS and FA.

Table 2.2 presents the tested model and estimated regression coefficients in the current study. Firstly, the HLM indicated that there was a negative effect of item value on DTL scores for the VNS group, $\beta_{10} = -.04$, $p < .001$, which was not significantly different for the FA condition, $\beta_{12} = .01$, $p = .56$. However, this was significantly different for the VS group, $\beta_{11} = .03$, $p = .03$. Rerunning the analysis with VS as the comparison group to calculate the simple slope indicated that value was not a significant predictor of DTL in the VS condition, $\beta = -.01$, $p = .53$. Returning to the original HLM, trial was a significant predictor for the VNS condition, $\beta_{20} = -.04$, $p < .001$, which was not significantly different for the VS condition, $\beta_{21} = -.01$, $p = .42$. This was significantly different for the FA condition however, $\beta_{10} = .04$, $p = .01$, which investigating the simple slope indicated trial was not a significant predictor of DTL scores in this condition, $\beta = -.001$, $p = .92$. Finally, returning to the original HLM, there was no significant interaction between value and trial in the VNS condition, $\beta_{30} = .002$, $p = .49$, the VS condition, $\beta_{31} = -.01$, $p = .75$, or the FA condition, $\beta_{32} = .002$, $p = .71$. To summarize, this analysis indicates that value was significantly negatively predictive of DTL scores in the VNS and FA conditions, but not the VS condition, and that DTL scores became smaller across trials in the divided attention conditions but remained constant in the FA condition.

Discussion

To summarize the results, both divided attentions had equivalent visual distractor accuracy and overall memory performance, which was significantly less accurate than the FA condition. Further, the divided attention conditions became more accurate with increasing task experience. Crucially, as revealed by the HLM, selectivity was equivalent between the FA and VNS conditions, with participants' memory accuracy increasing with item value. However, despite equivalent overall memory performance, participants in the VS condition were not at all selective, with memory performance insensitive to item value. As such, results from Experiment 2b indicate that participants' ability to prioritize information in visual-spatial memory is impaired when the secondary encoding task shares overlapping processing resources as the primary memory task (i.e., visual-spatial attention and memory resources).

General Discussion of Experiments 2a and 2b

The goal of the current study was to determine whether secondary encoding tasks that shared similar processing resources to the primary memory task would result in impairments to goal-directed memory prioritization. Previous work has found that memory capacity is lowered, but memory selectivity unaffected in a dual-task paradigm when the secondary encoding distractor task relies on relatively distinct processing resources (cf. Elliott & Brewer, 2019; Middlebrooks et al., 2017; Siegel & Castel, 2018b). In both Experiments 2a and 2b, secondary encoding distractors reduced memory accuracy relative to full attention conditions. Further, when the distractor attention task did not share the *exact* same processing resources as the primary visual-spatial memory task (i.e., the audio-nonspatial, audio-spatial, and visual-nonspatial conditions), selectivity was equivalent to full attention conditions demonstrating unaffected memory prioritization ability. The only distractor task that impaired selectivity was the visual-spatial pattern discrimination which resulted in no sensitivity to item value in participants' memory performance. This result provides the first instance of reduced attentional resources leading to impaired encoding selectivity in cognitively healthy individuals relative to a wealth of prior work showing intact prioritization including in older adults (Castel et al., 2002; Siegel & Castel, 2018a, 2019), younger adults under dual-task conditions (Middlebrooks et al., 2017; Siegel & Castel, 2018b), and individuals with lower working memory capacity (Hayes et al., 2013; Robison & Unsworth, 2017). As such, these results suggest that in dual-task conditions when both tasks require the same processing resources, constraints are placed not only on memory capacity, but on cognitive control during encoding with participants less able to engage in selective attentional control processes.

The findings of the current study are consistent with predictions made by Wickens' (1980, 1984) multiple resources theory. According to multiple resources theory, there are four dimensions in which cognitive tasks can be categorized: processing stages (perception, cognition, action), perceptual modality (visual, auditory), visual channels (focal, ambient), and processing codes (verbal, spatial), all of which have physiological correlates in the brain (Wickens, 2002). In a dual-task setting in which finite resources are split between multiple tasks, more interference will occur when the two tasks both demand resources from the same level of the dimension (e.g., two tasks that require visual perception) relative to when the two tasks require resources from different levels (e.g., one task that requires visual perception and one that requires auditory perception). In the context of the current study, the primary memory task involved the visual modality and both verbal and spatial codes, with participants likely recoding the visual information into verbal form in working memory (e.g., the key in the top left corner of the grid). The secondary distractor tasks in Experiment 2a required auditory-nonspatial (e.g., distinguishing low pitch from high pitch tones) and auditory-spatial (e.g., distinguishing left channel from right channel tones) processing resources resulting in overall primary task performance decrements, but no effect on selective encoding strategies. In Experiment 2b, the visual-nonspatial task (e.g., distinguishing between different shades of grey) affected performance similarly.

Only the visual-spatial (i.e., intra-modal) task distinguishing between different spatial patterns in the visually presented array interfered with both memory performance *and* the ability to selectively allocate attention. It is likely, then, that the combination of the visual modality and the spatial processing code led to these observed cognitive control deficits, as precisely these resources were required to encode information for the primary memory task, whereas either of these dimensions on their own were not sufficient to do so. Evidently, these resources that would otherwise be devoted to engaging in value-based encoding strategies are instead diverted to completion of the secondary task. When resources exactly overlapped between the tasks, this resulted not only in decrements memory output, but also the effectiveness of top-down attentional control processes that would usually aid in encoding items differentially as a function of their value. As such, while it is well established that memory performance suffers as a consequence of additional cognitive load during encoding (e.g., Castel & Craik, 2003; Craik et al., 1996; Fernandes & Moscovitch, 2000; Naveh-Benjamin, 2000), the results from the current study add novel evidence that cognitive control processes can also be negatively affected when tasks share overlapping processing resources.

It is important to reconcile the results of the current study with previous work investigating memory selectivity under divided attention conditions (Elliott & Brewer, 2019; Hu et al., 2014, 2016; Middlebrooks et al., 2017). Firstly, in the non-associative verbal domain, Middlebrooks et al. (2017) found no effect of a variety of auditory tone tasks on selectivity for individual words of varying value. In this study, the divided attention tasks were all auditory in nature and included tone monitoring (i.e., pressing a key when a tone was played), paired tone discrimination (i.e., pressing a key when a pair of two tones were the same frequency), and 1-back tone discrimination (i.e., determining whether the current tone was the same or different frequency than the prior tone). While the word stimuli were presented visually, they were likely recoded into verbal working memory (Baddeley, 1986). It is evident then that the auditory tone distractor tasks employed did not interfere with selective verbal encoding, as the two types of stimuli (i.e., asemantic tones at differing pitches and semantically meaningful nouns) may have been sufficiently perceptually distinct to draw upon different processing resources, as suggested by multiple resources theory (Wickens, 2002). As such, the tasks utilized in Middlebrooks et al. (2017) may essentially be considered similar to “cross-modal” tasks that rely on separate resource pools resulting in negligible effects on selective encoding as seen in Siegel and Castel (2018b) and the audio-nonspatial, audio-spatial, and visual-nonspatial conditions in the current study.

In Elliott and Brewer (2019), results indicated that random number generation, but not articulatory suppression, impaired selectivity in a remember/know recognition paradigm. A follow-up experiment using a tone monitoring secondary encoding task, similar to Middlebrooks et al. (2017), also eliminated the effect of value on recognition memory, representing contrasting results with maintained selectivity under divided attention in free recall (Middlebrooks et al.,

2017) and cued recall (Siegel & Castel, 2018b). These observed differences may be due to the nature of recognition testing, which may be less sensitive to effects of value in the first place, as (i) participants can rely on both recollective and familiarity-based memory (Hennessee et al., 2017) and (ii) recognition is unconstrained by working memory capacity (Unsworth, 2007) or output interference (Roediger & Schmidt, 1980) as is free recall. Thus, with memory less sensitive to value in recognition memory from the outset, interference of a secondary task in memory selectivity may be more likely to emerge from the data.

Other work has shown that cognitively demanding secondary tasks can influence the ability to remember high-value items when using a dichotomous value structure in which participants were asked to prioritize the first or last item presented in a series of items (Hu et al., 2014, 2016). Taxing attentional resources may have a more detrimental effect on high-value information in this type of paradigm, where the value structure is dichotomous – that is, if the single high-value item is not remembered, then participants' ability to selectively encode high-priority information is considered impaired. In the current study, where the value structure is continuous, the effects of a secondary task during encoding may be more dispersed over a range of values, rather than one high-value item in particular. As such, these apparent differences in the effects of attentional load on memory may be due to the differences in value structure of the tasks, rather than participants' ability to remember information of differing importance.

Our results add to previous work indicating that some cognitive control processes can be influenced by the availability of processing resources. A substantial body of work has indicated that the ability to filter out and ignore task-irrelevant information, another form of cognitive control, is reduced under conditions of high working memory load (Burnham, 2010; Gil-Gómez de Liaño et al., 2016; Kelley & Lavie, 2011; Konstantinou et al., 2014; Lavie & De Fockert, 2005; Lavie et al., 2004; Rissman et al., 2009; Sabri et al., 2014), especially when task resources overlap (Burnham et al., 2014; Kim et al., 2005; Lin & Yeh, 2014). Perceptual load theory (Lavie, 2005; Lavie & Dalton, 2013; Murphy et al., 2016) accounts for these results by positing that the effectiveness of selective attention is dependent on the demands of the task, such that distractor inhibition may be more likely to fail when cognitive load is high. In particular, our results are highly consistent with Burnham et al. (2014) who found that performance on a visual search task was more susceptible to distractors when participants simultaneously completed separate visual or spatial working memory tasks relative to a verbal working memory task which had no effect on distractor interference. These results suggest less effective attentional control (in the form of distractor rejection) when concurrent tasks required the same resources. The current study extends these predictions to the domain of selective attention and memory encoding in a value-directed remembering context, with concurrent tasks that share processing resources impairing cognitive control.

Future work might benefit from examining whether this effect of concurrent intra-modal tasks in a dual-task paradigm extends to verbal associative memory. That is, it would be useful to consider whether cognitive control processes used to selectively encode verbal associative information (e.g., unrelated word pairs) as have been used in previous memory prioritization work (Ariel et al., 2015) are similarly effected by an intra-modal, but not cross-modal, distractor task. Results from the current study would predict reduced selectivity when the secondary task involves verbal resources, especially those requiring semantic processing (e.g., determining whether concurrently presented words represent living creatures), but not when visual resources are required (e.g., making color judgments similar those used in the current study). Similarly, it would be informative to clarify the role of spatial attentional resources in this interference. While visual and spatial perception and memory are intricately interlinked (Logie, 1995; McAfoose & Baune, 2009), verbal and spatial resources may be less so (Paivio, 1977; Polson & Friedman, 1988). As such, concurrent tasks that require verbal and spatial information may be less likely to cause interference (and reduce selectivity) than similarly constructed visual-spatial dependent tasks. Finally, future studies should examine the extent to which intra-modal resource-sharing tasks may affect strategy adoption relative to strategy execution. That is, when participants were unable to selectively remember high-value information in the current study, was that a result of an inability to recognize and adopt a value-based encoding strategy in the first place or an inability to execute a strategy despite recognizing its necessity? Teasing apart this distinction would allow for further understanding of the mechanisms underlying the strategic control of attention under differentially demanding encoding conditions. As such, these avenues of future work may provide informative boundary conditions to this effect of intra-modal interference of cognitive control processes.

The ability to prioritize important information in memory using selective attentional control processes is a robust finding that has generally been shown to persist under conditions of increased cognitive load (Middlebrooks et al., 2017; Siegel & Castel, 2018b) and reduced cognitive resources (Castel et al., 2002; Hayes et al., 2013; Robison & Unsworth, 2017; Siegel & Castel, 2018a). The current study provides novel evidence of a reduced ability to selectively remember information in a dual-task paradigm, but only when tasks rely on the same processing resources. These findings are informed by multiple resource theory (Wickens, 1980, 1984) and load theory (Lavie, 2005; Lavie & Dalton, 2013; Murphy et al., 2016) suggesting that the cognitive control processes responsible for selective encoding can be negatively impacted when relevant processing resources are redirected to a secondary task. As such, the current study identifies important constraints on the effectiveness of the cognitive control processes involved in memory for high-value information. Given the natural limitations of memory capacity, examining the conditions under which cognitive load impairs executive functioning is crucial for understanding the adaptivity of memory when resources are taxed by competing task demands. In sum, goal-directed selective memory processes are indeed vulnerable to interference in some circumstances which should continue to be studied to provide further understanding of the complex relationship between attention, memory, and cognitive control.

Chapter 2 Conclusion

Attentional control is critical when binding information in memory. Substantial prior work has demonstrated that when attentional control is limited during encoding through dual-task conditions or presentation format manipulations, participants are less effective in remembering feature conjunctions. Feature integration theory (Treisman & Gelade, 1980; Treisman & Sato, 1990) would suggest that this occurs because feature binding requires the allocation of focused attention to different spatial locations and that the ability to focus attention is limited by the secondary task or more demanding presentation format. On the other hand, other work has shown that the ability to prioritize information in memory seems to be unaffected by diminished attention in the context of verbal memory. Experiment 1 extended this finding to visuospatial associative memory in that higher levels of attentional load during encoding led to lower overall memory accuracy, but had no impact on participants' ability to selectively remember high-value information over low-value information. These results taken along with prior findings indicate that the executive resources necessary for selective prioritization during encoding tend to be relative robust and unaffected by changes in attentional control. Experiment 2, however, further clarified this relationship between attention and prioritization by utilizing cross-modal and intra-modal secondary tasks. We hypothesized that because prior work like Experiment 1 has used cross-modal dual-task paradigms (e.g., a secondary audio-nonspatial task with a primary visual-spatial task) that participants selectivity was unaffected as resources could be effectively divided. However, perhaps when a secondary task recruited the precise attentional resources as the primary task, a deficit in prioritization may be observed, consistent with theories of modality specific attentional pools. Our hypotheses were confirmed as the results of Experiments 2a and 2b indicated that while overall memory was equivalent between different types of secondary tasks, a concurrent task sharing overlapping resources with the primary task (i.e., visual-spatial) resources impaired value-based study strategy execution adding an important boundary condition to a previously ubiquitous finding. Taken together the prior work and results described in Chapter 2 highlight the crucial role of attention in visuospatial binding and how decrements in attentional resources may result in different patterns of memory performance when bottom-up, automatic factors and top-down, encoding strategies are preferentially allocated towards subsets of information as a function of value. As described throughout the experimental general discussions in this chapter, this line of work requires further investigation to clarify the role of these motivating factors on attention and visuospatial memory binding.

Table 2.1 (Experiment 1)

Two-Level Hierarchical Linear Model of Memory Performance and Relocation Error

Fixed Effect Coefficients	**Item-Location Recall**	**Spatial Relocation Error**
Intercept (β_{00})	0.93***	1.57***
Predictors of intercept		
Comparison 1: Sim-FA v. Sim-DA (β_{01})	–1.23***	0.30***
Comparison 2: Sim-FA v. Seq-FA (β_{02})	–0.81**	0.34***
Comparison 3: Sim-FA v. Seq-DA (β_{03})	–1.58***	0.41***
Value (β_{10})	0.10**	–0.04***
Predictors of Value		
Comp1: Sim-FA v. Sim-DA (β_{11})	–0.02	0.03*
Comp2: Sim-FA v. Seq-FA (β_{12})	–0.05	0.05**
Comp3: Sim-FA v. Seq-DA (β_{13})	–0.04	0.03*
Grid number (β_{20})	–0.04	0.004
Predictors of Grid number		
Comp1: Sim-FA v. Sim-DA (β_{21})	0.23***	–0.04+
Comp2: Sim-FA v. Seq-FA (β_{22})	–0.01	0.01
Comp3: Sim-FA v. Seq-DA (β_{23})	0.19***	–0.03
Value x Grid number (β_{30})	–0.003	–0.004
Predictors of Value x Grid number		
Comp1: Sim-FA v. Sim-DA (β_{31})	0.002	–0.005
Comp2: Sim-FA v. Seq-FA (β_{32})	–0.001	0.004
Comp3: Sim-FA v. Seq-DA (β_{33})	0.02+	0.01
Random Effect Coefficients	**Variance**	**Variance**
Intercept (person-level) (r_0)	0.40***	0.03***
Value (r_1)	0.01***	0.001
Grid Number (r_2)	0.01***	0.0003
Value x Grid number (r_3)	0.0002	0.00001

Note. In these analyses, item-location recall was coded as 0 (*not correctly placed*) or 1 (*correctly placed*) and spatial relocation error was coded on a scale from 1 (*directly adjacent to target location*) to 4 (*distance of four steps from target location*) A logit link function was applied to address the binary dependent variable item-location recall. Levels 1 models were of the form $\eta_{ij} = \pi_{0j} + \pi_{1j}$ (Value) + π_{2j} (Grid number) + π_{3j} (Value x Grid number). Level 2 models were of the form $\pi_{0j} = \beta_{00} + \beta_{01}$ (Comp1) + β_{02} (Comp2) + β_{03} (Comp3) + r_{0j}, $\pi_{1j} = \beta_{10} + \beta_{11}$ (Comp1) + β_{12}

(Comp2) + β_{13} (Comp3) + r_{1j}, $\pi_{2j} = \beta_{20} + \beta_{21}$ (Comp1) + β_{22} (Comp2) + β_{23} (Comp3) + r_{2j}, $\pi_{3j} = \beta_{30}$ + β_{31} (Comp1) + β_{32} (Comp2) + β_{33} (Comp3) + r_{3j}.

$^{+}p < .10$ $^{*}p < .05$ $^{**}p < .01$ $^{***}p < .001$.

Table 2.2 (Experiments 2a and 2b)

Two-Level Hierarchical Linear Model of DTL Scores

Fixed Effects	**Exp. 2a Coefficients**	**Exp. 2b Coefficients**
Intercept (β_{00})	1.42***	0.58***
Predictors of intercept		
Comp. 1: ANS/VNS v. FA (β_{01})	–0.58***	–0.22**
Comp. 2: ANS/VNS v. AS/VS (β_{02})	–0.06	0.03
Value (β_{10})	–0.03*	–0.04***
Predictors of Value		
Comp. 1: ANS/VNS v. FA (β_{11})	–0.01	0.01
Comp. 2: ANS/VNS v. AS/VS (β_{12})	0.01	0.03*
Trial (β_{20})	–0.03*	–0.04***
Predictors of Trial		
Comp. 1: ANS/VNS v. FA (β_{21})	0.06**	0.04**
Comp. 2: ANS/VNS v. AS/VS (β_{22})	–0.02+	–0.01
Value × Trial (β_{30})	–0.003	0.002
Predictors of Value × Trial		
Comp. 1: ANS/VNS v. FA (β_{31})	–0.0003	0.002
Comp. 2: ANS/VNS v. AS/VS (β_{32})	0.001	–0.001
Random Effects	**Variance Components**	**Variance Components**
Intercept (person-level) (r_0)	0.09***	0.06***
Value (r_1)	0.002***	0.001***
Trial (r_2)	0.001**	0.001**
Value × Trial (r_3)	0.0001+	0.00004

Note. In these analyses, the outcome variable distance to location (DTL) was coded as 0 (*correctly placed*) to 4 (*four steps away from target location*). Levels 1 and 2 models were of the same form in Table 2.1.

+p < .10 *p < .05 **p < .01 ***p < .001.

CHAPTER 3: MEMORY FOR RISKS AND REWARDS IN YOUNGER AND OLDER ADULTS

Portions of the following introductory comments, description of Experiments 3a and 3b, and conclusion are taken directly from Siegel and Castel (2018a)

In one of his many critically acclaimed novels, famed Colombian writer Gabriel García Márquez stated, “[I]t is a triumph of life that old people lose their memories of the inessential things, though memory does not often fail with regards to things that are of real interest to us. Cicero illustrated with the stroke of a pen: No old man forgets where he has hidden his treasure” (García Márquez, 2005, p. 10). Without any professional psychological training, García Márquez points out what many people may observe in their own lives as they age: memory for what is important remains, while memory for the inconsequential fades. This is true not only in memory for verbal information, but also in memory for objects and locations (while García Márquez was not likely alluding to visuospatial memory specifically in his metaphor, though the reference to the location of valuable treasure fits well into the context of the current chapter). So, while older adults may be more likely to forget unimportant names, facts, locations, they are much less likely to forget the names of important people they may interact with in the future (Hargis & Castel, 2017), facts in which they are personally interested (McGillivray, Murayama, & Castel, 2015), and the location of their treasured objects (Siegel & Castel, 2018b).

Empirically, much has been revealed about how younger and older adults remember the identity and location of objects in the environment. Age-related impairments in memory for visuospatial information appear to be driven both by individual component deficits in visual and spatial memory, as well as an associative memory deficit in linking or binding multiple visual features. Given older adults’ reduced cognitive resources (Castel & Craik, 2003; Craik & Byrd, 1982), these associative memory deficits may be due to the serial and effortful allocation of attention required to bind features. Not all is negative, however. As alluded to by García Márquez, when older adults deem information valuable, they can use that value judgment to guide their encoding and retrieval. Older adults, with an awareness of limited memory capacity, can selectively remember important visuospatial information in order to maximize their potential gains and compensate for potential losses. As such, this chapter will explore age-related differences in memory binding and the different strategies used by older adults to compensate for memory declines.

Older adults often experience marked declines in various types of memory. However, in some cases, they are able to use strategies to compensate for age-related memory deficits. The selection, optimization, and compensation model (SOC; Baltes, 1993; Baltes & Baltes, 1990) posits that older adults, aware of their overall memory deficits, are able to selectively focus on specific information in an effort to alleviate those memory deficits. The model predicts that older adults *select* important information to which they can focus cognitive resources in order to *optimize* potential gains and *compensate* for potential losses. The SOC model predicts that older adults may be able to selectively focus on and later remember information that they deem important. In the context of VDR, older adults are able to select valuable items (i.e., words or objects) in order to optimize their point scores to compensate for a limited memory capacity. Given clear memory deficits, this strategy represents an efficient use of cognitive resources by older adults. In the presence of age-related deficits, then, older adults appear to be using what cognitive resources they have available in an efficient manner, as predicted by the SOC model.

Chapter 3 explores age-related differences in memory binding and how this binding is affected by information importance. Experiments 3a and 3b examine younger and older adults' memory prioritization under difficult binding conditions. Experiments 4a and 4b explored how visuospatial information is remembered under different levels of load when potential gains and losses are present in younger adults. In addition to including older adults as a main population of interest, the current chapter also seeks to focus on the relevant memory mechanisms rather than the attentional mechanisms that were discussed in Chapter 2, although similar attentional manipulations are made in the experiments (e.g., varying the presentation format) in order to investigate memory performance when the amount of available cognitive resources during encoding differs.

Experiment 3: Memory for Important Item-Location Associations in Younger and Older Adults

Older adults tend to experience declines in visuospatial memory, the ability to remember *what* and *where* objects are in the environment (e.g., Park et al., 2002). These declines have been attributed to age-related associative memory deficits. In order to successfully remember visuospatial information, one must effectively encode and later retrieve the association between relevant visual and spatial information. As such, visuospatial memory failures may be due to inaccurate memory for individual features (the identity or location of an item), an inability to effectively associate these features in memory, or both. While prior research has found age-related impairments in both individual visual (Park et al., 2002; Vaughan & Hartman, 2010) and spatial (Light & Zelinski, 1983; Pezdek, 1983) component memory, the current study is primarily interested in deficits in remembering visuospatial associations.

Studies investigating visuospatial memory consistently find larger age-related impairments when the binding of visual and spatial features is required relative to memory for single features (e.g., Chalfonte & Johnson, 1996; Mitchell et al., 2000; Thomas et al., 2012).

These impairments in visuospatial binding are likely reflective of a more general associative deficit such that older adults' episodic memory deficits are largest when multiple features are required to be linked, or bound, in memory. This associative deficit found in visuospatial memory has also been replicated using a variety of materials including word pairs (Castel & Craik, 2003; Naveh-Benjamin, 2000), word-nonword pairs (Naveh-Benjamin, 2000), word-face pairs (Overman & Becker, 2009), name-face pairs (Naveh-Benjamin, Guez, Kilb, & Reedy, 2004), face pairs (Rhodes, Castel, & Jacoby, 2008), picture pairs (Naveh-Benjamin, Hussain, Guez, & Bar-On, 2003) and object-location pairs (Cowan, Naveh-Benjamin, Kilb, & Saults, 2006). As such, binding deficits seem to be a consistent driving force behind visuospatial memory impairment in older adults (see also Old & Naveh-Benjamin (2008) for a detailed meta-analysis examining the associative deficit hypothesis under various conditions).

While memory deficits are certainly present throughout old age, some studies have demonstrated that older adults are able to strategically utilize their available cognitive resources. Prior research in the domain of memory selectivity has shown that older adults are able to focus on high-value items at the expense of competing low-value items, a process termed value-directed remembering (VDR; Castel, 2008; Castel et al., 2002). In this verbal item-based experimental paradigm, older and younger adults were shown a list of 12 unrelated words, each paired with a point value 1-12. Participants were told that they would receive the point value associated with a word if they correctly remembered it and that their goal was to maximize their score (the summation of all the points associated with correctly remembered words). Although the older adults remembered a lesser proportion of the lower value words (values 1-9) during recall, they remembered the same proportion of high-value words (values 10-12) as the younger adults. Older adults, aware of their limited memory capacity, were able to selectively attend to and remember the high-value words in order to maximize their score. So, while older adults remembered a lesser proportion of words overall, they were able to compensate for age-related memory deficits by focusing on the important information to boost their point scores. Importantly, the ability to selectively remember high-value information is dependent upon the strategic control of attention at encoding (Castel, 2008). This notion is further supported by evidence demonstrating that those with deficits in attentional resources like children with attention-deficit/hyperactivity disorder (ADHD) and older adults with very mild to mild Alzheimer's disease are less selective than healthy controls (Castel et al., 2009, 2011).

Prior work has investigated how value may influence associative memory for verbal information. Ariel, Price, and Hertzog (2015) used a VDR paradigm to investigate the effect of value on younger and older adults' ability to bind unrelated word pairs of differing value. Older adults' use of strategic control processes may not be impaired when required to remember associated information because 1) older adults' metacognitive monitoring ability (used to make study decisions) may be spared in old age (Hertzog, 2016) and 2) older adults' beliefs about age-related memory impairment may encourage them to use value-based strategies to remember the most important information (Dixon & de Frias, 2007). However, their results showed that while both younger and older adults remembered more high- than low-value word pairs, an age-related associative deficit was still present for information of all values. So, while both groups of participants were able to use strategic attentional control processes to guide their memory for associations, age-related deficits still emerged, even for high-value information. This suggests that while value can guide older adults' memory for single items and associations between multiple items, the memorial benefit for high-value information may not be as great when required to bind multiple features, at least for verbal information.

The Current Study

While value can influence free recall (Castel et al., 2002) and recognition (Hennessee, Castel, & Knowlton, 2017) in both younger and older adults, it is it is unclear how the attentionally-demanding binding of information in a visuospatial context could be influenced by information importance and the strategic control processes that guide what people try to remember. The goal of the current experiments then was to clarify how value may affect the binding of item identity and location information, whether this effect varies between younger and older adults, and how presentation format may differentially affect participants' visuospatial binding ability. Building on prior work that has examined how value influences memory for verbal materials (Castel et al., 2002; Hayes, Kelly, & Smith, 2013; Robison, & Unsworth, 2017), we developed a novel paradigm to test how value could influence memory for items and their spatial locations to determine how the strategic control of attention at encoding may influence the binding of information in visuospatial memory. This paradigm also allowed for the systematic investigation of the pattern of errors produced by using a measurement of spatial "relocation error" or spatial displacement (i.e., how far participants misplaced an item from its target location). Using this measure, we were able to investigate older adults' use of visuospatial memory in a gist-based manner when they were unable to retrieve an exact memory trace. In the verbal domain, there is evidence that older adults may be more likely to rely on gist-based memory than younger adults (e.g., Brainerd & Reyna, 2001; Koutstaal, 2006; Reder, Wible, & Martin, 1986). Extending the work in the verbal domain, the findings obtained in the current study represented a more precise measure spatial displacement and allowed us to investigate how visuospatial gist memory might vary as a function of age and information importance. In the present task, we refer to this novel measure of gist-based spatial memory as spatial resolution.

Given the well-established deficits in both individual visual and spatial memory found in older adults, the current study was specifically interested in age-related changes in the binding, or associative, mechanism underlying visuospatial memory. As such, the experimental paradigm used here does not examine component memory (item identity or location) individually, but rather the association between the two. As the binding aspect of visuospatial memory is particularly taxing on attentional resources, we wanted to determine whether visuospatial associative deficits could be alleviated with the usage of value-based study strategies by older adults. Such selectivity would imply that older adults could effectively allocate attention during encoding even in a particularly attention-dependent visuospatial memory task.

Older adults' associative memory for items and their locations could be influenced by value in several ways. First, given significant binding deficits in old age (Chalfonte & Johnson, 1996; Thomas et al., 2012), it is entirely possible that older adults may not be able to use value to guide their visuospatial memory. That is, whereas older adults are able to selectively focus on high-value information for verbal materials (that do not require the binding of multiple features) or associations between verbal information, they may not be able to do so in the context of a more resource-demanding task (binding items to locations) and thus remember all information at a similar rate. Second, similar to findings by Ariel et al. (2015), older adults may be able to use strategic control processes to remember associations, but age-related deficits for associated high-value information may not be completely eliminated. That is, older adults may be able to use value to guide their memory for associated visual and spatial information, but still remember less high-value information than younger adults. It is possible that larger age-related deficits emerge when required to bind visual and spatial information, as compared to the word pairs used by Ariel et al. (2015). Even though the concrete noun-noun pairs were semantically unrelated (e.g., *icebox-elephant*), participants may have still been able to elaborately encode pairs by forming rich mental images (e.g., a shivering elephant sitting in an icebox), whose later retrieval has been shown to increase memory of associated information for both younger and older adults (Naveh-Benjamin, Brav, & Levy, 2007; Richardson, 1998). However, this elaborative encoding strategy may not be possible when attempting to bind item and location pairs. In contrast to concrete noun pairs, forming a vivid mental image of an item in a bare visuospatial array (simple grids in the current study) may be much more difficult. As such, testing memory for items and locations may be a more "pure" test of that association, rather than a test for an elaborately encoded mental image. Third, older adults may be able to use value to eliminate age-related associative memory deficits for high-value information. That is, older adults may show similar patterns of selectivity found in previous VDR tasks using verbal materials to remember the same proportion of high-value information as younger adults (Castel et al., 2002).

Experiment 3a

In Experiment 3a, we examined younger and older adults' ability to bind item and location features for sequentially presented information in a visuospatial memory task. We were interested in whether older adults would be able to use strategic control processes to alleviate age-related associative memory deficits in the context of visuospatial memory and how strategy use might change with increasing task experience. To do so, we presented two groups of younger adults (with varying presentation times) and older adults with a grid containing items paired with point value. After viewing the grid, participants were given a memory test in which they were required to place items into their previously viewed locations and were then given feedback on their performance. Participants then repeated this procedure for a total of twelve study-test cycles, with unique item-location pairs in each grid.

We hypothesized that both younger and older adults would be able to use strategic control processes to guide their visuospatial binding. However, given prior research, we expected that age-related deficits would still emerge for information of all values. We expected that the sequential presentation of items, the need to bind items to locations, and implementation of value-based study strategies would tax attentional resources during encoding, especially for older adults. Due to this, we expected age-related binding deficits to occur for information of all values. However, similar to results obtained in prior VDR tasks, we also predicted that participants would exhibit greater selectivity with continued task experience, as strategy use may have become more refined as participants completed trials and received feedback on their performance.

In addition to a group of younger adults and older adults matched on presentation time (30s), we also included a younger adult group that was presented with information for half the duration (15s). By placing a group of younger adults under time constraints, we hoped to examine how their overall memory and selectivity would compare to older adults who tend to remember less information overall, but are also able to effectively execute value-based memory strategies. Prior research using verbal materials has found that a reduction in presentation time lowers overall memory, but does not affect younger adults' ability to selectively focus on and later remember high-value information (Middlebrooks et al., 2017). However, other research has shown that limiting study time may lead to less efficient execution of value-based agendas in younger adults (Ariel & Dunlosky, 2013), although neither of the previously mentioned studies required participants to encode associated or visuospatial information under time constraints. Given that participants tend to have worse memory for associated features of an item compared to single features, it may be difficult for younger adults to prioritize high-value associated information with a reduction in study time. However, consistent with Middlebrooks et al. (2017), we expected that a reduction in study time would cause younger adults perform similarly to older adults in that they would remember less information overall, but would maintain their ability to selectively focus on high-value visuospatial information.

Method

Participants. The participants in Experiment 3a were 48 younger adults evenly split into two experimental conditions and a group of 24 older adults. The first group of 24 younger adults (16 females) were given 30s presentation time and ranged in age from 19 to 25 years (*M* = 20.79 years, *SD* = 1.59). The second group of 24 younger adults (9 females) were given 15s presentation time and ranged in age from 18 to 25 years (*M* = 20.42 years, *SD* = 1.69). The group of 24 older adults (9 females) ranged in age from 62 to 92 years (*M* = 78.75 years, *SD* = 8.01). All younger adults were University of California, Los Angeles (UCLA) undergraduate students who participated for course credit. Older adults were recruited from the local community and compensated $10 per hour, plus parking expenses. Younger adults with 30s presentation time had completed an average of 13.50 years of education (*SD* = 1.06), while younger adults with 15s presentation time had completed an average of 13.83 years of education (*SD* = 1.31). Older adults had completed an average of 17.00 years of education (*SD* = 1.44). All older adult participants were in self-reported good health and did not report any significant visual impairment.

Materials. The items used as stimuli in this study were selected from a normed picture database (Snodgrass & Vanderwart, 1980) and were 120 simple black and white line drawings of everyday household items (e.g., key, camera, iron). Each item was approximately 2 x 2 cm in size (although this varied depending on the external shape of the item). From that pool, ten items were randomly selected and placed within a 5 x 5 grid with the constraint that no more than two items be present in any row or column (to avoid arbitrarily forming spatial patterns that may aid memory). On the computer screen, the size of each grid was approximately 15 x 15 cm (with each cell approximately 3 x 3 cm in size). To manipulate the value, each item was randomly assigned a value ranging from 1 (lowest value) to 10 (highest value), which was indicated in the top left portion of the cell in which the item was located (in the same manner as Experiment 6a). This process was repeated to form twelve unique grids each with a different set of ten items. In order to avoid testing effects, the values, locations, and grid numbers of items were completely randomized. That is, while one participant may have been presented with a key paired with the 10-point value in the top left cell of the fourth grid, that same item could be paired with the 2-point value in the bottom right cell of the ninth grid for a different participant. As such, each participant was presented with a different set of 12 completely randomized grids.

Procedure. The procedure used in this study was based upon methodologies used in prior experiments investigating VDR (e.g., Castel et al., 2002; Hayes et al., 2013; Robison & Unsworth, 2017) and visuospatial memory (e.g., Chalfonte & Johnson, 1996; Thomas et al., 2012). Participants were instructed that they would be shown a grid with various items placed throughout the grid's cells and to remember the location of the items for a later test. They were then instructed that the items presented within the grid would differ in value, ranging from 1 (lowest value) to 10 (highest value) indicated by a number in the top left corner of the cell and that their goal would be to maximize their score (a summation of the points associated with a correctly remembered item). Importantly, in this experiment, items were presented sequentially. Younger adults in the 30s presentation time group were shown each item for 3s (totaling 30s for the 10 presented items), while younger adults in the 15s presentation time group were shown each item for 1.5s (totaling 15s). Older adults had equivalent study time to the first younger adult group (i.e., each item for 3s).

After viewing the grid, participants were shown a brief visual mask and then a blank 5 x 5 grid with the previously presented items in a row underneath. Participants were instructed to replace the items in their previously viewed locations using the computer mouse (prior to this task, older adults reported they could use the mouse comfortably). If unsure about an item's location, participants were instructed to guess, as their score would not be penalized for misplaced items. There was no time limit for participants during test. After participants placed all 10 items, they were given feedback both on their total score (out of 55 possible points per grid) and the percentage of the total points they received. Participants were able to review their feedback for however long they pleased and were instructed to click a button that would advance them to the next grid at a time of their choosing. After choosing to advance, the subsequent trial would commence with participants immediately shown the new grid to study. Participants then repeated this procedure for all 12 grids. All materials and procedures used in the current study were approved by the UCLA Institutional Review Board.

Results

Overall Memory Performance

In order to examine age-related differences in memory performance regardless of item value, we conducted a 3 (Group: younger adults with 30s, younger adults with 15s, older adults) x 12 (Grid number: 1, 2, ..., 12) repeated-measures analysis of variance (ANOVA) on the proportion of items correctly placed. An item was only counted as correctly placed if participants placed the item in its exact previously viewed cell of the grid. This analysis revealed a significant main effect of group, $F(2, 69) = 18.36$, $p < .001$, $\eta^2 = .35$. Post-hoc t-tests with a Bonferroni correction revealed that younger adults with 30s (M = .47, SD = .22) correctly placed a greater proportion of items, as compared to older adults (M = .26, SD = .17), $t(46) = 6.00$, $p < .001$. Younger adults with 15s (M = .39, SD = .20) also correctly placed a greater proportion of items than older adults, $t(46) = 3.74$, $p = .001$. There was a marginal difference between younger adults with 30s and younger adults with 15s, $t(46) = 2.26$, $p = .08$. There was no significant main effect of grid number and no significant interaction between group and grid number.

Memory Selectivity

Participants may have engaged in strategic control to prioritize item-location pairs in memory to maximize their point total, such as focusing on information of differing point values. As such, we wanted to examine how memory performance differed with regard to item value. Similar to results from previous VDR studies (Castel et al., 2002; Hayes et al., 2013; Robison & Unsworth, 2017), participants who recall a higher proportion of high-value items as compared to low-value items can be seen as being selective towards important information given the goal of the task. By examining the relationship between item value and the probability of its correct placement, we could determine whether the odds of correctly placing an item are affected by its value and whether those odds differ between groups or change with continued task experience.

The binning of items into value groups (e.g., low value items: values 1-3, medium value items: values 4-7, high value items: values 8-10) may not accurately depict participants' use of value-based strategies. Some participants may consider items with values 7+ to be "high value" while others may consider items with values 8+ to be "high value". Thus, the arbitrary binning of items into value groups post-hoc may not sufficiently capture differences in participants' value-directed strategies, as value is not treated as a continuous variable. Rather, the current study uses hierarchical linear modeling (HLM) which accounts for both within- and between-participant differences in strategy use (Raudenbush & Bryk, 2002). This statistical method has been used in numerous prior studies examining age-related differences in strategy use in the VDR paradigm (Castel et al., 2013; Middlebrooks et al., 2016, 2017).

In order to examine correct item placement as a function of age group, grid number, and item value, a two-level hierarchical linear model (HLM) was used. The probability of correctly placing an item (0 = not correctly placed, 1 = correctly placed; level 1 = items; level 2 = participants) was modeled as a function of item value, grid number, and the interaction between item value and grid number. Item value and grid number were entered into the model as group-mean centered variables (with item value anchored at the mean value of 5.5 and grid number anchored at the mean value of 6.5). Age group (0 = younger adults with 30s, 1 = older adults, 2 = younger adults with 15s) was included as a level-2 predictor. In this analysis, younger adults with 30s were treated as the comparison group, while Condition 1 compared younger adults with 30s to older adults and Condition 2 compared younger adults with 30s to younger adults with 15s.

Figure 3.1 depicts participants' memory performance as a function of group and item value across grids. Table 3.1 presents the tested model and estimated regression coefficients for all experiments in the current study. Estimated regression coefficients can be interpreted by taking their exponential, Exp(β) (Raudenbush & Bryk, 2002). Exp(β) represents an odds ratio of successful item placement. An Exp(β) value greater than one indicates a positive effect of a predictor, while an Exp(β) value less than one indicates a negative effect of a predictor. Results from Experiment 3a indicated that item value was a significantly positive predictor of correct item placement for younger adults with 30s, $\beta_{10} = 0.10$, $p < .001$, which was not significantly different for the other groups (ps > .74). Thus, for each increase in item value participants were

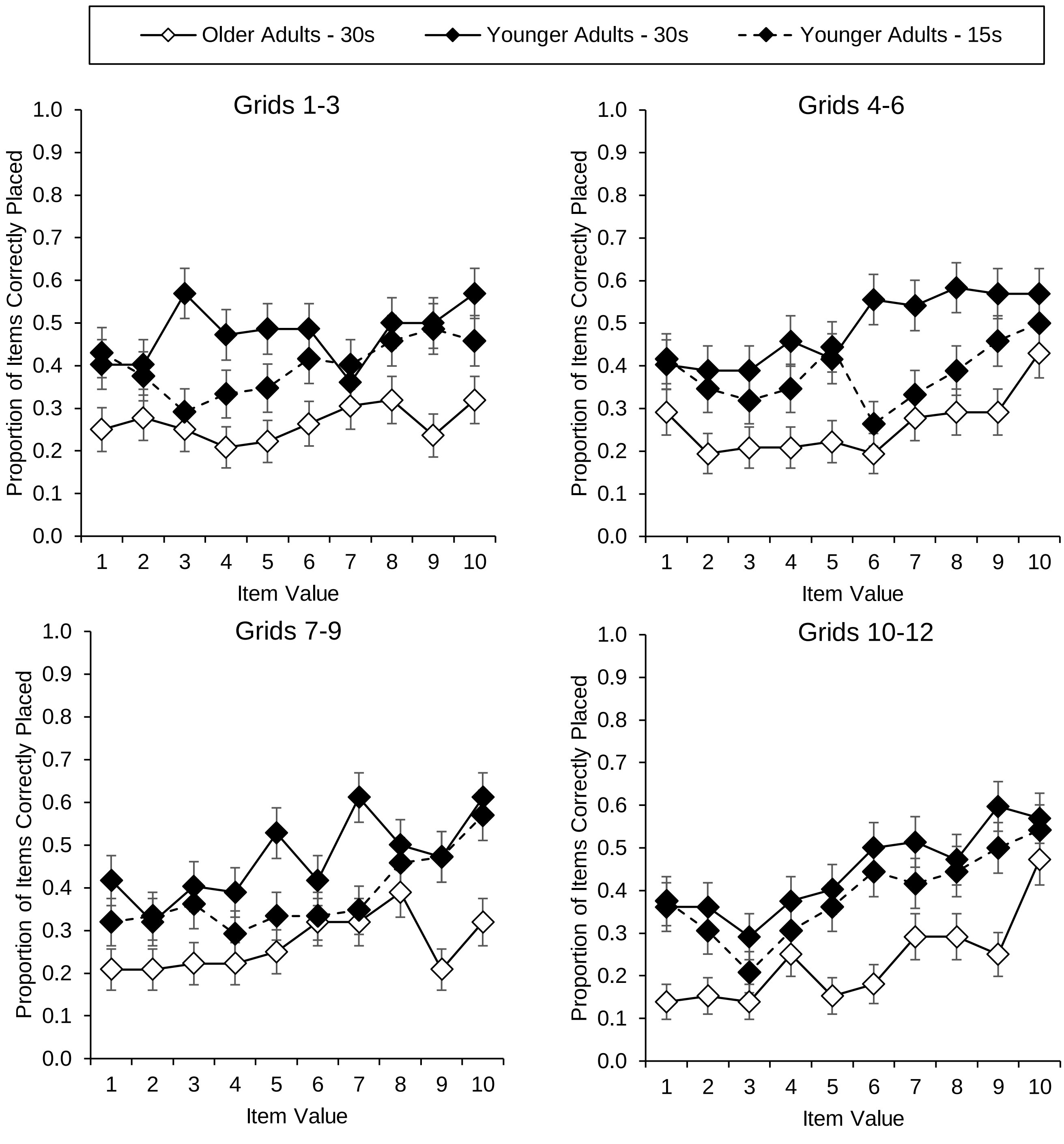

Figure 3.1. The proportion of items correctly placed by item value when presented sequentially in Experiment 3a displayed in grid quartiles. Error bars represent ±1 standard error.

$e^{0.10}$ = 1.10 times more likely to successfully place that item in its correct location. Regardless of grid number or group, participants were $e^{0.10*10}$ = 2.61 times more likely to correctly place a 10-point item, as compared to a 1-point item.

The analysis also revealed that grid number was not a significant predictor of correct item placement for younger adults with 30s, β_{20} = -0.02, p = .33, which again was not significantly different for the other groups (ps > .59), indicating that all participants recalled the same amount of information regardless of item value throughout the task. Finally, results indicated a significantly positive interaction between item value and grid number for younger adults with 30s, β_{30} = 0.01, p = .02, which was not significantly different for the other groups (ps > .66). This indicates that the positive relationship between item value and the probability of correctly placing an item increased with every increase in grid number. Thus, while participants remembered the same amount of information from grid-to-grid, they increased their selectivity towards high-value items.

Bayesian Analysis

To reinforce the findings of null effects of value on memory performance obtained between groups in the HLM, we computed Bayes factors using a Bayesian analysis. First, using logistic regression, the proportion of items correctly placed was regressed on item value within each grid for each participant. Then, a 3 (Group: younger adults with 30s, older adults, younger adults with 15s) x 12 (Grids: 1, 2, ..., 12) repeated-measures Bayesian ANOVA was conducted on the obtained slopes using default priors. This analysis produced a Bayes Factor$_{10}$ (BF_{10} = .080) representing the probability of the data under the alternative, as compared to the null hypothesis. The obtained BF_{10} indicates that the data are 1/.080 = 12.50 times more likely to result from the null model versus the alternative. As detailed by Kass and Raftery (1995), a BF_{10} of this magnitude represents “strong” evidence that the obtained results are indicative of a true null effect. Thus, the lack of difference between younger adults (with 30s and 15s) and older adults likely reflects a similar effect of value on memory performance for these groups.

Spatial Resolution

An advantage of the design used in the current study is the ability to not only investigate participants’ memory for information that they correctly remembered, but also examine participants’ spatial resolution (i.e., not only if a participant misplaced an item, but the magnitude of that error) by examining the pattern of errors made by participants and whether these errors varied as a function of group, value, or grid number. In other words, the usage of items within grids as the stimuli in this task allowed us to analyze the distance between a participants’ erroneous placement of an item and the item’s previously presented location. This type of systematic analysis has not been possible in previous VDR studies using verbal materials such as unrelated words pairs, as determining the distance between an incorrectly provided word and the correct target word proves to be quantitatively difficult (e.g., when cued with *icebox*-__________, is the incorrect answer of *hippopotamus* or *rhinoceros* closer to the correct answer *elephant*?). In these studies, incorrect responses largely remain unanalyzed. By calculating a spatial relocation error score for each incorrectly placed item, we were able to analyze this large section of the data to further inform our findings. This spatial relocation error measure was identical to that used in Experiment 6a.

First, we examined spatial relocation error across grids and between conditions, without regard to item value. We averaged across grid quartiles (Grids 1-3, 4-6, etc.) in order to minimize missing data for participants who correctly placed all 10 items for a grid resulting in no spatial relocation error value for that particular grid. After collapsing into grid quartiles, no participants had missing data and all were included in the following analysis. We conducted a 3 (Group: younger adults with 30s, younger adults with 15s, older adults) x 4 (Grid numbers: 1-3, 4-6, 7-9, 10-12) repeated-measures ANOVA on spatial relocation error and found a main effect of group, $F(2, 69) = 5.13$, $p = .01$, $\eta_2 = .13$. Post-hoc comparisons with a Bonferroni correction indicated that spatial relocation error for younger adults with 30s ($M = 1.88$, $SD = 0.34$) was significantly smaller than older adults ($M = 2.05$, $SD = 0.28$), $t(46) = 3.01$, $p = .01$, and marginally smaller than younger adults with 15s ($M = 2.02$, $SD = 0.29$), $t(46) = 2.46$, $p = .05$. There was no difference between the spatial relocation error of older adults and younger adults with 15s. Additionally, there was no main effect of grid number and no interaction between group and grid number.

To examine spatial relocation error with regard to item value between groups, an HLM framework similar to the previous one conducted on memory performance was applied to participants' spatial relocation error scores. Spatial relocation error as a function of age group and item value in Experiment 3a is depicted in Figure 3.2. The same two-level HLM (level 1 = items, level 2 = participants) used previously was conducted using spatial relocation error as the outcome variable (1 = directly adjacent to correct cell, 4 = four steps from correct cell). In this analysis, older adults were coded as the comparison group, Condition 1 compared older adults and younger adults with 30s adults, and Condition 2 compared older adults with younger adults with 15s. The resulting estimated regression coefficients and variance components are shown in Table 3.2. Results indicated that value was a significantly negative predictor of spatial relocation error for older adults, $\beta_{10} = -0.03$, $p < .001$, which was significantly different between older adults and younger adults with 30s, $\beta_{11} = 0.04$, $p < .001$, and marginally different for younger adults with 15s, $\beta_{11} = 0.02$, $p = .07$. Rerunning the analysis with younger adults with 30s as the

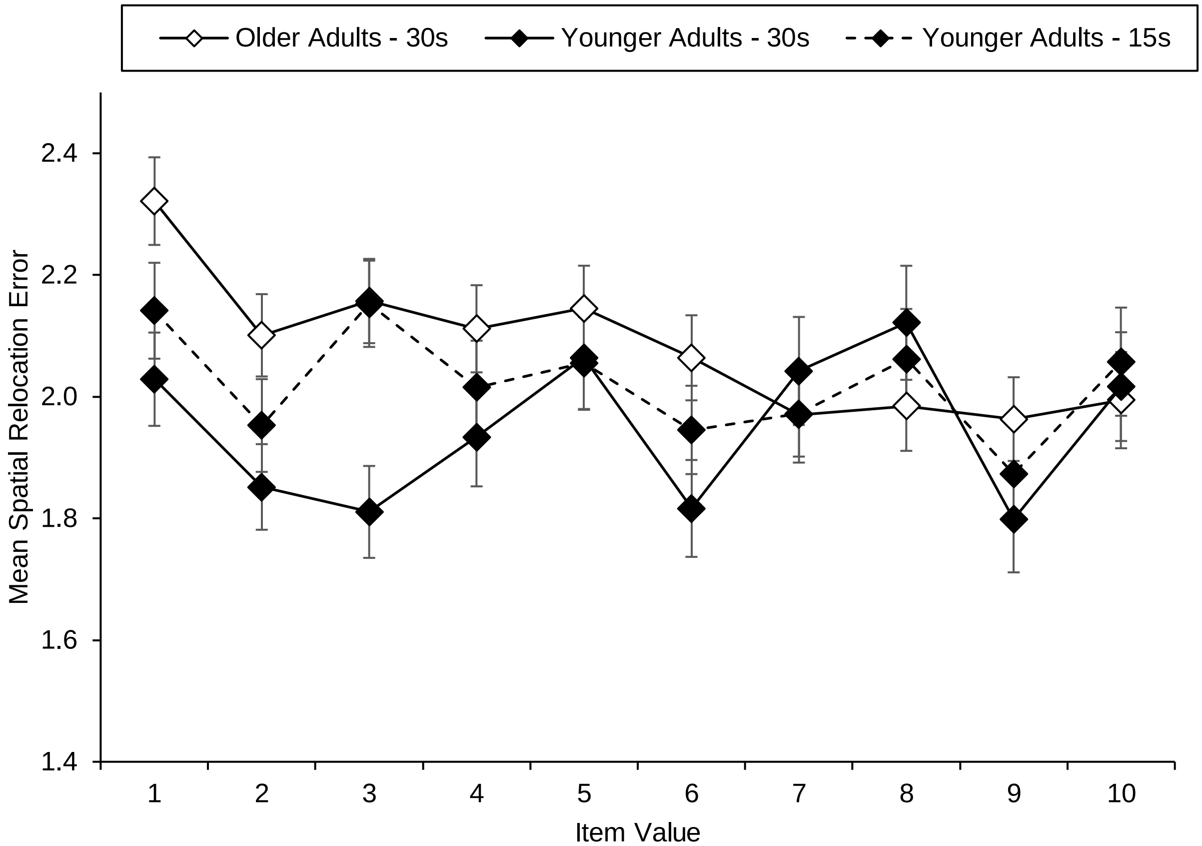

Figure 3.2. Mean spatial relocation error by item value and group averaged across grids for sequentially presented items in Experiment 6a. Error bars represent ±1 standard error.

comparison group confirmed that value was not a significant predictor of spatial relocation error for that group, $\beta_{10} = 0.01$, $p = 0.47$, or for younger adults with 15s, $\beta_{11} = -0.02$, $p = .15$.

Returning to the HLM with older adults as the comparison group, grid number was a marginal positive predictor of spatial relocation error for older adults, $\beta_{20} = 0.01$, $p = .08$, which was consistent for the other groups (*p*s > .35). Further, there was no interaction between item value and grid number for older adults, $\beta_{30} = -0.002$, $p = .51$, which was also consistent for the other groups (*p*s > .53). Taken together, these results suggest that the higher the item value, the smaller the spatial relocation error for older adults, while younger adults' (with both 30s and 15s) spatial relocation error did not vary systematically as a function of item value.

Discussion

For sequentially presented information, younger adults' overall associative memory for item-location pairs was consistently more accurate than older adults and younger adults with reduced study time as reflected by a greater proportion of items correctly placed and smaller spatial relocation error for incorrectly placed items throughout the experiment. Interestingly, results obtained in HLM analyses indicated that all three groups of participants became more selective by correctly placing more a higher proportion of high-value information with continued task experience. When examining spatial resolution, only older adults' spatial displacement errors were influenced by value, with high-value items being placed closer to the target location than low-value items throughout the task. This was not the case for either group of younger adults, whose spatial displacement errors exhibited a more random pattern during throughout the task.

Experiment 3b

As demonstrated in Experiment 3a, when items were presented sequentially in a visuospatial environment, participants may not immediately engage in effective strategic control processes during encoding and require task experience to reach peak selectivity. The goal of Experiment 3b, then, was to determine whether the simultaneous presentation of items would result in differences in overall memory and selectivity. Given that all associated information would be available to participants for the entire presentation time, would participants more effectively select a subset to study, and would older adults benefit more under these conditions? And if so, how might selectivity change with increased task experience? The sequential presentation of information may inhibit participants from allocating study time towards items of their choice, which may limit their ability to engage in strategic control processes during encoding (Robison & Unsworth, 2017). On the other hand, when information is presented simultaneously, participants are able to voluntarily allocate study time, which may enable more effective strategy use. We wanted to examine whether this would be the case in a more cognitively demanding visuospatial binding task. Finally, similar to Experiment 3a, we wanted to determine whether younger adults' pattern of selectivity would be altered when study time was reduced.

Method

Participants. Experiment 3b was conducted with a new group of 48 younger adults evenly split into two experimental conditions and a new group of older adults. Again, the first group of 24 younger adults (17 females) were given 30s presentation time and ranged in age from 18 to 25 years (*M* = 20.17 years, SD_{age} = 1.66). The second group of 24 younger adults (15 females) were given 15s presentation time and ranged in age from 18 to 25 years (*M* = 21.75 years, *SD* = 1.56). The group of 24 older adults (11 females) ranged in age from 64 to 90 years (*M* = 77.29 years, *SD* = 8.14). All younger adults were UCLA undergraduate students who participated for course credit. Older adults were recruited from the local community and were compensated $10 per hour, plus parking expenses. The younger adults with 30s presentation time had completed an average of 13.50 years of education (*SD* = 1.35), while the younger adults with 15s had completed an average of 14 years of education (*SD* = 0.83). The older adults had completed an average of 16.25 years of education (*SD* = 1.70). All older adult participants were in self-reported good health and did not report any significant visual impairments. None of the participants from Experiment 3a participated in Experiment 3b.

Materials. The materials used in Experiment 3b were identical to those used in Experiment 3a (i.e., 120 simple black-and-white line drawings of everyday household items). As in the previous experiment, 10 items were randomly selected, paired with point values 1-10, and placed within a 5 x 5 grid to form the 12 unique grids used as the stimuli in this experiment.

Procedure. The procedures in this experiment were identical to those in Experiment 3a, except for the presentation format of the items. As in the previous experiment, participants were instructed that they would be studying items paired with point values within a grid and their goal was to maximize their point score. In this experiment, however, participants were instructed that they would see all 10 items within the grid at the same time. The first group of younger adults studied the grid for 30s, while the second group of younger adults studied the grid for 15s. All older adults studied the grid for 30s. After the allotted study time had elapsed, participants were shown a brief visual mask and asked to place items in their previously viewed locations. Participants were then given feedback on their performance and repeated the process for all 12 grids.

Results

Overall Memory Performance

To examine overall memory performance when items were presented simultaneously, we conducted a 3 (Group: younger adults with 30s, younger adults with 15s, older adults) x 12 (Grid number: 1, 2, ..., 12) repeated-measures ANOVA on the proportion of items correctly placed overall (out of 10 items per grid). This analysis revealed a main effect of group, $F(2, 69) = 16.49$, $p < .001$, $\eta^2 = .32$. Post-hoc comparisons with a Bonferroni correction revealed that younger adults with 30s ($M = .66$, $SD = .26$) correctly placed a significantly higher proportion of items, as compared to older adults ($M = .40$, $SD = .23$), $t(46) = 5.73$, $p < .001$, and as compared to younger

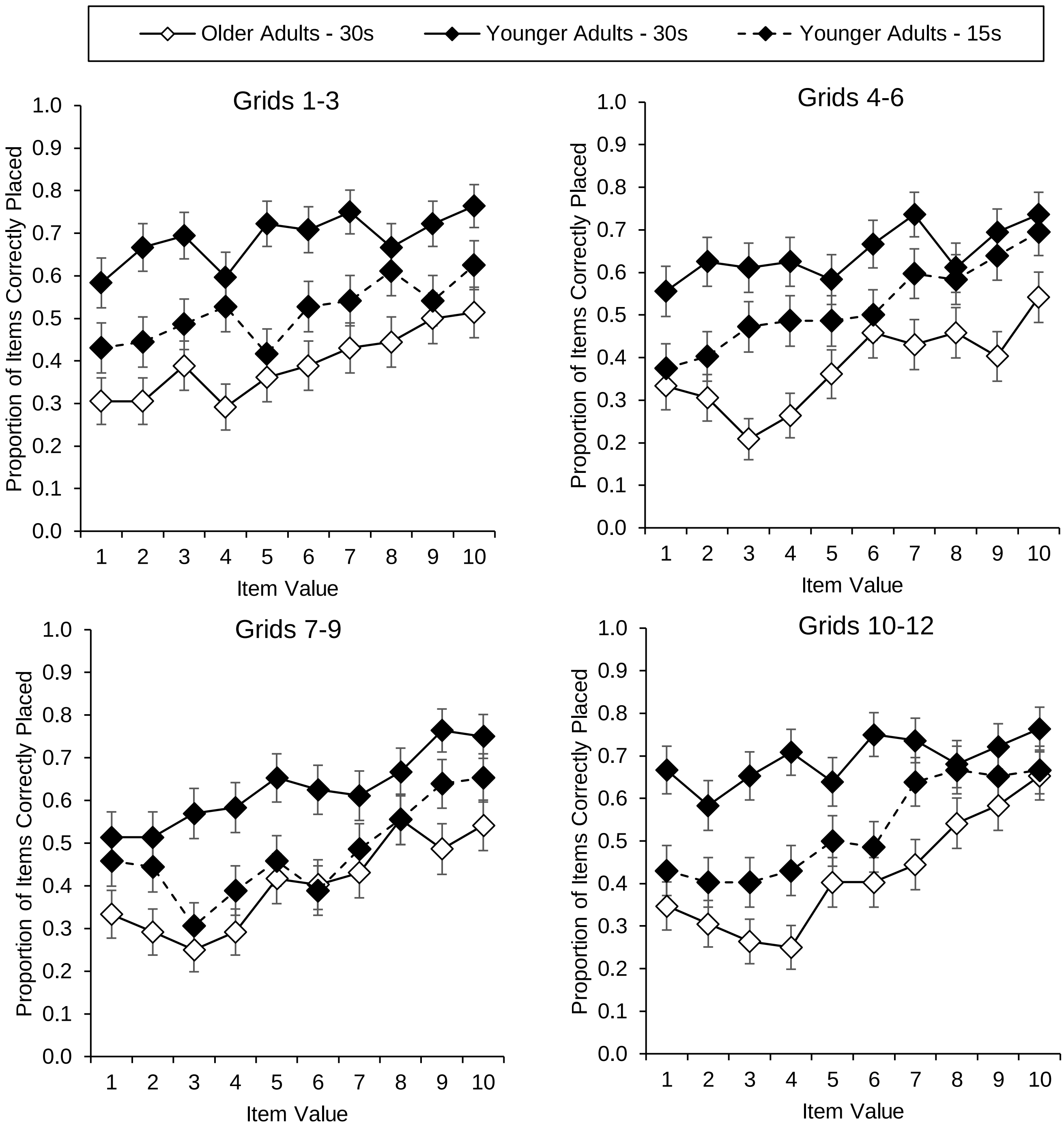

Figure 3.3. The proportion of items correctly placed as a function of item value when presented simultaneously in Experiment 3b. Error bars represent ±1 standard error.

adults with 15s (M = .51, SD = .25), $t(46) = 3.26$, $p = .01$. Further, there was a marginal difference between younger adults with 15s and older adults, $t(46) = 2.46$, $p = .05$. There was no main effect of grid number and no interaction between group and grid number.

Memory Selectivity

Participants' memory performance as a function of age group and item value in Experiment 3b is depicted in Figure 3.3. The same two-level HLM analysis (level 1 = items, level 2 = participants) conducted in Experiment 3a was applied to the new sample collected in this experiment with younger adults with 30s as the comparison group, Condition 1 comparing younger adults with 30s with older adults, and Condition 2 comparing younger adults with 30s with younger adults with 15s. The analysis revealed that item value was a significantly positive predictor of correct item placement for younger adults with 30s, $\beta_{10} = 0.08$, $p = .02$, which was not significantly different for the other groups (ps > .14). Thus, with each increase in value, participants were $e^{0.08} = 1.09$ times more likely to correctly place that item, regardless of grid number or group. Similarly, participants were $e^{0.08*10} = 2.31$ times more likely to correctly place a 10-point item, as compared to a 1-point item, regardless of grid number or group. Further, there was no effect of grid number for younger adults with 30s, $\beta_{20} = 0.0001$, $p = .99$, which was consistent for the other groups (ps > .67). This indicates that participants correctly placed the same proportion of items (within each group and irrespective of item value) across grids. Notably, in contrast to Experiment 3a, there was not a significant interaction between item value and grid number for younger adults with 30s, $\beta_{30} = 0.004$, $p = .31$, which again was consistent for the other groups (ps > .47).

Bayesian Analysis

Similar to Experiment 3a, Bayes factors were calculated using a Bayesian analysis to investigate the lack of differences in the effect of value on memory performance between groups. The same two-step process (e.g., logistic regression to obtain slopes for each participant on each grid and a 3 (Group) x 12 (Grid) repeated-measures Bayesian ANOVA using default priors) was applied to the data collected in Experiment 3b and a BF_{10} of .083 was obtained. This indicates that the data are 1/.083 = 12.05 times more likely to be consistent with the null model as compared to the alternative model. Again, this provides "strong" evidence that the lack of group differences is a result of a similar effect of value on memory performance (Kass & Raftery, 1995) and not due to inadequate sample size.

Spatial Resolution

We also examined participants' spatial resolution by examining the pattern of errors produced by participants using spatial relocation error as a dependent variable. After averaging into grid quartiles, six participants were excluded from the following analysis due to missing data on at least one grid quartile (indicating that those participants correctly placed all 10 items for three consecutive grids). After exclusion, $n_{younger\ 30s}$ = 20, $n_{younger\ 15s}$ = 23 and n_{older} = 23. We conducted a 3 (Group: younger adults with 30s, younger adults with 15s, older adults) x 4 (Grid numbers: 1-3, 4-6, 7-9, 10-12) repeated-measures ANOVA on spatial relocation error and found a main effect of group, $F(2, 63) = 4.07$, $p = .02$, $\eta^2 = .11$. Post-hoc comparisons with a Bonferroni correction indicated that younger adults with 30s (M = 1.61, SD = 0.46) had significantly smaller spatial relocation error scores than older adults (M = 1.83, SD = 0.32), $t(41) = 2.58$, $p = .04$, and marginally smaller spatial relocation error scores than younger adults with 15s (M = 1.82, SD = 0.38), $t(41) = 2.41$, $p = .06$. There was no difference in spatial relocation error scores between older adults and younger adults with 15s. Additionally, there was no main effect of grid number and no interaction between group and grid number.

Again, to examine spatial relocation error with regard to item value between groups, an HLM was applied to the relocation error data obtained in Experiment 3b. No participants were excluded for this analysis. Spatial relocation error as a function of age group and item value in Experiment 3b is depicted in Figure 3.4. The coding of groups followed the same pattern as Experiment 3a (comparison = older adults, Condition 1 = older adults v. younger adults with 30s, Condition 2 = older adults v. younger adults with 15s). Results indicated that item value was a significantly negative predictor of spatial relocation error for older adults, $\beta_{10} = -0.04$, $p < .001$, which was consistent for the other groups (ps > .25). Grid number was not a significant predictor of spatial relocation error for older adults, $\beta_{20} = -0.01$, $p = .36$, which was not significantly different between older adults and younger adults with 30s, $\beta_{21} = 0.01$, $p = .28$. There was a marginal difference of the effect of grid number between older adults and younger adults with 15s, $\beta_{22} = 0.02$, $p = .06$. Rerunning the analysis with younger adults with 15s as the comparison group indicated that grid number was only a marginal positive predictor of spatial relocation error for that group, $\beta_{20} = 0.01$, $p = .07$. These results demonstrate that the higher the item value, the closer participants' placement of items was to the target location for simultaneously presented information.

Discussion

For simultaneously presented information, we again found that younger adults' overall memory for item-location associations was more accurate than that of older adults and younger adults with 15s, both in terms of correctly placed information and spatial displacement errors. However, HLM results indicated that all three groups of participants maintained a similar level

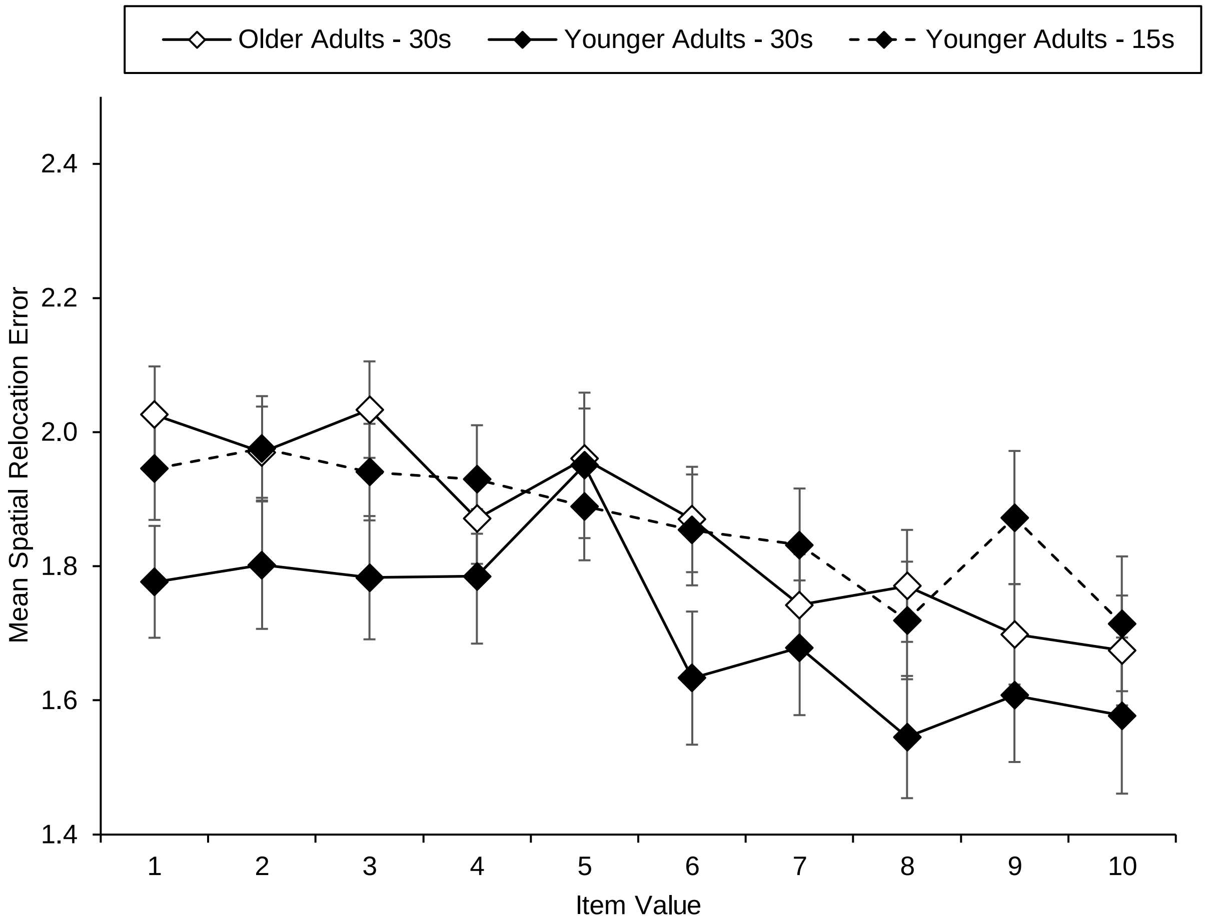

Figure 3.4. Mean spatial relocation error as a function of item value and group averaged across grids for simultaneously presented item-location associations in Experiment 3b. Error bars represent ±1 standard error.

of selectivity throughout the task. Further, with regard to incorrectly placed items, all three groups exhibited a negative relationship between item value and spatial displacement errors such that participants placed higher value items closer to the target location than lower value items. This deviates from the sequentially presented information in Experiment 3a in which only older adults spatial relocation errors were influenced by item value.

General Discussion of Experiments 3a and 3b

Previously established age-related impairments in visuospatial memory are reflective of an associative memory deficit that occurs with advancing age (Chalfonte & Johnson, 1996; Naveh-Benjamin, 2000) and may be due to the effortful allocation of attention required to bind the identity and location features of an object during encoding (Treisman & Gelade, 1980; Treisman & Sato, 1990). The goal of these experiments was to determine whether age-related deficits in visuospatial binding could be influenced by younger and older adults' use of strategic attentional control processes to focus on and later remember high-value information. Further, we were interested in how varying presentation formats may differentially influence these value-based encoding strategies by making their usage more demanding or strategical in nature. In both experiments, younger adults remembered more information overall than older adults across the task when matched on study time. With regard to information that was misremembered, younger adults placed items closer to the target location than older adults. These findings support prior research demonstrating significant age-related deficits in visuospatial memory related to an impaired ability to bind visual and spatial features of items due to an associative deficit (Naveh-Benjamin, 2000; Park et al., 2002; Thomas et al., 2012).

More interesting differences arose when examining memory based on the value of information. As previously discussed, research using verbal versions of the VDR task has shown that older adults are able to selectively focus on high-value information at the expense of competing low-value information, often remembering as much of the high-value information as their younger adult counterparts (Castel et al., 2002). Importantly, these value-based strategies are dependent upon the strategic allocation of attention at encoding (i.e., allocating attention towards high-value and away from low-value information). Consistent with previous VDR findings (e.g., Castel et al., 2002; Hayes et al., 2013; Robison & Unsworth, 2017), we found that increasing value had a significantly positive effect on the probability of correct placement for both younger and older adults in both experiments. That is, participants in all experiments were more likely to correctly place high-value information (i.e., those 10-, 9-, and 8-point items), as compared to medium- or low-value information. Thus, overall, participants appeared to be using strategic attentional control processes in these tasks, as both younger and older adults were able to successfully remember associations between high-value items and their locations. Relatedly, Ariel and colleagues (2015) demonstrated older adults' ability to use value-based strategies to aid associative memory for word pairs. However, they also found age-related memory impairments for all associated information and perhaps even larger differences for associated high-value information. Our results are generally consistent with these findings – while both younger and older adults were able to selectively study and later remember high-value information, age-related memory differences were still present for information of all values.

There are two likely explanations for these impairments in the current study. Firstly, unlike word pairs, item-location associations are not easily verbally rehearsed. As has been well-documented, elaborative rehearsal leads to better subsequent memory performance (e.g., Craik & Watkins, 1973) and prior research has shown that older adults tend to re-rehearse high-value information after study in an attempt to better encode that information for later test (Castel et al., 2013). However, in the context of the current task, it may be difficult, or even impossible, for participants to elaborately rehearse the presented visuospatial associations. For example, how would one rehearse that the kettle is at the intersection of the first row and the second column? Thus, limiting this ability to rehearse associations may have disproportionately affected older adults' value-based strategy use, which in turn may have inhibited their ability to eliminate age-related memory differences for high-value information, as found in prior VDR research (Castel et al., 2002). Secondly, the binding of visual and spatial features of an item presents a unique challenge. Associating item identity and location information likely involves the use of serial and effortful allocation of attention (Treisman & Gelade, 1980; Treisman & Sato, 1990). For older adults, this may have been particularly difficult given their diminished cognitive resources (Craik & Byrd, 1982), which would limit their ability to engage in strategic attentional control processes. So, while older adults were equally as selective as their younger adult counterparts, age-related differences in memory for item-location associations still emerged likely due to these two factors.

Further, the results of the current experiments support prior work demonstrating that participants may be less effective in carrying out agendas related to task goals when information is encountered in a sequential fashion (Ariel et al., 2009; Dunlosky & Thiede, 2004). In the current task, when information was presented sequentially, participants became more selective as task experience increased. In this presentation format, participants were forced to maintain the association between the item and its spatial location in visuospatial working memory while concurrently making judgments on whether to attempt to encode newly presented items based on their point value. Given the strain placed on attentional resources by both sequentially presented information and the binding of item identity and location information, it may have been more difficult for both younger and older participants to effectively allocate attention towards high-value information. After continued task experience, however, participants may have been motivated to try different strategies in order to increase their point total, leading to more effective attentional control later in the task. In contrast, when information was presented simultaneously, participants' pattern of selectivity did not change across the task. Participants were able to strategically allocate attention towards high-value item-location pairs with little task experience. All information was available to participants for the duration of the study period. As such, participants may be better able select a subset of items to study and more efficiently allocate study time and return multiple times to study items that they deemed important. There was also no maintenance of information required throughout the study phase as all information was available to participants for the duration of the study period. These factors likely account for this difference in selectivity across task experience between the different presentation formats. It is almost important to note that these patterns of selectivity were consistent between younger and older adults in each experiment. This may not have been the case, as the increased demands on attentional and working memory resources in the sequential presentation may have disproportionately affected older adults' ability to remember visuospatial associations. As such, these results lend further support towards older adults' preserved ability to engage in strategic attentional control processes in light of resource demanding tasks like binding visual and spatial features and engaging in value-based strategies for sequentially presented information.

Further, results from our spatial resolution analyses demonstrate that participants relied on gist-based visuospatial information in the absence of any explicit item-location recall and that only older adults' gist-based visuospatial memory was stronger for high- relative to low-value information regardless of presentation format. In contrast, younger adults at both presentation rates only demonstrated this effect of value on spatial resolution when information was presented simultaneously. Younger adults, who may not use gist memory to the same extent as older adults (e.g., Brainerd & Reyna, 2001; Koutstaal, 2006; Reder et al., 1986), may have only exhibited value effects on spatial resolution when encoding conditions were less cognitively demanding. Under more demanding encoding conditions, younger adults may have relied more on verbatim item-location memory which would result in the more random pattern of spatial resolution that were observed in the current study. This novel finding adds further support to notion that strategic encoding processes are most efficiently implemented by younger adults when information is presented simultaneously, while older adults may voluntarily engage, or need to engage, in such processes regardless of presentation format.

It is also important to note that participants appeared to recall more information overall in the simultaneous condition ($M_{younger30s}$ = 0.66, $M_{younger15s}$ = 0.51, M_{older} = 0.40, as compared to the sequential condition ($M_{younger30s}$ = 0.47, $M_{younger15s}$ = 0.39, M_{older} = 0.26), at least numerically. No analyses were conducted between experiments to determine whether these differences were statistically significant because participants were not randomly assigned to presentation format condition. One can imagine that if less information is recalled overall, participants may selectively remember more high-value information (as is the case when comparing younger adults' greater memory capacity to that of older adults). However, a decrease in overall associative memory accuracy for sequentially-presented information did not lead to greater selectivity, as compared to simultaneously-presented information – rather it seemed to hinder participants' ability to study selectively, which they overcame with increased task experience. So, both overall recall and ability to use strategies related to task goals appeared to be impaired when information was encountered sequentially, as compared to simultaneously. However, we approach any direct comparison between presentation formats with caution given the design of the current study. Future research should directly compare the effects of presentation format on the execution of value-based study strategies in the context of a cognitively demanding visuospatial binding task.

Finally, while prior research investigating VDR in younger adults has shown that a reduction in study time may reduce participants' overall memory performance, there seems to be no effect on participants' ability to selectively remember high-value information (Middlebrooks, et al., 2017). In the current study, a similar pattern of results was found when presentation time was reduced for younger adults. Although they remembered less visuospatial information overall as compared to younger adults with 30s study time, younger adults' pattern of selectivity was not significantly different with shorter encoding time, regardless of presentation format. Thus, while reduced encoding time limited the amount of information younger participants could later remember, it did not affect their ability to selectively allocate study-time towards and later remember high-value information.

One limitation of the current study relates to the manner in which participants' memory was tested. By having participants' place items in their previously viewed locations, participants' associative memory for the item-location pairs was queried, as we were particularly interested in the potential effects of information importance under attentionally-demanding conditions like visuospatial binding. However, we did not investigate participants' component memory for visual (i.e., the presence or absence of a particular item in any location within the grid) or spatial (i.e., the presence or absence of any item in a particular location within the grid) memory individually. As such, it is possible that the observed effects of value may be due to a change in component, rather than associative memory. Given the current experimental design, we cannot claim that value-based study strategies exclusively or more drastically influence associative, as compared to component memory. That said, for participants to correctly place a previously viewed item, they were required to successfully remember the item-location association. As such, we feel confident that value did indeed influence visuospatial binding. As to whether this influence was through direct (i.e., an exclusive memory boost to high-value item-location pairs) or indirect (i.e., a boost to individual visual or spatial component memory leading to better overall memory for high-value item-location pairs) means, the results remain inconclusive. An interesting line of future should directly compare the effects of value on visual, spatial, and binding memory to more specifically identify the source of the observed value effects in the current study.

Future research should also explore the effect of the vividness of context or the use of schemas on visuospatial binding ability. Prior studies have shown that older adults may show item and spatial memory benefits when the presented visuospatial context has greater visual complexity (e.g., a three-dimensional model of a bedroom is more distinctive than a two-dimensional map of the same room; Sharps & Gollin, 1986), although other research only found this benefit for spatial memory (Park, Cherry, Smith, & Lafronza, 1990). Increasing the visuospatial distinctiveness may also provide more schematic support for older adults (e.g., knowing that the fork belongs somewhere in the kitchen). Prior research has shown that associative memory may be improved when older adults can rely on prior knowledge and schemas (Castel, 2005; Hess & Slaughter, 1990). When including the added factor of value, one may expect to find similar, or even enhanced, effects on visuospatial binding. For example, older adults may be better at remembering where their eyeglasses (commonly a high-value item in daily life) are located in a room, as compared to where their pen (commonly a low-value item) is located, especially when they are able to rely on schematic support. While the present study used a rather sparse spatial environment, this allowed for a more precise examination of how strategic encoding factors can influence memory in the absence of other schematic factors that could support, or interfere with, the binding of items and locations in visuospatial memory.

Experiments 3a and 3b sought to determine whether age-related deficits in visuospatial binding ability could be alleviated by engaging in strategic control processes and whether the ability to implement these strategies would vary given the presentation format and the amount of task experience. Despite overall visuospatial associative memory deficits for older adults, all participants were able to engage in strategic control processes after sufficient task experience when information was presented sequentially, and from the beginning of the task when information was presented simultaneously. Older adults, who may have reduced attentional and working memory resources, were still able to selectively remember associative information in the face of resource demanding tasks like visuospatial binding and remembering sequentially presented information. Reducing presentation time for younger adults led to lower overall memory performance, but did not affect the pattern of selectivity. Further, the introduction of novel spatial resolution analyses extended older adults' reliance on gist-based memory to the visuospatial domain, while younger adults gist-based visuospatial memory was only influenced by value under less demanding encoding conditions. Overall, while the current study finds further support for age-related deficits in the binding of visual and spatial information, it also provides evidence that older adults are able to use effective value-based strategies to remember the most important associated information in a visuospatial context.

Experiment 4: Strategic Encoding and Enhanced Memory for Positive Value-Location Associations

The ability to remember the locations of items is one form of visuospatial memory. Much like other forms of memory, capacity constraints limit the amount of visuospatial information that we remember, with visuospatial memory capacity similar to that of verbal memory (Kane et al., 2004; Park et al., 2002). Furthermore, visuospatial memory often involves the binding of identity (visual) to location (spatial) information (Chalfonte & Johnson, 1996; Thomas, Bonura, Taylor, & Brunyé, 2012). That is, it is usually important to remember not only the visual features of the item (e.g., the front of the restaurant, the signage, etc.) or the location features (e.g., where it is located in town, what stores are adjacent, etc.), but also the linkage between these features (e.g., that this particular restaurant is in this particular location). The need to bind multiple features into a coherent unit in memory represents a form of associative memory that may be fairly cognitively demanding relative to memory for single features (Shing et al., 2010) and which typically suffers marked deficits in cognitive healthy aging (associative deficit hypothesis; Naveh-Benjamin, 2000; Old & Naveh-Benjamin, 2008) and pathological aging, as in Alzheimer’s disease (Gallo, Sullivan, Daffner, Schacter, & Budson, 2004).

Despite the demanding nature of associative binding, similar to memory for individual units of information, people can selectively attend to and prioritize associations in memory based on their value. This finding, referred to as value-directed remembering (VDR; Castel, Benjamin, Craik, & Watkins, 2002; Nguyen, Marini, Zacharczuk, Llano, & Mudar, 2019; Stefanidi, Ellis, & Brewer, 2018), has been found in both the verbal memory domain using unrelated word pairs as stimuli (Ariel, Price, & Hertzog, 2015) and the visuospatial memory domain using item-location associations (Siegel & Castel, 2018a, 2018b). The ability to selectively prioritize information in memory is maintained under various conditions in which cognitive resources are depleted including dual-task paradigms where a secondary distractor task is present during encoding (Middlebrooks & Castel, 2018; Siegel & Castel, 2018b) and to a certain extent in children with attention deficit/hyperactivity disorder (ADHD; Castel, Lee, Humphreys, & Moore, 2011) and older adults with Alzheimer’s disease (Castel, Balota, & McCabe, 2009; Wong et al., 2019; cf. Elliott & Brewer, 2019 who found that selectivity was impaired under dual-task conditions in a recognition memory task). These findings indicate that when capacity, either working memory capacity as in dual-task paradigms or short-term memory capacity as in aging and cognitive impairment, is exceeded the prioritization of information remains fairly robust and relatively insensitive to changes in the amount of available cognitive resources.

Importantly, prior work investigating this prioritization of information based on value characteristics has primarily examined this effect under conditions when points can be *gained*, not lost. That is, in a typical associative VDR task, participants are instructed that a particular word pair or item-location pair is worth a certain amount of points if correctly remembered or correctly replaced in a location (e.g., CHAIR-DOG – 8 points, *hammer* in top left corner of grid array – 3 points, for words and items that range in point values from 1-10). Participants are instructed to maximize their point score, which leads to an attentional focus on and better memory for high-value over low-value information (Castel et al., 2002; Middlebrooks et al., 2017; Siegel & Castel, 2018a). In these studies, and others like them, however, participants are not penalized if the paired associate is not recalled or an item is misplaced during the testing phase. As such, participants can truly focus on the prioritization of the highest value information, without much consideration for items of lesser value. In real-world situations, information we seek to remember can be highly positive, highly negative, or somewhere in between. Other empirical work has suggested that subjective valuations associated with losses may be different than those associated with gains (Mitchell & Wilson, 2010), which may extend to participants' strategy use and subsequent memory performance. As such, the current study seeks to systematically examine how participants prioritize information when misremembering is penalized, by introducing the potential to *lose* points.

Some work has investigated how participants study information of differing value with the potential of point loss. For example, in an application of associative VDR using more naturalistic materials, Castel et al. (2016) presented participants with faces randomly paired with monetary values ranging in magnitude from -$100 to +$100 (values presented included 1, 2, 5, 10, 20, 50, and 100). Positive values indicated fictional money that was owed to them, while negative values indicated money that they owed. This study found that the extreme values (i.e., those higher in overall magnitude) were better recalled than those of smaller magnitude, regardless of positivity and negativity. Other related work also suggests that extreme values rather than exclusively high positive reward may enhance memory performance due to their bottom-up salience (Madan, Ludvig, & Spetch, 2014; Madan & Spetch, 2012), which has been supported by various neuroimaging studies showing reward-processing brain regions, like the nucleus accumbens and striatum, automatically respond to reward saliency (Cohen, Rissman, Suthana, Castel, & Knowlton, 2014; Cooper & Knutson, 2008; Shigemune, Tsukiura, Kambara, & Kawashima, 2013; Zink, Pagnoni, Martin-Skurski, Chappelow, & Berns, 2004).

While the aforementioned work was primarily interested in the automatic, bottom-up effects of reward on memory performance, the current sought to explore how participants attempt to study positive and negative information in a more top-down, controlled manner. Prior studies have investigated how participants allocate attention to information differing in positive value, with only the potential to gain points (e.g., Middlebrooks & Castel, 2018). Perhaps unsurprisingly, when participants were afforded more control over their study choices and study time, they were more selective in their memory for high-value items, indicating more efficient prioritization relative to when they were given less control. This finding suggests that when top-down strategic processing can be more effectively implemented participants choose to focus on high-value information. However, it is currently unclear how the presence of high-value *negative* information may or may not influence participants' study choices and value-based memory.

The potential influence of losing points on one's value-based study strategies is a theoretically interesting avenue to explore. As proposed by the seminal prospect theory (Kahneman & Tversky, 1979; Tversky & Kahneman, 1992), people tend to be risk averse when making financial decisions about potential gains (e.g., they would rather have an 100% chance at winning $50 than a 50% chance at winning $100), while they are risk seeking in terms of potential losses (e.g., they would rather choose a 50% chance at losing $100 or losing $50 than an 100% chance at losing $50). With this theory, they were able to account for the finding that "losses loom larger than gains" – that is, the subjective feeling of losing $50 is more highly negative than the subjective feeling of winning $50 is positive. As such, prospect theory predicts that participants should adopt a point-loss avoidance approach in the current study, as negative point values may receive more attentional focus and better subsequent memory.

Another theoretical framework that provides different predictions regarding participants' value-based study strategies in the presence of positive and negative information is the regulatory fit theory (Higgins, 2005, 2006; Spiegel, Grant-Pillow, & Higgins, 2004). Regulatory fit theory proposes that participants' goal orientation, which is dependent on individual and situational factors, leads to different types of goal pursuit, such as a promotion-focused or prevention-focused goal orientation (Cesario, Higgins, & Scholer, 2007; Higgins, 2006). Therefore, engagement in and success on a task may be driven by the goal orientation that participants are directed to follow. In the current study, given that participants are prescribed a particular motivation orientation to pursue at the beginning of the task (i.e., to *maximize* their score, clearly a promotion-focused orientation), regulatory fit theory predicts a focus on engagement in strategies that pursue this prescribed goal, with participants potentially focusing more on remembering positive items to gain points rather than negative items to avoid losing points. The current study was interested in determining whether regulatory fit would account for participants' adoption of a points-gained approach in accordance with the prescribed goal to maximize the points earned throughout the task. The main goal of the following experiments, then, was to provide evidence of a gain-oriented (as predicted by regulatory fit theory) or loss-avoidance-oriented (as predicted by prospect theory) approach to studying associative information of both positive and negative value.

Further, the effectiveness of participants' strategy implementation may depend on the level of available cognitive resources. Numerous studies have indicated that participants remember more information and are more effective in implementing strategies when information is presented simultaneously (i.e., all at the same time) relative to sequentially (i.e., one at a time; Ariel, Dunlosky, & Bailey, 2009; Dunlosky & Thiede, 2004; Middlebrooks & Castel, 2018; Robison & Unsworth, 2017; Siegel & Castel, 2018b). The mechanisms underlying this benefit of simultaneous over sequential presentation include various factors related to the amount of attentional control during encoding. When information is presented sequentially, there is a higher demand on cognitive resources during encoding, as participants have to store previously presented information in working memory and make decisions about whether to allocate attention to upcoming items. During this presentation format, study time for each item is experimenter-allocated, so it is more difficult for participants to make comparisons across items in order to select specific ones to study. Instead, participants are forced to make item-by-item selection decisions, which may distract them from their overall agenda. However, when information is presented simultaneously, participants can more effectively compare across all information, select items that fit their strategy, and return to restudy these items. During this presentation format, since study time for each item is participant-allocated, participants have greater attentional control during encoding.

In the present study, therefore, participants were tested on their ability to remember visuospatial information containing items of both positive (+25, +20, +15, +10, +5) and negative (-25, -20, -15, -10, -5) values. As participants encoded and recalled the specific value-location associations, they had the choice to utilize their own strategy (i.e., avoid losing points by correctly recalling negative value locations and/or gaining points by correctly recalling positive value locations), all while attempting to maximize their score. In Experiment 4a, selectivity strategies regarding the encoding and retrieval of both positive and negative value locations were investigated through varying presentation format. By utilizing multiple formats in Experiment 4a, we were able to determine how participants' approaches may be influenced under varying levels of cognitive load, with the assumption that participants would more effectively implement their strategy under simultaneous, relative to sequential, presentation format conditions due to the increased amount of cognitive control. It is important to note that although bottom-up processes may have a greater influence on memory performance in the sequential format and top-down processes may have a greater influence in the simultaneous format, both types of processing are undoubtedly present in both formats. That is, while memory performance may be driven primarily by item characteristics when sequentially presented, participants are also likely to engage in strategies to remember items (i.e., opting to study some items and not others, engaging in relational/elaborative processing, etc.). On the other hand, simultaneously presented items may allow for more strategic processing, but individual items may also capture attention and influence later memory. As such, the presentation format may not implicate the exclusive influence of either bottom-up or top-down processes on memory, but rather “tips the scale” towards one type of processing. In Experiment 4b, participants were given the most control over their study decisions by utilizing a self-selected and self-paced VDR paradigm in which participants chose which items they wanted to study and for how long. This experiment allowed us to more directly examine value-based study strategizing and whether participants were more likely to adopt a gain or loss-avoidance approach.

Experiment 4a

In Experiment 4a, participants studied sequentially or simultaneously presented items represented by positive and negative numerical values in a 5 × 5 grid. We were interested in how participants would approach studying these items of varying magnitude and how this might change with both increasing task experience (across multiple trials) and varying levels of attentional resources (by manipulating presentation format). After viewing the study grid, participants were given a memory test in which they were required to place items into their previously viewed locations and were immediately given detailed feedback on their performance, including which positive and negative items were correctly or incorrectly placed and their total score. Participants then repeated this procedure for a total of 8 study-test cycles, with both positive and negative value-location pairs appearing in each grid. Prior research has revealed the importance of examining across multiple trials for assessing strategy optimization coupled with increasing task experience (Ariel & Dunlosky, 2013; Castel, 2008; Middlebrooks et al., 2017; Nelson & Narens, 1990; Siegel & Castel, 2018b; Wong et al., 2019). This motivated the utilization of 8 study-test cycles in the current study as detailed feedback was provided at the end of each study-test cycle so that participants could incorporate it and modify their study strategies on this value-based, goal-directed task. We hypothesized then, that with increased task experience and feedback, participants may engage in more effective encoding strategies and earn more points on each successive trial.

With regards to memory for positive and negative items, we hypothesized that participants would remember higher overall magnitudes (regardless of sign) better than lower magnitudes. Further, we expected that participants would remember positive and negative information equally, consistent with prior work demonstrating that both rewards and punishments may produce equivalent memory enhancement (Castel et al., 2016; Madan et al., 2014; Shigemune et al., 2013). However, this proposed equivalence between negative and positive items may only be the case when participants are able to effectively engage in strategic control processes during encoding (as in the simultaneous presentation format) with a more efficient, top-down directed implementation of strategy. Yet, when resources are more strained during encoding (as in the sequential format), top-down strategic processes may be less effective, and the bottom-up influence of particular item characteristics may have a greater effect on memory performance. One potential hypothesis is that participants' attention may be more captured by negative items, as the losses may loom larger than the gains, in line with prospect theory (Kahneman & Tversky, 1979; Tversky & Kahneman, 1992). On the other hand, as predicted by the regulatory fit theory (Higgins, 2005, 2006; Spiegel et al., 2004, participants in this demanding sequential format may adopt a points-gained approach consistent with the phrasing of task goals to maximize points earned, focusing on and remembering more positive item-locations.

Method

Participants

One-hundred and ten younger adults (84 females, M_{age} = 20.78 years, SD_{age} = 1.50 years, age range: 18-27 years), randomly assigned into two experimental presentation conditions: sequential (n = 55, 45 females, M_{age} = 20.65 years, SD_{age} = 1.68 years, age range: 18-27 years) and simultaneous (n = 55, 39 females, M_{age} = 20.91 years, SD_{age} = 1.29 years, age range: 18-24 years), volunteered to participate in this study. All participants were University of California, Los Angeles (UCLA) undergraduate students who participated for course credit. All participants presented with normal or corrected-to-normal vision, no physical disability, and clinically normal cognitive function.

Materials

The items used as stimuli in this study were designed in Adobe Photoshop and were 10 simple numerical values ranging from -25 to +25, in increments of 5 with no 0-value (Figure 3.5). On the computer screen, each item was 200 × 200 px in size, consisting of text typed in 'Open Sans' bold-weight font, size 106.1 pt, colors: #b80001 (red, negative items) and #02a747 (green, positive items). Each of the presentation orders (sequential) and assigned locations (sequential, simultaneous) of the number-items were pseudorandomized and placed within a 5 × 5 grid with the constraint that no more than two items be present in any row or column (to avoid arbitrarily forming spatial patterns that may aid memory). On the computer screen, the size of each grid was 550 × 550 px (with each cell 110 × 110 px in size). Each item and its number displayed represented the locations' value ranging from -25 (lowest value) to +25 (highest value). This process of adding the number-items to different spatial locations within each study grid was repeated to form eight unique grids each with a different arrangement of the 10 number-

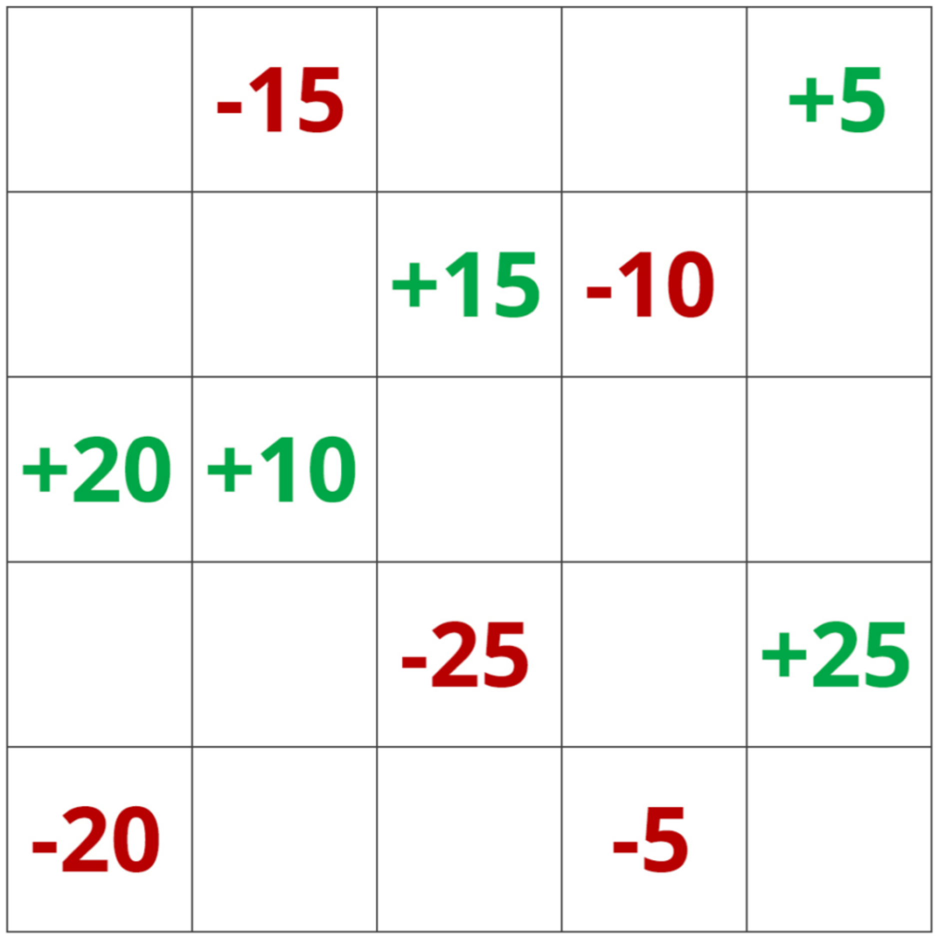

Figure 3.5. An example of a grid that participants may have been presented with during the simultaneous study phase (Experiment 4a). Ten values (five positive, five negative), ranging from -25 to +25 in increments of 5, excluding 0, were randomly assigned a location in the grid. No row or column had more than two values. In Experiment 4a, values were presented sequentially or simultaneously, as seen in this figure.

items (e.g., the -20 item was in a different location on each of the eight trials). In order to prevent against testing effects, the locations of the positive and negative item values within each grid were completely randomized per trial and per participant. That is, while one participant may have been presented with a +25 number-item in the top left cell of the third grid, that same +25 number-item could have been located in the bottom right cell of the seventh grid for a different participant. Positive value items were always green and negative value items were always red. As such, each participant was presented with a different set of eight completely randomized study grids.

Procedure

The procedure used in this study was based upon methodologies used in prior experiments investigating VDR (e.g., Castel et al., 2002; Hayes, Kelly, & Smith, 2013; Robison & Unsworth, 2017) and visuospatial memory (e.g., Chalfonte & Johnson, 1996; Thomas et al., 2012; Siegel & Castel, 2018a, 2018b). Participants were instructed that they would be shown a grid with various numbers placed throughout the grid's cells and to remember the locations of the values for a later test. They were then instructed that the numbers presented within the grid would differ in value, ranging from -25 (lowest value) to +25 (highest value), in increments of 5, excluding 0, indicated by the number of the item in the cell, and that their goal would be to maximize their score (a summation of the points associated with a correctly remembered item). Participants were also instructed that the penalty for misplacing negatively valued number-items would be losing that value from their overall score. For example, if the participant correctly placed a number that was worth +25 points, they would receive +25 points towards their total score. If they correctly placed a number that was worth -10 points, they would *avoid* losing 10 points from their total score. For the sequential presentation format, participants were shown each number-item for 3 s (totaling 30 s for the 10 presented number-items). There was no inter-stimulus interval in between each stimulus presentation as sequentially presented items were shown with each preceding item disappearing directly before the appearance of the next item.

For the simultaneous presentation format, participants were instructed that they would see all 10 number-items within the grid at the same time, while studying the grid for a total of 30 s.

After viewing the grid, participants were shown a brief visual mask for 0.5 s and then a blank 5 × 5 grid with the previously presented number-items in a row underneath. Participants were instructed to replace the items in their previously viewed locations using the computer mouse. If unsure about a value's location, participants were instructed to make a guess at its location. There was no time limit for participants during the testing phase. After participants placed all 10 items, they were given immediate feedback both on their total score (out of 75 points per grid) and the number of points *gained* (by correctly placing positively-valued number-items), *lost* (by incorrectly placing negatively-valued number-items), *failed-to-gain* (by incorrectly placing positively-valued number-items), and *avoided-losing* (by correctly placing negatively-valued number-items). Participants were able to review their feedback for as long as they desired and were instructed to click a button to advance them to the next grid when they felt ready to do so. After choosing to advance, the subsequent trial would commence with participants immediately shown the new grid to study. Participants then repeated this procedure for all eight grids. After conclusion of the eight study-test cycles, the experiment was completed. All materials and procedures used in the current study were approved by the UCLA Institutional Review Board.

Results

Scoring Performance

Participants had the opportunity to score a minimum of -75 points, and a maximum of +75 points, in each study-test cycle. To examine their overall scoring performance with regard to grid number between the two presentation formats, we conducted a 2 (Presentation format:

sequential, simultaneous) × 8 (Grid number: 1, 2, …, 8) mixed analysis of variance (ANOVA) on the overall points-scores. Grid number was included as a factor in this and later analyses as prior research has consistently demonstrated that participants may not optimally execute a value-based study strategy on the first trial, but increase their performance with continued task experience and feedback (Castel, 2008; Middlebrooks et al., 2017; Siegel & Castel, 2018a).

This analysis revealed a significant main effect of presentation format, $F(1, 108) = 47.49$, $p < .001$, $\eta^2 = .31$, with participants in the simultaneous condition scoring relatively higher (M = -0.62, SD = 1.91) than participants in the sequential condition (M = -2.90, SD = 1.55), $t(108) = 6.89$. A significant main effect of grid number was revealed, $F(7, 756) = 2.46$, $p = .02$, $\eta^2 = .02$, but follow-up post-hoc independent samples t-tests with a Bonferroni correction revealed no significant differences (all adjusted ps > .24). Finally, there was no interaction between presentation format and grid number, $F(7, 756) = 0.34$, $p = .94$, $\eta^2 = .003$.

To further examine the potential presence of a linear or quadratic trend between grid number and points-scores despite no significant differences in Bonferroni-corrected t-tests, we conducted a polynomial regression predicting points-scores from grid number averaged between presentation formats (given the lack of format × grid number interaction). The regression model took the following form: Points = $\beta_0 + \beta_1$ (Grid number) + β_2 (Grid number)^2. The continuous predictor grid number was entered into the model as a mean-centered variable. The quadratic term was entered in the model to account for the possibility of a U-shaped relationship between grid number and points score (i.e., potentially higher performance at the beginning and end of the task). The model was a significant predictor of points-scores, $R^2 = .01$, $F(2, 877) = 5.07$, $p = .01$. Both the coefficients for the intercept, $\beta_0 = -1.73$, $p < .001$, and the linear term, $\beta_1 = .17$, $p = .002$, were significant predictors, while the quadratic term coefficient was not, $\beta_2 = -.01$, $p = .83$. This finding indicates a positive linear relationship between grid number and points such that with each increase in grid number the amount of points earned also increased.

Memory Performance

Overall memory performance was assessed by the ability of participants to correctly replace values into the exact target locations in which they were viewed in the prior study phase for each grid. Error magnitude (i.e., how many cells away an item was misplaced) was also examined as a function of grids and item value. These results were largely consistent with those examining correct recall performance described below.

Recall Across Grids. To examine overall memory performance with increasing task-experience when number-items were presented either sequentially or simultaneously and regardless of item value, we conducted a 2 (Presentation format: sequential, simultaneous) × 8 (Grid number: 1, 2, …, 8) mixed ANOVA on the proportion of items correctly placed (out of 10 possible items; Figure 3.6). This analysis revealed a significant main effect of presentation format, $F(1, 108) = 55.29$, $p < .001$, $\eta^2 = .34$, such that participants in the simultaneous condition ($M = .45$, $SD = .12$) correctly replaced a greater proportion of items, as compared to participants in the sequential condition ($M = .29$, $SD = .09$). There was no main effect of grid number, $F(7, 756) = 1.88$, $p = .07$, $\eta^2 = .02$, and no significant interaction between presentation format and grid number, $F(7, 756) = 0.31$, $p = .95$, $\eta^2 = .003$.

Recall by Item Value. To examine overall memory performance as a function of item values between presentation formats, we conducted a 2 (Presentation format: sequential, simultaneous) × 10 (Item value: -25, -20, …, +25) mixed ANOVA on the proportion of items correctly placed (Figure 3.7). Mauchly's Test of Sphericity indicated that the assumption of sphericity had been violated, $\chi^2(44) = 141.36$, $p < .001$; therefore, a Greenhouse-Geisser (ε =

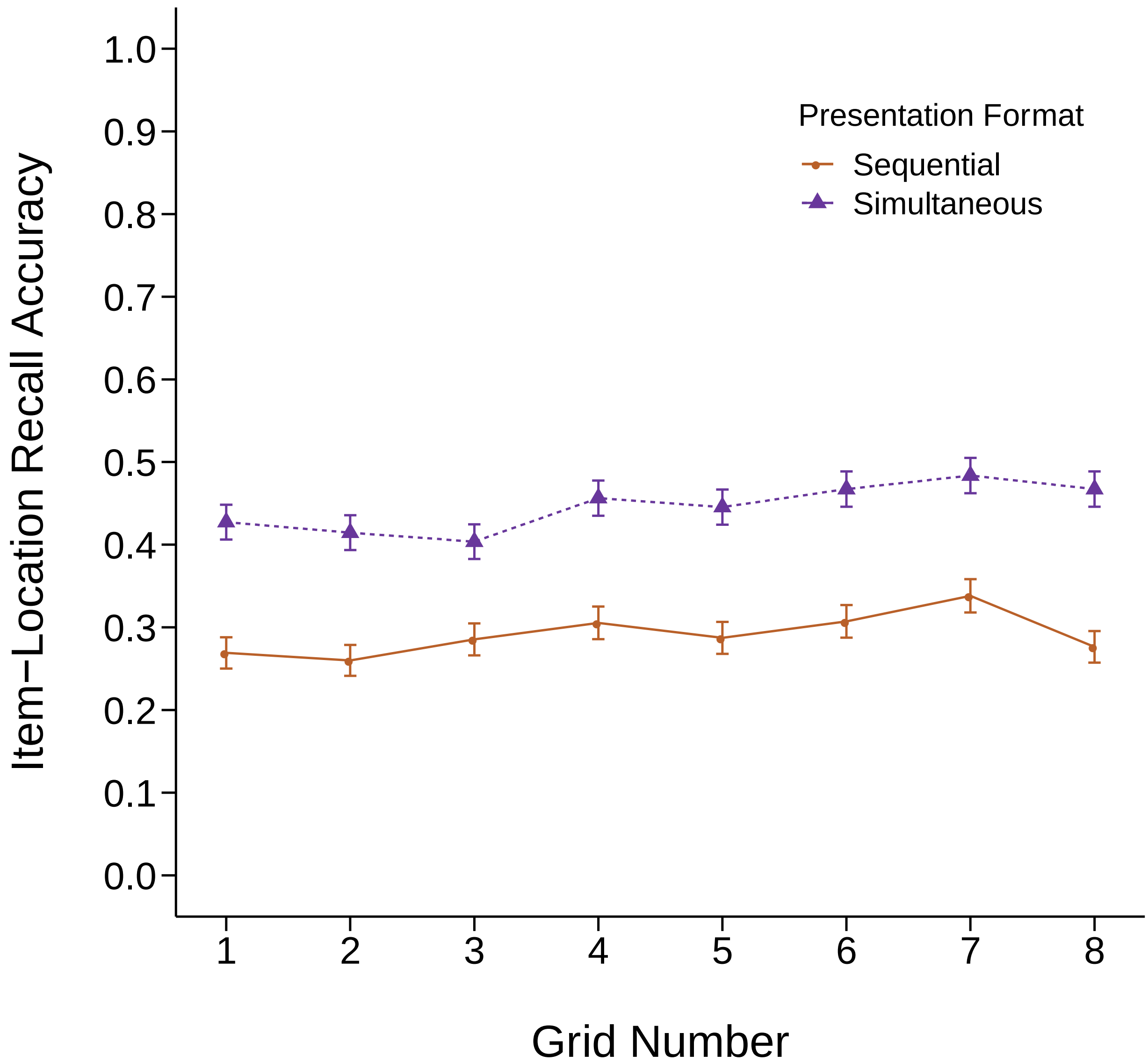

Figure 3.6. The proportion of number-items correctly placed as a function of grid number when presented sequentially or simultaneously in Experiment 4a. Error bars represent ± 1 standard error.

.76) correction was used. The previously described main effect of presentation format was found again, $F(1, 108) = 55.29$, $p < .001$, $\eta_2 = .34$. There was also a significant main effect of item value, $F(6.81, 735.33) = 12.80$, $p < .001$, $\eta^2 = .11$, but no interaction between item value and presentation format, $F(6.81, 735.33) = 1.09$, $p = .37$, $\eta^2 = .01$.

The significant main effect of item value suggests that item value differentially influenced recall accuracy. Assessing the relationship between recall accuracy and item value in an ANOVA framework would require many post-hoc comparisons due to the number of item value pairs reducing our ability to detect any significant differences. Instead, we conducted linear and quadratic model fits for memory performance as a function of item value in a regression framework to examine overall trends. As the previously described ANOVA indicated no significant difference between presentation formats in terms of the relationship between item value and recall, we collapsed across these conditions in the following regressions. Tested linear models were of the following form: Recall Accuracy = $\beta_0 + \beta_1$ (item value). Tested quadratic models were of the following form: Recall Accuracy = $\beta_0 + \beta_1$ (item value) + β_2 (item value)^2. The quadratic model was significant, $R^2 = .81$, $F(2, 9) = 15.35$, $p = .003$, with the following standardized coefficients, $\beta_1 = .66$, $p = .01$, and $\beta_2 = .62$, $p = .01$, indicating a U-shaped relationship between item value and recall accuracy. This result indicates that more extreme values (i.e., those closer to ±25) were better remembered than more median values (those closer to ±5) in both presentation formats.

Recall by Sign. In addition to looking at the overall trends through regression analyses, we were also interested in examining the differences between positive and negative values of the same magnitude for each of our dependent measures (e.g., comparing recall between -25 and +25). While our regression analyses allowed us to determine overall trends, they did not reveal the individual differences between the positive and negative values of the same magnitude. Thus,

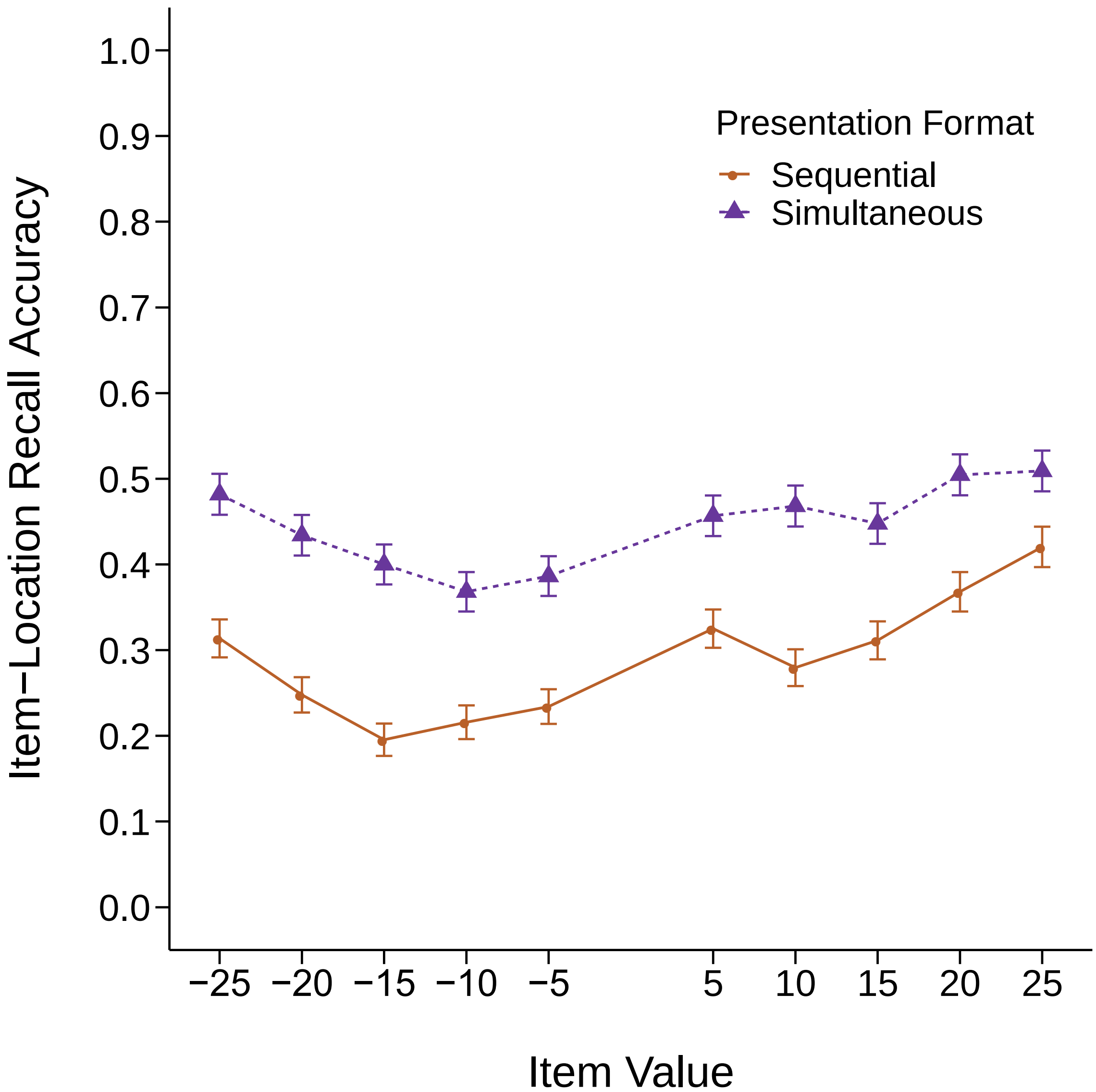

Figure 3.7. The proportion of number-items correctly placed as a function of item value when presented sequentially or simultaneously in Experiment 4a. Error bars represent ± 1 standard error.

to determine whether there was a bias for positive or negative values, we conducted paired-samples *t*-tests with a Bonferroni correction collapsed across grids. For each item magnitude, the positive value (e.g., +20) was recalled more accurately than the corresponding negative value (e.g., -20), adjusted *p*s < .03. Overall, there was higher recall accuracy for positive ($M = .41$, $SD = .15$) relative to negative ($M = .33$, $SD = .15$) items, $t(109) = 5.65$, $p < .001$.

Response Order by Item Value

Another way of examining participants' strategies was to examine the order in which they output items. If a participant's strategy was to remember negative or positive items first, then this would likely be reflected in their recall order, with those items placed earlier in the recall phase (Middlebrooks & Castel, 2018). In the context of the current task, as participants were required to place all 10 items before proceeding to the next trial, we were able to analyze the order in which information was outputted and whether this varied as a function of presentation format.

To examine the order in which they replaced each item into the test grid, we conducted a 2 (Presentation format: sequential, simultaneous) × 10 (Item value: -25, -20, …, +25) mixed ANOVA on output order (Figure 3.8). Output order ranged from 1 (the first item placed during the recall phase) to 10 (the last item placed during the recall phase) with lower scores indicating an earlier output and higher scores indicating a later output. Given that participants were able to move items around in the grid at their discretion (i.e., an item was not "locked in" after its first placement), we used the final output position for each item. For example, if participants placed all 10 items and then shifted the item that they had placed fourth to a new location, that item would then become the last item placed and receive an output order score of 10. This output order variable was used as the outcome variable in the following analyses. Mauchly's Test of Sphericity indicated that the assumption of sphericity had been violated, $\chi^2(44) = 342.79$, $p < .001$; therefore, a Greenhouse-Geisser ($\varepsilon = .505$) correction was used. There was a significant main effect of item value, $F(4.55, 490.93) = 19.66$, $p < .001$, $\eta^2 = .15$, and a significant

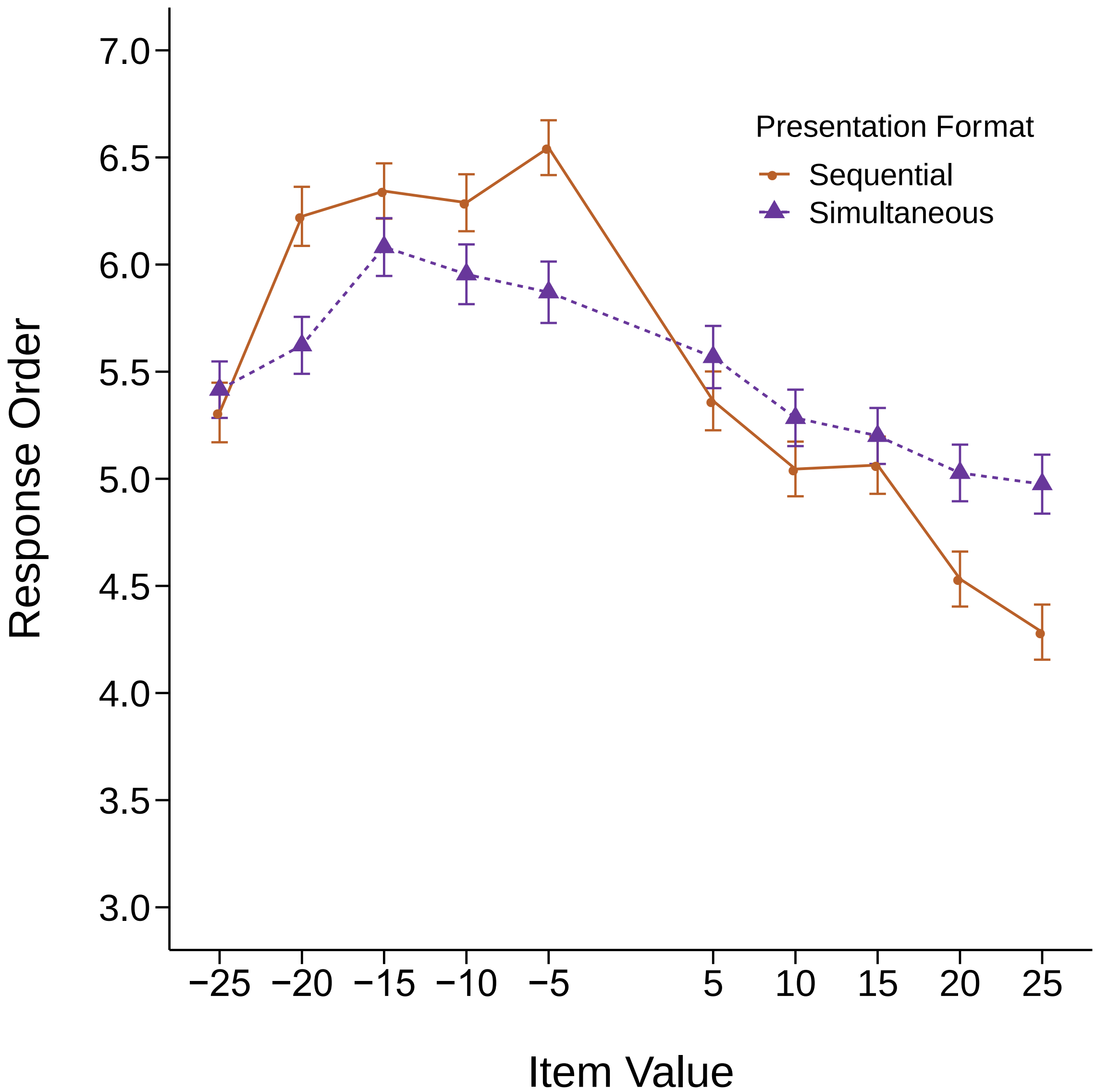

Figure 3.8. Mean response order for number-items during the testing phase as a function of item value when presented sequentially or simultaneously in Experiment 4a. All error bars represent ± 1 standard error.

interaction between item value and presentation format, $F(4.55, 490.93) = 2.91$, $p = .02$, $\eta_2 = .02$.

Given the significant interaction, the relationship between item value and response order was analyzed separately within each presentation format using the same linear and quadratic models described in the recall by item value section. In both presentation formats, a significant quadratic relationship was found indicating an inverted U-shape relationship between item value and response order, $R^2 = .84$, $F(2, 9) = 18.48$, $p = .002$, and $R^2 = .81$, $F(2, 9) = 15.55$, $p = .003$, for the sequential and simultaneous formats, respectively. In each model, both the linear ($\beta_{Seq} = -.77$, $p = .001$ and $\beta_{Sim} = -.73$, $p = .003$) and quadratic ($\beta_{Seq} = -.50$, $p = .01$ and $\beta_{Sim} = -.53$, $p = .01$) standardized coefficients were significant. As such, participants in both presentation formats placed items of higher magnitude (regardless of sign) earlier in the test phase than items of lower magnitude.

To determine if response order varied as a function of sign (i.e., between negative and positive items), for items presented sequentially, response orders for items of all magnitudes were significantly different compared to their respective counterparts (adjusted *p*s < .001), with positively valued items placed before negatively-valued items. For items presented simultaneously, items of value +15 were placed earlier than those valued -15 ($p < .001$), while the remaining items of magnitudes 5, 10, 20, and 25 did not differ in response order between positive and negative values (adjusted *p*s > .09). Further, a 2 (Presentation format: sequential, simultaneous) × 2 (Sign: positive, negative) mixed ANOVA on response order revealed a significant interaction, $F(1, 108) = 5.61$, $p = .02$, $\eta^2 = .04$. Follow-up paired-samples *t*-tests to examine response order differences within each presentation format were conducted. For the sequential format, positive items ($M = 4.86$, $SD = 0.81$) were replaced earlier in the testing phase than negative items ($M = 6.14$, $SD = 0.81$), $t(54) = 5.90$, $p < .001$. This was also the case for the simultaneous format ($M_{Pos} = 5.21$, $SD_{Pos} = 0.76$, $M_{Neg} = 5.79$, $SD_{Neg} = 0.76$), $t(54) = 2.84$, $p = .01$. This indicates that while both presentation formats resulted in earlier placement of positive relative to negative items overall, this difference was larger in the sequential relative to simultaneous format.

Discussion

Simultaneously presented information was more accurately recalled compared to information presented sequentially which led to higher point totals in the simultaneous presentation format. While there was better memory for extreme values (e.g., ±25) in both presentation formats, participants more accurately recalled positive items relative to negative items, suggesting a surprising positivity bias for recall accuracy. Examining response order as an indicator of participants' strategy use indicated that all participants attempted to place positive items before negative items, although this preference appeared to be greater for sequentially presented items. This may have been due to participants attempting to recall as many positive items as they could, thus evidencing a positivity-first, points-gained approach for the more demanding sequential presentation format that reduces top-down influence relative to the simultaneous presentation format. Overall, these results demonstrate preferential treatment of positive items relative to negative items under varying degrees of attentional load during encoding despite their equivalent influence on participants' total score. This evident points-gained approach was further explored in Experiment 4b in which participants had complete control over their study choices.

Experiment 4b

The resulting positivity bias from Experiment 4a prompted Experiment 4b to further investigate the selective control strategies being employed by participants for the prior sequential and simultaneous visuospatial memory tasks. As demonstrated in Experiment 4a, participants selectively encoded positive value locations with the highest priority over negative value locations; however, better understanding the strategies that participants utilized to selectively encode these important items required the implementation of a self-regulated study task. Self-regulated paradigms allow participants to more efficiently implement study strategies by giving them the choice to allocate attention and study time to particular items and effectively ignore other items (Castel, Murayama, Friedman, McGillivray, & Link, 2013; Dunlosky, Ariel, & Thiede, 2011; Middlebrooks & Castel, 2018). As such, participants in Experiment 4b not only chose which value-location associations to study during the encoding-phase, but also the duration and frequency of study.

By allowing participants to control their study choices, we could directly examine whether the positivity bias observed in Experiment 4a was more heavily influenced by an overt, top-down strategy enacted by participants or bottom-up, item characteristics. If a pattern similar to Experiment 4a is observed, then it can be inferred that participants actively and selectively attend to and encode positive items over negative items. However, if this difference is eliminated and positive and negative items are remembered at an equivalent rate, then the results of Experiment 4a can be attributed to the bottom-up, attention capturing nature of positive items, which may be attenuated when more strategic control is afforded to participants during encoding, especially in the self-regulated task of the current study where participants would be expected to require less time to implement strategies when they have full control over the presentation and study of items.

Method

Participants

A new group of fifty-four younger adults (43 females, M_{age} = 20.44 years, SD_{age} = 1.51 years, age range: 18-27 years) volunteered to participate in Experiment 4b. Three participants were excluded from further analyses due to procedural error and missing data (n = 2) and outlying age (n = 1, age: 42 years). As previously in Experiment 4a, all younger adults were UCLA undergraduate students who participated for course credit. All younger adult participants presented with normal or corrected-to-normal vision, no physical disability, and clinically normal cognitive function. None of the participants in Experiment 4a participated in Experiment 4b.

Materials

The items used as stimuli in this study were the same as those used previously in Experiment 4a (i.e., 10 red and green, negatively- and positively valued number-items, respectively). As in the previous experiment, the 10 number-items, ranging from -25 to +25 in increments of 5 with no 0-value, were randomly placed within a 5 × 5 grid to form the 8 unique grids used as the stimuli in this experiment.

Procedure

Whereas participants in Experiment 4a were shown study grids with number-items presented either sequentially or simultaneously for 30 s, participants in Experiment 4b were shown a blank grid for 30 s that was supported by interactive buttons representing each of the 10 to-be-studied number-items ranging from -25 to +25 (Figure 3.9). Participants were instructed to choose the items to study for as long as they wanted, by pressing the buttons which displayed the corresponding number item and its associated location on the grid, for as long as the participant chose to view it. Participants were thus able to control which number-items they studied, as well as for how long to study each item (i.e., *self-regulated learning*), and were allowed to view each number item as many times as they desired during the study phase. These

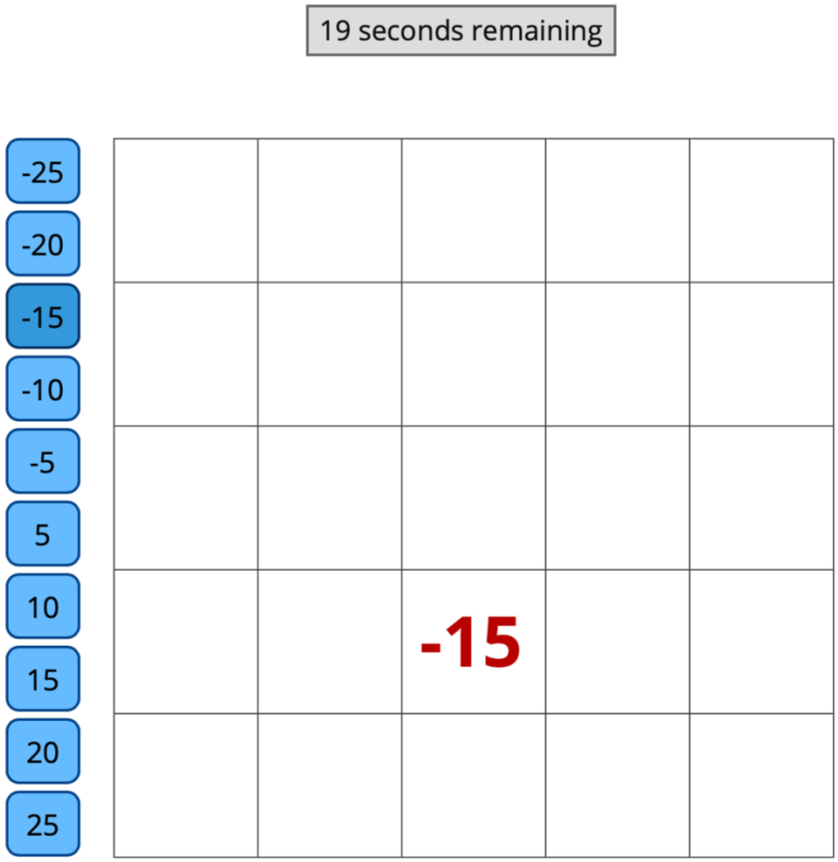

Figure 3.9. An example of a grid that participants may have been presented with during the self-regulated study phase (Experiment 4b). Ten values (five positive, five negative), ranging from -25 to +25 in increments of 5, excluding 0, were randomly assigned a location in the grid. No row or column has more than two values. Participants interacted with the buttons to the left of the grid to control which number-items they studied, as well as for how long each value was studied for with one item present in the grid at any point.

interactive number-item value buttons were vertically displayed on the screen directly to the left of the grid, with the presentation of the first, top-most values being counter-balanced across alternating grids. That is, participants would either begin with +25, +20, +15, … or -25, -20, -15,

… as the presented top-most values for the button display, which were then flipped accordingly to the opposing format in an alternating fashion for each of the eight study grids.

Apart from the participant having full control over which randomly placed stimuli within the grid were studied, as well as the length of time they studied that item for, the procedures for Experiment 4b were identical to those of Experiment 4a: participants were told to maximize their overall score (out of 75 points), and were shown a brief visual mask for 0.5 s before being asked to replace the items in their previously studied locations during the 30 s self-regulated study period. Participants were given the same immediate feedback on their performance, as in Experiment 4a, after completing each study-test grid and repeated the process for all eight study-test cycles.

Results

Scoring Performance

As in Experiment 4a, participants had the opportunity to score a minimum of -75 points, and a maximum of +75 points, in each study-test cycle. To examine their overall scoring performance with regard to grid number, we conducted a 1 (Presentation format: self-regulated) × 8 (Grid number: 1, 2, …, 8) repeated-measures ANOVA on the overall points-scores. This analysis revealed a significant main effect of grid number, $F(7, 371) = 2.58$, $p = .01$, $\eta^2 = .05$. Post-hoc paired-samples *t*-tests with a Bonferroni correction indicated that scores were higher on Grid 8 ($M = -1.10$, $SD = 3.07$) relative to Grid 1 ($M = -2.96$, $SD = 3.15$), $t(53) = 3.43$, $p = .03$, and Grid 2 ($M = -2.94$, $SD = 2.91$), $t(53) = 3.38$, $p = .04$. No other comparisons were significant, adjusted *p*s > .48. This suggests that participants scored more points at the end of the task relative to the beginning.

Similar to Experiment 4a, we conducted the same polynomial regression predicting points-scores from grid number to follow-up on the significant main effect. The model was a significant predictor of points-scores, R^2 = .02, F(2, 429) = 5.32, p = .01. Both the coefficients for the intercept, β_0 = -2.21, p < .001, and the linear term, β_1 = .21, p = .001, were significant predictors, while the quadratic term coefficient was not, β_2 = -.0004, p = .99. Consistent with Experiment 4a, this finding indicates a positive linear relationship between grid number and points such that with each increase in grid number the amount of points earned also increased.

Memory Performance

Memory performance for Experiment 4b was assessed in the same way that it was for Experiment 4a by investigating the ability of participants to correctly replace items into the exact target locations in which they were viewed in the prior study phase for each grid. This was first examined across grids and then as a function of item value.

Recall Across Grids. To examine overall memory performance with increasing task-experience in the self-regulated presentation format, we conducted a 1 (Presentation format: self-regulated) × 8 (Grid number: 1, 2, …, 8) repeated-measures ANOVA on the proportion of items correctly placed. This analysis revealed no main effect of grid number, F(7, 371) = 1.82, p = .08, η^2 = .03, suggesting that a consistent amount of information was recalled across trials regardless of item value.

Recall by Item Value. To examine overall memory performance for each associated item value of the individual number-items in the self-regulated presentation format, we conducted a 1 (Presentation format: self-regulated) × 10 (Item value: -25, -20, …, +25) repeated-measures ANOVA on the proportion of items correctly placed (Figure 3.10). Mauchly's Test of Sphericity indicated that the assumption of sphericity had been violated, χ^2(44) = 248.19, p <

.001; therefore, a Greenhouse-Geisser (ε = .419) correction was used. There was a significant main effect of item value, $F(3.77, 199.76) = 8.12$, $p < .001$, $\eta^2 = .13$.

Similar to Experiment 4a, we conducted linear and quadratic model fits for memory performance as a function of item value using a regression framework to avoid many post-hoc comparisons. Tested linear models were of the following form: Recall Accuracy = $\beta_0 + \beta_1$ (item value). Tested quadratic models were of the following form: Recall Accuracy = $\beta_0 + \beta_1$ (item value) + β_2 (item value)^2. The quadratic model was significant, $R^2 = .97$, $F(2, 9) = 112.90$, $p < .001$, with both significant linear, $\beta_1 = .25$, $p = .01$, and quadratic, $\beta_2 = .95$, $p < .001$, standardized coefficients indicating a U-shaped relationship between item value and recall accuracy.

Recall by Sign. We followed a similar procedure to that of Experiment 4a for examining the differences between positive and negative values of the same magnitude for each of our dependent measures. To determine whether there was a bias for positive or negative values, we conducted paired-samples *t*-tests with a Bonferroni correction. In contrast to Experiment 4a, there was no difference in recall accuracy between positive and negative items for any of the magnitudes, adjusted *p*s > .30. Further, there was no difference in overall recall performance for positive ($M = .34$, $SD = .15$) and negative ($M = .30$, $SD = .14$) items, $t(53) = 1.26$, $p = .21$.

Response Order by Item Value

As in Experiment 4a, participants were allowed to replace items in the test grid in any order. To examine the order in which they replaced each item into the test grid, we conducted a 1 (Presentation format: self-regulated) × 10 (Item value: -25, -20, …, +25) repeated-measures ANOVA on response order (Figure 3.11). Mauchly's Test of Sphericity indicated that the assumption of sphericity had been violated, $\chi^2(44) = 335.79$, $p < .001$; therefore, a Greenhouse-

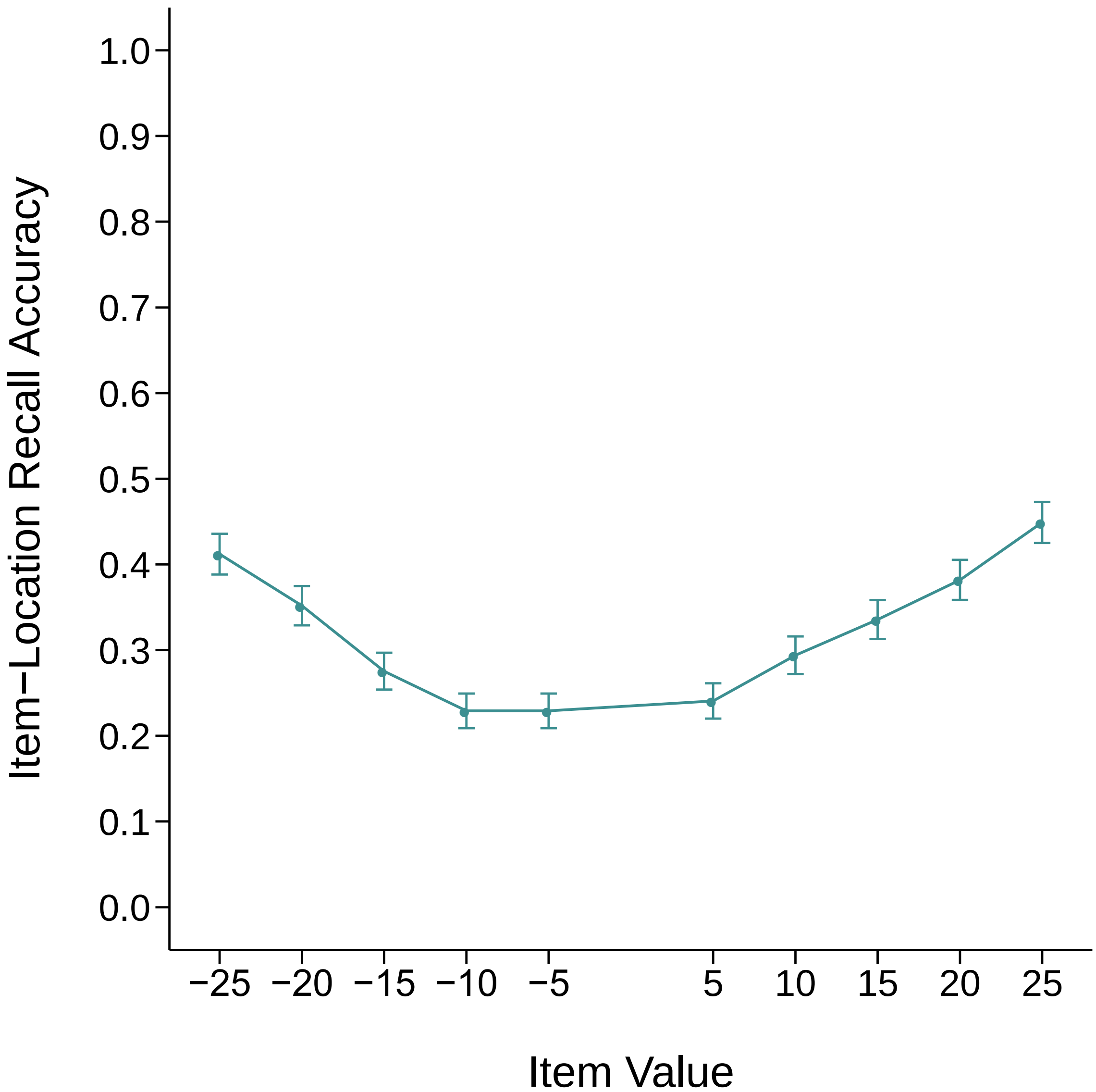

Figure 3.10. The proportion of number-items correctly placed as a function of item value when presented in the self-regulated study format in Experiment 4b. Error bars represent ± 1 standard error.

Geisser (ε = .357) correction was used. There was a significant main effect of item value, $F(3.22, 170.40) = 17.01$, $p < .001$, $\eta^2 = .24$. To examine the overall trend, linear and quadratic models were fitted to the data. The quadratic model was significant, $R^2 = .97$, $F(2, 9) = 99.60$, $p < .001$, with significant linear, $\beta_1 = -.31$, $p = .003$, and quadratic, $\beta_2 = -.93$, $p < .001$, standardized coefficients indicating an inverted U-shaped relationship between item value and response order. As such, higher magnitude positive and negative items were both replaced earlier on in the testing phase relative to lower magnitude items. With regards to the particular sign, Bonferroni-adjusted paired-samples *t*-tests between items of the same magnitude indicated no significant differences in individual item values, adjusted *p*s > .19. Overall, however, there was a significant difference in the response order of positive ($M = 5.25$, $SD = 0.91$) relative to negative ($M = 5.75$, $SD = 0.91$) items, $t(53) = 2.03$, $p = .047$, suggesting that positive items were replaced earlier than negative items.

Study Frequency

With the implementation of the self-regulated study paradigm, we were also able to examine the number of times participants studied each item as a function of its value. Study frequency was measured by averaging the number of study visits per item, per grid throughout the self-regulated study task. This was possible to do since the self-regulated study task gave participants control over (a) which items they studied, (b) the order in which they were studied, (c) for how long to study each item, and (d) how many times to study (or not study) each item. We conducted a 1 (Presentation format: self-regulated) × 8 (Grid number: 1, 2, …, 8) repeated-measures ANOVA on study frequency and found no main effect of grid number, $F(7, 371) = 0.69$, $p = .68$, $\eta^2 = .013$, indicating that participants visited (studied) relatively the same number of items during each of the eight self-regulated study phase grids.

To determine the effects of item value on study frequency, we conducted a 1 (Presentation format: self-regulated) × 10 (Item value: -25, -20, …, +25) repeated-measures ANOVA on study frequency (Figure 3.12). Mauchly’s Test of Sphericity indicated that the

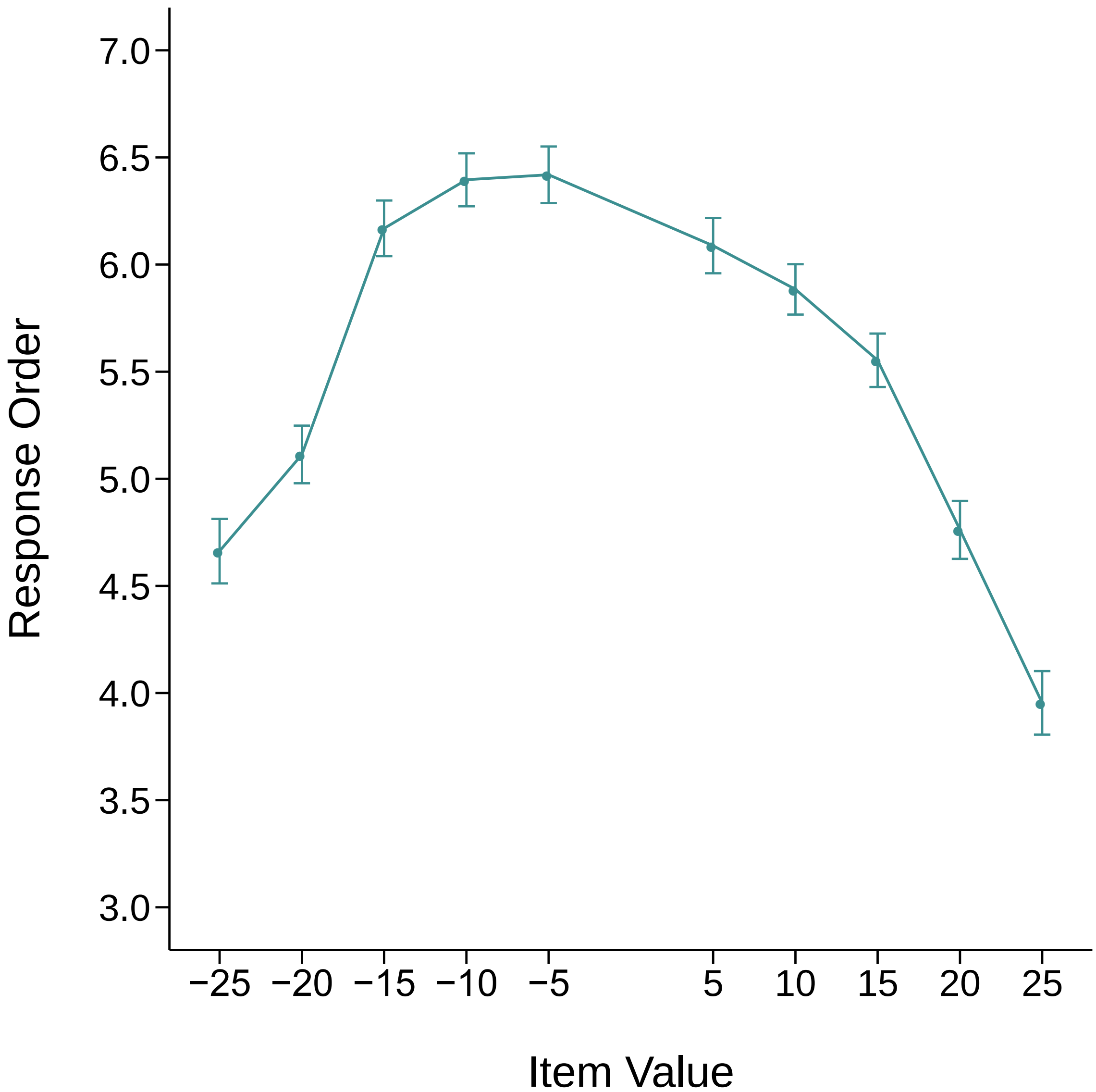

Figure 3.11. Mean response order for values during the testing phase as a function of item value when presented in the self-regulated study format in Experiment 4b. All error bars represent ± 1 standard error.

assumption of sphericity had been violated, $\chi^2(44) = 841.24$, $p < .001$; therefore, a Greenhouse-Geisser ($\varepsilon = .276$) correction was used. We found a significant main effect of item value, $F(2.49, 131.71) = 21.80$, $p < .001$, $\eta^2 = .29$. Linear and quadratic models were fitted to examine overall trends. The quadratic model was significant, $R^2 = .92$, $F(2, 9) = 40.25$, $p < .001$, with both significant linear, $\beta_1 = .37$, $p = .01$, and quadratic, $\beta_2 = .88$, $p < .001$, standardized coefficients indicating a U-shaped relationship between item value and study frequency. This suggests that participants studied higher magnitude items more frequently than lower magnitude items.

In terms of which sign was favored, Bonferroni-adjusted paired-samples *t*-tests indicated that the +25 and +20 items were studied more frequently than the -25 and -20 items, $t(53) = 3.26$, $p = .01$, and $t(53) = 2.83$, $p = .04$, respectively. There was no difference in study frequency between the other magnitudes, adjusted *p*s > .05. Overall, on average, positive items were studied more frequently ($M = 2.12$, $SD = 0.81$) than negative items ($M = 1.73$, $SD = 0.71$), $t(53) = 2.85$, $p = .01$.

Study Time

We were also able to examine the average length of time spent on each item when it was selected. Study time was measured by averaging the number of seconds that each item was viewed for, per study visit. We conducted a 1 (Presentation format: self-regulated) × 8 (Grid number: 1, 2, …, 8) repeated-measures ANOVA on study frequency. Mauchly's Test of Sphericity indicated that the assumption of sphericity had been violated, $\chi^2(44) = 54.81$, $p < .001$; therefore, a Greenhouse-Geisser ($\varepsilon = .790$) correction was used. We found a significant main effect of grid number, $F(5.53, 293.25) = 3.29$, $p = .01$, $\eta^2 = .06$. Follow-up paired-samples *t*-tests with a Bonferroni correction indicated that participants' spent less time on each study visit on Grid 7 ($M = 1.16$, $SD = 0.43$) relative to Grid 1 ($M = 1.41$, $SD = 0.56$), $t(53) = 3.65$, $p = .02$, and Grid 2 ($M = 1.40$, $SD = 0.52$), $t(53) = 3.86$, $p = .01$. No other comparisons were significant, adjusted *p*s > .11.

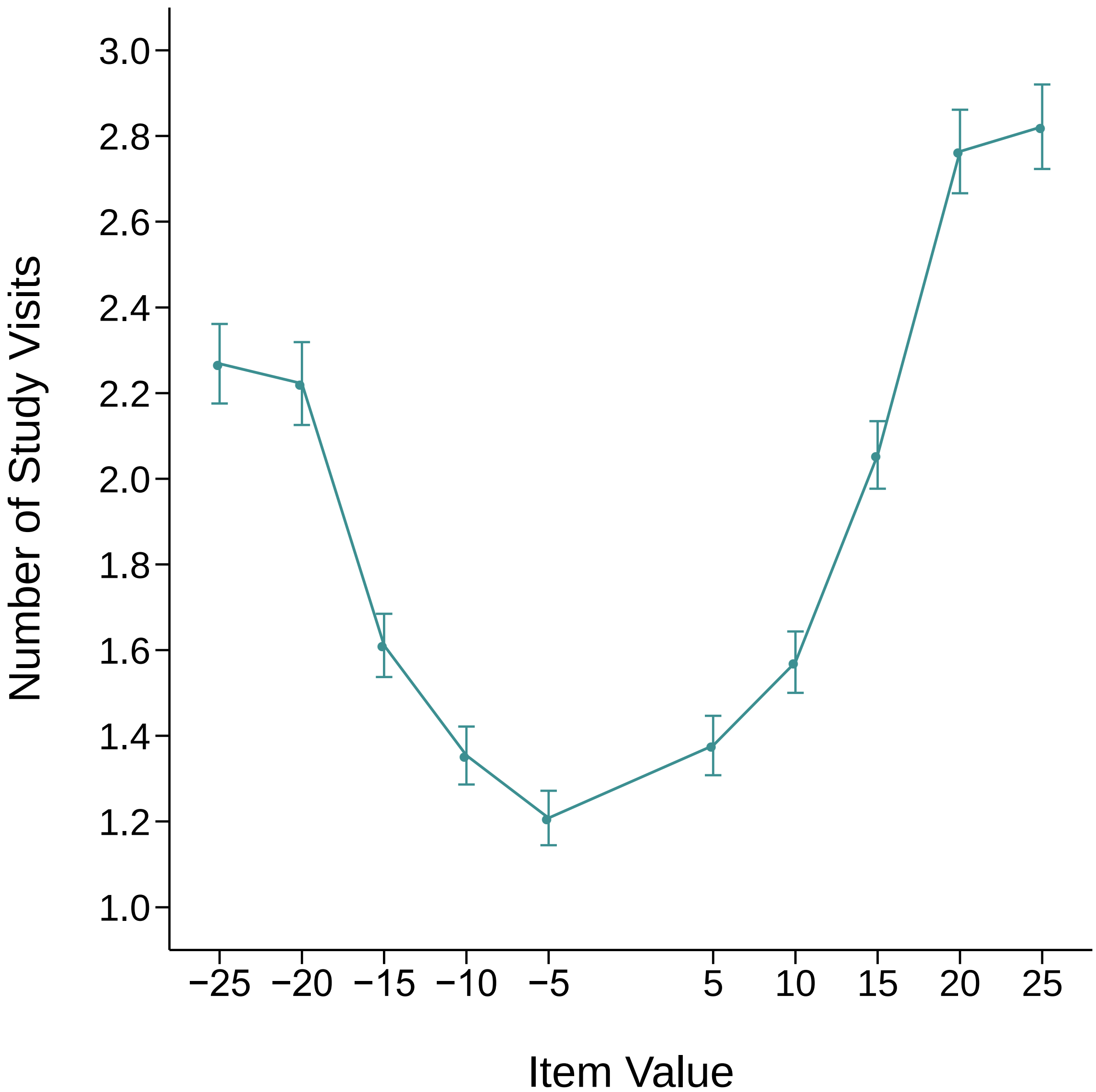

Figure 3.12. Mean number of study visits (frequency) as a function of item value for self-regulated value-location associations in Experiment 4b. All error bars represent ± 1 standard error.

We conducted a 1 (Presentation format: self-regulated) × 10 (Item value: -25, -20, …, +25) repeated-measures ANOVA on study time (Figure 3.13). Mauchly's Test of Sphericity indicated that the assumption of sphericity had been violated, $\chi_2(44) = 345.69$, $p < .001$;

therefore, a Greenhouse-Geisser (ε = .498) correction was used. There was no main effect of item value, $F(4.48, 237.31) = 2.19$, $p = .06$, $\eta^2 = .04$, suggesting that study time did not differ as a function of item value. When comparing between positive and negative items of the same magnitude, no significant differences were found, as indicated by the Bonferroni-adjusted paired-samples *t*-tests, adjusted *p*s > .67. Overall, on average, positive ($M = 1.34$, $SD = 0.42$) and negative ($M = 1.26$, $SD = 0.51$) items were studied for the same amount of time per study visit, $t(53) = 1.13$, $p = .26$.

Discussion

For information studied in the self-regulated presentation format, we found consistently higher recall accuracy for the high-end positive and negative items, compared to the low-end positive and negative items. The positivity preference exhibited in Experiment 4a was not present in participants' memory performance in this experiment despite participants replacing positive items earlier on during testing. However, there was a positivity preference when examining participants' study choices. While higher magnitude items were studied more frequently than lower magnitude items in general, there was an additional increase in study frequency for the most positive (i.e., the +20 and +25) items relative to the most negative (i.e., -20 and -25) items. This positivity preference in study frequency, however, did not manifest in more study time per individual study visit for positive items. Contrary to the differences in recall for positive over negative items found in Experiment 4a, these null differences in recall for positive and negative items in Experiment 4b may be due to an implicit averaging of the points-gained and loss-avoidance approaches, especially when more cognitive resources are available frequency for the most positive (i.e., the +20 and +25) items relative to the most negative (i.e., -20 and -25) items. This positivity preference in study frequency, however, did not manifest in

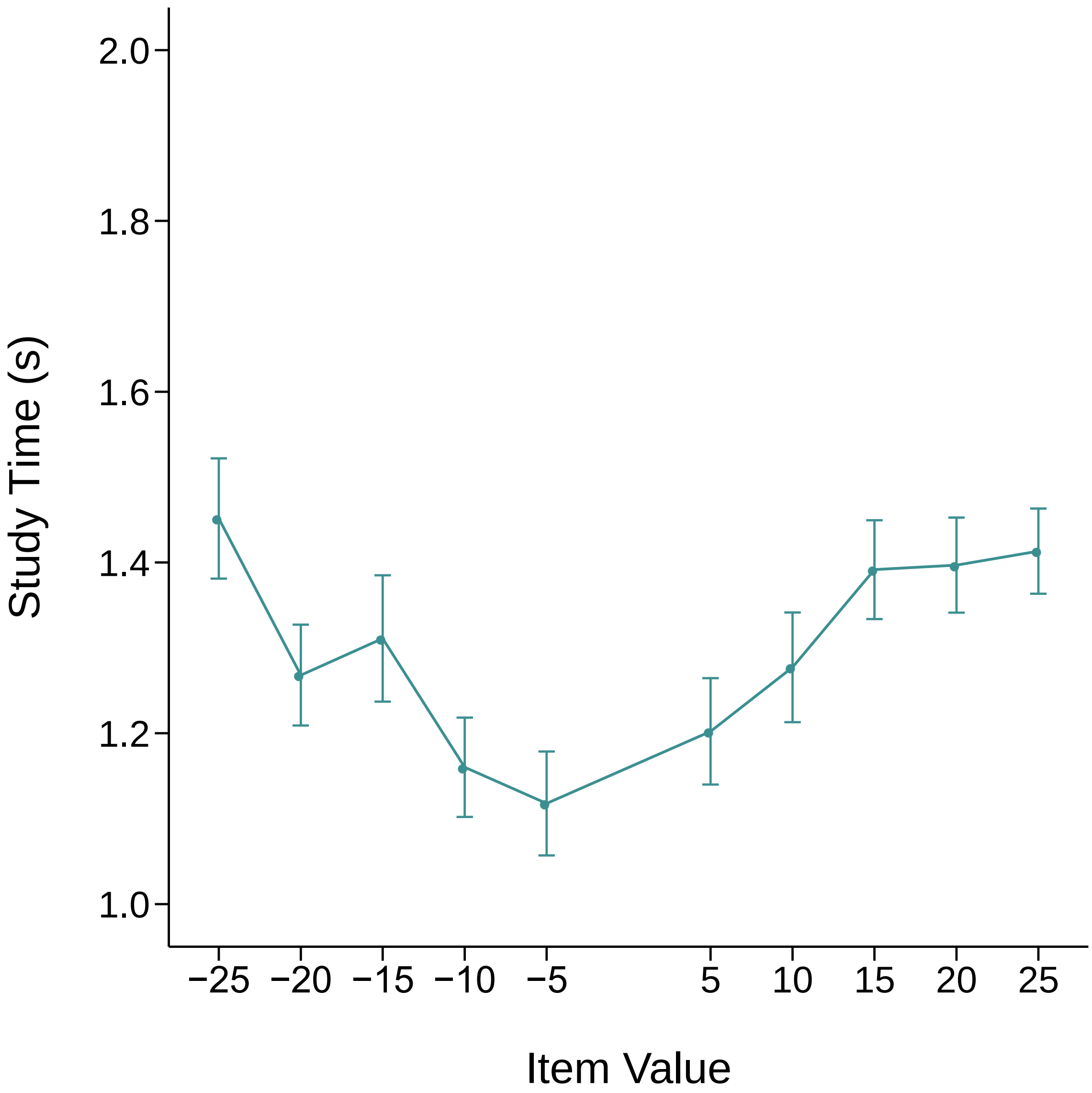

Figure 3.13. Mean number of seconds spent studying values per visit during the testing phase as a function of item value when presented in the self-regulated study format in Experiment 4b. All error bars represent ± 1 standard error.

more study time per individual study visit for positive items. Contrary to the differences in recall for positive over negative items found in Experiment 4a, these null differences in recall for positive and negative items in Experiment 4b may be due to an implicit averaging of the points-gained and loss-avoidance approaches, especially when more cognitive resources are available

General Discussion of Experiments 4a and 4b

Prior research investigating the role of value-directed remembering in the visuospatial domain established that items with a higher associated value were consistently better remembered compared to items with a lower value (Ariel et al., 2015; Castel et al., 2002; Middlebrooks et al., 2017; Siegel & Castel, 2018a; Siegel & Castel, 2018b). However, the opportunity to lose points in this kind of paradigm has not been well researched and may have critical implications for participants' study strategies when information varies in importance. Under various presentation formats in Experiment 4a, participants adopted a selective strategy by remembering higher magnitude items over lower magnitude items. Yet, there was a positive memory preference in both presentation formats despite negative items having an equal influence on total scores. This focus on gaining points (as compared to avoiding losing points) was further explored in Experiment 4b, where we were able to directly measure participants' study-time allocation given the employed experimental paradigm. In essence, the simultaneous presentation format of Experiment 4a and the interactive presentation format of Experiment 4b are both self-regulated study formats; however, participants in the simultaneous presentation format of Experiment 4a are presented with all stimuli at once within the visuospatial domain while participants in Experiment 4b only saw one item at a time (i.e., more similar to the sequential presentation format of Experiment 4a). As such, the amount of perceived visual information that occurred all-at-once was different during the study phases of Experiments 4a and 4b, which could have had downstream influences on the strategies that participants used to allocate study time to items of varying value. When more control was afforded to participants during study, their recall suggested a more measured approach, with equivalent memory for positive and negative items. This occurred even though participants studied positive items more frequently and output them earlier during the testing phase. Perhaps one explanation for the positivity bias during the self-regulated study phase of Experiment 4a not improving memory performance is the labor-in-vain effect, which suggests that increasing self-paced study time does not subsequently result in higher memory performance (Nelson & Leonesio, 1988). Though participants in Experiment 4b were not found to have studied positive items longer than corresponding negative items, highly positive information was studied more frequently, for the same amount of time per study visit, compared to the other to-be-learned positive and negative information. An alternative explanation may then is that the generally more arousing nature of negative information may have automatically captured participants' attention, compared to the less salient positive information, as found in an abundance of prior work (Bowen, Kark, & Kensinger, 2018; Carretié, Hinojosa, Martín-Loeches, Mercado, & Tapia, 2004; Clewett & Murty, 2019; Eastwood, Smilek, & Merikle, 2003; Hochman & Yechiam, 2011; Kensinger & Corkin, 2003a, 2003b; Mickley & Kensinger, 2008; Mickley Steinmetz & Kensinger, 2009; Siegel, Graup, & Castel, 2020). Participants may have therefore been required to utilize their top-down strategic control by allocating more frequent study visits to positive items to match the salience of the corresponding negative items, producing equivalent memory for items of these two signs.

Additionally, this observed positivity preference may be driven by the regulatory fit theory (Higgins, 2005, 2006; Spiegel et al., 2004), as the phrasing of the prescribed task goals for participants to maximize their overall score may have influenced their experience of value within the current study. The results we observe seem to be more supported by the regulatory fit theory than by prospect theory when attentional resources are more strained during encoding, in that the type of goal that participants pursued was primarily a points-gained approach (i.e., a promotion-focused goal orientation; Cesario et al., 2007; Higgins, 2006). In sum, when presented with information varying in positive and negative value, participants in this task adopted a points-gained approach, focusing on studying and remembering positive information over equally valued negative information.

Given that participants could selectively attend to and remember higher magnitudes relative to lower magnitudes, this finding replicates previous work suggesting participants are effective in prioritizing important associative information, even under attentionally-demanding conditions (Ariel et al., 2015; Castel et al., 2002; Siegel & Castel, 2018b). Such selectivity is emphasized by participants' study decisions in Experiment 4b, with higher magnitudes receiving more study visits (and thus more total study time) despite equivalent study time per visit with lower magnitudes. As such, these results add further evidence that participants are effective in prioritizing important information, consistent with a large body of work demonstrating preserved selectivity with various materials like unrelated word pairs (Ariel et al., 2015), name-face pairs (Hargis & Castel, 2017), medication side effects (Hargis & Castel, 2018), and item-location pairs (Siegel & Castel, 2018b), and under varying degrees of cognitive ability, like healthy aging (Castel et al., 2002; Hayes et al., 2013; Siegel & Castel, 2018a), Alzheimer's disease (Castel et al., 2009), attention-deficit/hyperactivity disorder (Castel et al., 2011), and different working memory capacities (Griffin, Benjamin, Sahakyan, & Stanley, 2019; Middlebrooks et al., 2017; Miller, Gross, & Unsworth, 2019; Robison & Unsworth, 2017).

Despite this ability to prioritize high magnitude over low magnitude information, participants' strategy use was indeed flawed, as evidenced by the explicit focus on high-magnitude *positive* information. Prior to experimentation, we expected that participants would remember positive and negative information equally, consistent with prior work demonstrating that both rewards and punishments may produce equivalent memory enhancement (Castel et al., 2016; Madan & Spetch, 2012; Madan et al., 2014; Shigemune et al., 2013). This would represent the optimal strategy in the task, as both positive *and* negative items equally contributed to participants' total score. In contrast, participants in the current study adopted a less-than-optimal strategy by favoring positive items.

The findings of the current study also appear to be contradictory to prior work using sequential encoding conditions with rewards and punishments that did not find a positivity bias (Castel et al., 2016; Shigemune et al., 2013). One potential reason for the discrepancy between results may be the difficulty of the task in the current study. Although words were required to be bound to specific locations in Shigemune et al. (2013) and dollar values to faces in Castel et al. (2016), encoding difficulty in the current visuospatial binding task may have been greater for three potential reasons. First, the amount of potential locations in the current task (25 in the 5 × 5) grid provided for a larger set of responses and lower chance performance than Shigemune et al. (2013) in which location options were either left or right. Secondly, the confusability of items in the current study was quite high, as items only differed in terms of their color (green for positive items and red for negative items) and magnitude (-25 to +25 in increments of five). As such, discriminating between individual items may have been more difficult due to their perceptual and conceptual similarity, and subsequent item-location associative memory more challenging (e.g., "was it +25 in cell (1, 4) or +20 in cell (1, 5)?") than when items were distinct, unrelated words paired to a left or right spatial location (e.g., "was it BANK-left or BANK-right?") in Shigemune et al. (2013) or when items were distinct faces paired with dollar values (e.g., “was it the woman with long hair who owed me $100 or the bald man?”). Thirdly, the current study used a free recall paradigm in which item-location associations needed to be retrieved entirely by the participant, in contrast to Shigemune et al. (2013) who used a recognition test and Castel et al. (2016) who used cued-recall testing. Free recall may be a more demanding process than cued recall or recognition as more encoding specificity is required to produce accurate performance (Tulving & Thompson, 1973; Watkins & Gardiner, 1979). Due to these factors, the sequential format in the current study may have been relatively more difficult compared to those in prior work finding a lack of positivity bias.

The task in general was indeed difficult, perhaps resulting in poor total point score performance in both experiments (M_{Seq} = -2.90, M_{Sim} = -0.62, and M_{Self} = -2.21 out of a possible 75 points). Crucially, participants in the sequential condition produced the worst performance on the task while also displaying the highest positivity preference, as evidenced by the order of their responses. Self-regulated studiers did remember an equivalent amount of positive and negative information, but their study decisions still reflected a bias towards positive items. It is also important to note that affording participants more direct control over their study choices did not, at least numerically, improve their performance on the task relative to a simultaneous presentation of information, consistent with the idea that learners may not always adopt ideal strategies when study is self-regulated (for a review, see Dunlosky & Ariel, 2011).

It is evident then, that in the context of the current experimental paradigm, participants gave preferential treatment to positive over negative information. Although correctly remembering the locations of negatively valued items was equally as important for attaining a high overall score, participants may have chosen to directly focus on a “points-gained” approach, as opposed to an “avoiding points lost” approach. This finding contrasts with predictions from prospect theory (Kahneman & Tversky, 1979; Tversky & Kahneman, 1992) which posits that losses may be weighted larger than gains. In the context of the current study, this may have resulted in a loss-avoidance-oriented approach (i.e., more focus on negative items) to studying associative information of differing value. Instead, the results suggest that when the opportunity to both lose and gain rewards is present, positive information may be attended to and remembered at the expense of negative information of a similar magnitude despite the obvious fault in this strategy use. Importantly, this was still the case when attentional resources were strained during encoding, suggesting that this positivity preference is still present under more demanding conditions.

Future research could also extend upon the self-regulated presentation format to develop two versions of the task: (1) similar to the current version (i.e., full control over which items to study, the order to study them, and for how long they are studied) and (2) a new version that only allows participants to control for study time and which items to study. For example, participants would see one item populated in the grid (similar to the sequential presentation format of Experiment 4a) and would be allowed to advance to the next item as soon as they were ready to do so. The next item would thus be random (i.e., not directly selected by the control of the participant as it would have been in the self-regulated study task of Experiment 4b). By forcing the presentation order of items in a new self-regulated study task where participants can still control for length of time of study, we could better understand the underlying processes of the sequential presentation when not knowing which item to next expect during encoding.

It may also be useful to directly ask participants after conclusion of the study which strategies they used to study information and whether or not they explicitly focused on a subset of the information. This may provide more explicit evidence of participants' awareness of their study strategies and the effects it may have had on their memory performance. Future research could even examine this points-gained approach under more demanding conditions like a dual-task paradigm in which a secondary task is to be completed during encoding (e.g., Middlebrooks et al., 2017; Siegel & Castel, 2018b). Under these conditions in which resources are further strained, we would expect an even more pronounced positivity preference, which would support and extend the results of the current study.

Finally, it would be useful to explore the extent to which these results apply to more naturalistic memory contexts. The items which were the to-be-remembered stimuli in the current study were individual numerical values which were used due to their simplistic nature. In everyday life, we have to remember the locations of more visually complex items that differ in importance (i.e., a high-value item like car keys or a low-value item like a pen). It would be interesting to compare competing predictions from prospect theory and regulatory fit theory using more naturalistic materials. For example, when required to remember the location of one's hypothetical car keys, the framing of the goal may influence memory strategies. Prospect theory would predict better memory for the following loss-avoidance-oriented framing: "If I forget where I put my car keys, I could get fired because I'll be late for work," than the positively framed equivalent: "If I remember where I put my car keys, I'll make it to work on time and I'll remain gainfully employed," while regulatory fit theory would predict the opposite pattern of results. The results from the current study suggest that the later framing would result in superior memory performance, but the naturalistic and personal nature of the task may result in different findings as the stakes may be higher for losses than gains in this real-world example. The current study intended to explore and shed light on the underlying mechanism in value-based strategy use for negative and positive information in a pared down paradigm (minimizing potential confounds like participants' current employment status, for example). A fruitful avenue for future work would be to examine the extension of these findings to more naturalistic memory contexts.

We sought to examine how the locations of both positive and negative important values might be selectively remembered in the visuospatial domain when studied in either a sequential, simultaneous, or self-regulated presentation format. Participants needed to change their encoding strategy, to alleviate memory deficits when more attentional resources were required, depending on the format in which these items were presented during encoding. Participants more accurately recalled the locations of these important values in the simultaneous relative to the sequential condition. Additionally, positively valued items were better remembered relative to the negatively valued items of the same magnitude representing an inefficient strategy given the equivalent influence of positive and negative items on participants' total scores. This positivity bias found in the current study expands upon prior work elucidating the positivity effect that is generally seen across the lifespan with successful aging (for a review, see Mather & Carstensen, 2005) in a novel domain, visuospatial memory. This adds to some relatively recent research showing that younger adults, despite generally prioritizing negative information in cognitive processing (Baumeister, Bratslavsky, Finkenauer, & Vohs, 2001; Rozin & Royzman, 2001), can have positivity effects in memory when their goal orientation is shifted to focus on the present (Reed & Carstensen, 2012; Sedikides & Skowronski, 2020). When participants were given full control over which items they studied, the order in which they were studied, and the length of study time per item, their memory performance was equivalent between positive and negative items, but positive items were still studied more frequently and for more time. Overall, while the current study finds further support for the value-directed remembering paradigm within the visuospatial domain when there is the potential to lose points, it also provides evidence for an inherent bias towards positively-valued items despite the relatively equal role that the positive and negative items played in terms of task goals.

Chapter 3 Conclusion

While it is clear that memory capacity steadily declines as we age, there are many preserved memory abilities as we age. Older adults are capable of selectively focusing on important information, even in the face of cognitively demanding conditions. Selection, optimization, and compensation model (SOC; Baltes & Baltes, 1990) would suggest that older adults select important information to focus cognitive resources towards in order to optimize potential gains and compensate for potential losses given their limited capacity. Prior work has found this to be the case in verbal memory (Ariel et al., 2015; Castel et al., 2002) and Experiment 3 extended this finding to visuospatial memory by demonstrating equivalent selectivity between younger and older adults in both presentation formats. However, older adults did still exhibit deficits relative to younger adults in that they did not remember the same amount of high-value information, perhaps due to the attentionally-demanding nature of the visuospatial binding task. In Experiment 4, younger adults were faced with the possibility to both gain *and* lose points under both sequential and simultaneous formats and self-regulated study conditions. Despite having an equal influence on participants' scores, participants displayed a bias in memory and study preferences towards positive over negative information, perhaps demonstrating a promotion-oriented focus as prescribed by the task goals of gaining as many points as possible (Higgins, 2005, 2006; Spiegel et al., 2004). As such, the experiments described in Chapter 3 illustrate older adults preserved prioritization ability in a demanding visuospatial binding context and highlight a potential bias in younger' adults strategy use when both risks and rewards are associated with to-be-remembered information.

Table 3.1 (Experiments 3a and 3b)

Two-Level Hierarchical Generalized Linear Model of Memory Performance

Fixed Effects	**Exp. 3a Coefficients**	**Exp. 3b Coefficients**
Intercept (β_{00})	–0.15	0.74***
Predictors of intercept		
Condition 1: Younger adults 30s v. Older adults 30s (β_{01})	–1.03***	–1.22***
Condition 2: Younger adults 30s v. Younger adults 15s (β_{02})	–0.34*	–0.69**
Value (β_{10})	0.10***	0.08*
Predictors of Value		
Cond1: YA 30s v. OA 30s (β_{11})	–0.001	0.07
Cond2: YA 30s v. YA 15s (β_{12})	–0.01	0.05
Grid number (β_{20})	–0.02	0.0001
Predictors of Grid number		
Cond1: YA 30s v. OA 30s (β_{21})	–0.01	0.01
Cond2: YA 30s v. YA 15s (β_{22})	0.01	0.001
Value x Grid number (β_{30})	0.01*	0.004
Predictors of Value x Grid number		
Cond1: YA 30s v. OA 30s (β_{31})	.003	0.003
Cond2: YA 30s v. YA 15s (β_{32})	–.001	0.005
Random Effects	**Exp. 3a Variance**	**Exp. 3b Variance**
Intercept (person-level) (r_0)	0.30***	0.59***
Value (r_1)	0.01***	0.02***
Grid Number (r_2)	0.003***	0.007***
Value x Grid number (r_3)	0.0002**	0.0001*

Note. In these analyses, correct item placement was coded as 0 (*not correctly placed*) or 1 (*correctly placed*). A logit link function was applied to address the binary dependent variable. Levels 1 models were of the form $\eta_{ij} = \pi_{0j} + \pi_{1j}$ (Value) + π_{2j} (Grid number) + π_{3j} (Value x Grid number). Level 2 models were of the form $\pi_{0j} = \beta_{00} + \beta_{01}$ (Cond1) + β_{02} (Cond2) + r_{0j}, $\pi_{1j} = \beta_{10}$ +

β_{11} (Cond1) + β_{12} (Cond2) + r_{1j}, π_{2j} = β_{20} + β_{21} (Cond1) + β_{22} (Cond2) + r_{2j}, π_{3j} = β_{30} + β_{31} (Cond1) + β_{32} (Cond2) + r_{3j}.

*$p < .05$ **$p < .01$ ***$p < .001$.

Table 3.2 (Experiments 3a and 3b)

Two-Level Hierarchical Generalized Linear Model of Spatial Relocation Error

Fixed Effects	**Exp. 3a Coefficients**	**Exp. 3b Coefficients**
Intercept (β_{00})	2.06***	1.84***
Predictors of intercept		
Condition 1: Older adults 30s v. Younger adults 30s (β_{01})	–0.13*	–0.17*
Condition 2: Older adults 30s v. Younger adults 15s (β_{02})	–0.05	0.02
Value (β_{10})	–0.03***	–0.04**
Predictors of Value		
Cond1: OA 30s v. YA 30s (β_{11})	0.04***	0.02
Cond2: OA 30s v. YA 15s (β_{12})	0.02	0.02
Grid number (β_{20})	0.01	–0.01
Predictors of Grid number		
Cond1: OA 30s v. YA 30s (β_{21})	–0.01	0.01
Cond2: OA 30s v. YA 15s (β_{22})	–0.01	0.02
Value x Grid number (β_{30})	–0.002	0.002
Predictors of Value x Grid number		
Cond1: OA 30s v. YA 30s (β_{31})	–0.002	0.002
Cond2: OA 30s v. YA 15s (β_{32})	0.002	–0.01
Random Effects	**Exp. 3a Variance**	**Exp. 3b Variance**
Intercept (person-level) (r_0)	0.02***	0.03***
Value (r_1)	0.001	0.001*
Grid Number (r_2)	0.001	0.003
Value x Grid number (r_3)	0.00002	0.00001

Note. In these analyses, spatial relocation error was coded on a scale from 1 (*directly adjacent to target location*) to 4 (*distance of four steps from target location*) and was included as the outcome variable. Levels 1 and 2 models were of the same form in Table 3.1.

*p < .05 **p < .01 ***p < .001

CHAPTER 4: THE METACOGNITIVE MONITORING OF IMPORTANT INFORMATION IN VISUOSPATIAL MEMORY

Human memory capacity is limited. Given that we cannot remember all of the information to which we are exposed, it is adaptive to be able to selectively focus on a subset of what is most important in order to increase the likelihood of remembering this information at the expense of lesser value information. This ability to strategically allocate attention towards and later remember high-value coined has been termed *value-directed remembering* (VDR; Castel et al., 2002; Castel, 2008). Prior research has shown that increasing the difficulty of encoding (and consequently lowering memory performance) surprisingly does not influence one's ability to prioritize high-value information (Middlebrooks & Castel, 2018; Middlebrooks et al., 2017; Siegel & Castel, 2018a, 2018b; cf. Elliott & Brewer, 2019). In fact, intact prioritization ability is found in a variety of circumstances in which cognitive resources may be depleted, such as in cognitively healthy older adults (Castel et al., 2002; Siegel & Castel, 2018a, 2019), younger adults under dual-task conditions (Middlebrooks, Kerr, et al., 2017; Siegel & Castel, 2018b), individuals with lower working memory capacity (Hayes et al., 2013; Robison & Unsworth, 2017) and even, to some extent, children with and without attention-deficit/hyperactivity disorder (ADHD; Castel, Humphreys, et al., 2011; Castel, Lee, et al., 2011) and older adults with Alzheimer's disease (Castel et al., 2009; Wong et al., 2019).

Importantly, this ability to selectively remember information relies on our metacognitive ability. Metacognition, the ability to monitor and control our cognitive processes, is a crucial aspect of daily functioning. More specifically, metamemory, the metacognitive processes associated with memory, allows us to assess memory quality or strength (i.e., metacognitive monitoring) and adjust our behavior to regulate our memories (i.e., metacognitive control). For example, when cramming last minute for an exam occurring on the next day (an ill-advised, but often used technique on college campuses), students must first be aware that they cannot possibly remember all of the information and adjust their study strategies to focus on remembering what is highly likely to appear on the exam (e.g., central theorems or examples) at the expense what is less likely to appear (e.g., peripheral details and nuances). While performance is unlikely to reach levels that are possible with more study preparation, errors can perhaps be minimized relative to another student who exhibits less metacognitive awareness and is indiscriminate towards information of differing value.

In the context of a typical VDR task, words in a list whose length exceeds memory capacity are paired with point values indicating their importance are shown to participants (e.g., Castel et al., 2002; Middlebrooks et al., 2017). In order to achieve the task goal of maximizing their point score, participants must be aware that they cannot possibly remember all of the presented information. This awareness then leads to participants adapting their strategy use in order to maximize their score, for example, by focusing on a smaller subset of high-value information to study and spending more time rehearsing these items. As such, metacognitive processes (both monitoring and control) play a crucial role in the prioritization of information in memory.

While important to many aspects of daily life, people may not always be accurate in their metacognitive assessments of their cognitive capabilities. For example, participants may not accurately assess how their memory may change under dual-task conditions (Barnes & Dougherty, 2007; Finley, Benjamin, & McCarley, 2014). Results from these studies found that while participants were aware that completing a secondary task may impair performance on the primary task, they underestimated the degree to which their performance may personally be impaired. As such, our metacognitive insight into our own performance may be subject to a variety of factors that may result in discrepancies between metacognition and performance.

Within the current study, we investigated how metacognitive monitoring ability may vary as a function of attentional load during encoding and how the importance of information may influence the accuracy of this monitoring. In general, we expected that, like overall memory performance, monitoring ability would also suffer when cognitive resources were strained during encoding. However, we expected that this effect may depend on the value of information, as high-value information may receive more attention and thus be spared from monitoring inaccuracies, while low-value information may be particularly negatively monitored. To examine these hypotheses, participants were tested on their ability to remember distinct visual stimuli of differing value displayed in spatial array under different encoding circumstances and were prompted to provide metacognitive judgements during test across a series of trials.

Experiment 5: Global and Local Differences in Metacognitive Monitoring on a Visuospatial Value-Directed Remembering Task

The goals of Experiment 5 were to examine how memory selectivity and local and global metacognitive measures may be influenced by encoding difficulty. Participants studied items paired with point values in different locations in a grid and were instructed to maximize their point score (a summation of the points associated with correctly recalled information). Encoding difficulty was varied by manipulating the degree of attentional control available to participants when studying the grid. Participants either studied the 10 items shown all simultaneously or one at a time in a sequential manner. They also studied either under single-task (only completing the grid task) or dual-task (with an additional concurrent tone discrimination task) conditions. Immediately after studying, participants were required to relocate items in their previously presented locations while providing both local (how confident they were an item was relocated correctly) and global (how many items out of the 10 they thought they correctly relocated) judgments. Participants completed a total of eight trials containing unique items in unique locations on each trial.

It was expected that overall memory performance would mirror numerous previous results in the visuospatial and other memory domains, with higher attentional control in the simultaneous and full attention (single-task) conditions leading to more accurate memory than sequential and divided attention (dual-task) conditions (Blalock & Clegg, 2010; Brown & Brockmole, 2010; Elsley & Parmentier, 2009; Feng, Pratt, & Spence, 2012; Lecerf & de Ribaupierre, 2005; Middlebrooks & Castel, 2018; Middlebrooks, Kerr, & Castel, 2017; Robison & Unsworth, 2017; Siegel & Castel, 2018a, 2018b). These studies suggest that when participants are allowed more attentional control during intentional encoding, they can more effectively engage in effective memory strategies (e.g., elaborative rehearsal, relational processing between items) resulting in higher memory performance. However, also consistent with prior work, we did not expect prioritization (i.e., memory selectivity) to vary as a function of encoding difficulty, as participants can generally maintain their ability to prioritize and selectively remember high-value information despite reduced attentional control during encoding (Hayes, Kelly, & Smith, 2013; Middlebrooks & Castel, 2018; Middlebrooks et al., 2017; Robison & Unsworth, 2017; Siegel & Castel, 2018b; cf. Elliott & Brewer, 2019). As such, we also expected participants in each encoding condition within our study to selectively prioritize high-value over low-value information.

We also had specific hypotheses for how encoding difficulty would influence local and global metacognitive judgments and the accuracy of those judgments. Previous work has suggested that participants are generally aware that reducing attentional control during studying may lead to impaired memory performance (Barnes & Dougherty, 2007; Beaman, Hanczakowski, & Jones, 2014; Finley, Benjamin, & McCarley, 2014; Kelley & Sahakyan, 2003; Sacher et al., 2009) which should manifest in the current experiment through lower local confidence ratings and global predictions in sequential and divided attention conditions relative to simultaneous and full attention conditions.

In terms of the accuracy of these judgments, encoding difficulty should too produce significant differences, with lower accuracy of metacognitive predictions under divided-attention relative to full-attention, consistent with previous work on local (Beaman et al., 2014; Kelley & Sahakyan, 2003; Sacher et al., 2009) and global assessments of performance (Barnes & Dougherty, 2007). In terms of presentation format, a different pattern of results was predicted. Sequentially presented information may draw more attention to individual items and their relevant features, producing a local-processing orientation during study; on the other hand, simultaneously presented information may emphasize the overall configuration of items, producing a global-processing orientation in which more focus is dedicated to the entire array (Blalock & Clegg, 2010; Taylor, Thomas, Artuso, & Eastman, 2014). We hypothesized, then, that these separate processing orientations would produce differentially accurate metacognitive judgments, with the sequential format more accurate in local judgments and the simultaneous format more accurate in global judgments due to the increased attentional focus on individual items and the global array, respectively.

Finally, we also expected participants' local metacognitive ratings to vary as a function of information importance, such that higher value items should be assigned higher confidence ratings. As is well established, selectivity in memory is dependent upon the strategic allocation of attention to high-value over low-value information (Castel, 2008), especially in the context of visuospatial memory (Schwartz, Siegel, & Castel, 2020; Siegel & Castel, 2018a, 2018b). This increased attentional focus on high-value information may produce more accurate knowledge about one's memory for this information (i.e., whether or not it has been correctly remembered) in addition to increased memory for the information itself. This may especially be the case when information is sequentially presented due to the hypothesized local-processing orientation induced by said presentation format.

Method

Participants

The participants in Experiment 5 were 96 University of California, Los Angeles (UCLA) undergraduate students who participated for course credit (72 females, M_{age} = 21.57 years, SD_{age} = 3.17, age range: 18-32). In terms of the highest education level obtained, participants reported the following: 63% had some college, 23% had an associate degree, and 14% had a bachelor's degree. Participants were all fluent in English and did not report any significant visual impairment.

Materials

The materials in this study consisted of eight unique 5 × 5 grids containing ten items each presented on a computer screen. These items were identical to those used in previous work conducted in our lab (Siegel & Castel, 2018a, 2018b). The grids were approximately 15 × 15 cm on the screen (17.06° visual angle) and contained 25 cells, each of which was approximately 3 × 3 cm in size (3.44° visual angle). Within each of ten randomly chosen cells was an item selected from a normed picture database (Snodgrass & Vanderwart, 1980). The items used were 80 black and white line drawings of everyday household items (e.g., a key, a camera, and an iron). On the computer screen, items were approximately 2 × 2 cm in size (2.29° visual angle). To form a grid, ten items were randomly selected from the pool and randomly placed in the cells of the grid with the constraint that no more than two items be present in any row or column of the grid (to reduce the likelihood of the item arbitrarily forming spatial patterns that may aid memory). Items were then randomly paired with point values ranging from 1 point (lowest value) to 10 points (highest value) indicated by the numerical value placed in the top left portion of each item-containing cell. Each value was used once per grid. This process was repeated to form eight unique grids for each participant. While one participant may have been presented with an iron paired with the 7-point value in the top left cell of the second grid, a different participant could encounter that same item paired with the 4-point value in the bottom right cell of the sixth grid. As such, each participant was presented with a different set of eight completely randomized grids.

Procedure

Participants were randomly assigned to one of four between-subjects encoding conditions: simultaneous presentation format/full attention (Sim-FA), simultaneous presentation format/divided attention (Sim-DA), sequential presentation format/full attention (Seq-FA), or sequential presentation format/divided attention (Seq-DA). There were 24 participants in each of the four conditions: all 24 participants were included for the full attention conditions, but for the divided attention conditions, data were collected until there were 24 participants in each condition who met the later described inclusion criteria.

All participants were instructed that they would be presented with ten items placed within a 5 × 5 grid and would later be tested on that information. Participants were further instructed that each item would be paired with a point value from 1 to 10 indicated by a number in the top left portion of each item-containing cell. The participants' goal was to maximize their point score (a summation of the points associated with correctly remembered information) on each trial. Participants in the simultaneous conditions were shown all ten items concurrently for a total of 30 s. Participants in the sequential conditions were shown items one at a time, each for 3 s (totaling 30 s for the ten items) and were presented randomly with regard to their location in the grid and their associated point value.

Participants were told that after they studied the information within the grid, they would immediately be shown the items underneath a blank grid and be asked to place each item in its previously presented location by first clicking on the item with the mouse, and then dragging the item to the cell in which they wanted to place it. If participants were unsure of an item's location, they were asked to guess, as they would not be penalized for incorrectly placed items. Participants were given an unlimited duration to complete this testing phase and were required to place all ten items in any order they desired before advancing to the next trial.

Importantly, during the testing phase, participants were required to complete two types of metacognitive measures. Firstly, as participants placed each item in the grid, they were prompted to provide a local, item-level confidence rating before moving on to place the next item. Participants were asked, "How confident are you that this item was presented in this location?" as an integer on a scale from 1 (*not at all confident*) to 10 (*extremely confident*). After participants entered their desired numerical value, they could then proceed to place the next item and provide its confidence rating and so on until all 10 items were replaced in the grid. If participants decided to move an item after initially replacing it, they were prompted to change their previous confidence rating if they wanted to, and the final confidence rating was used in later analyses. Secondly, after placing all 10 items, participants were asked to provide a global, trial-level judgment on the total number of items correctly replaced. Participants were asked "Of the 10 items that you placed, how many do you think were correctly placed?" and were required to enter an integer value ranging from 0 to 10 before proceeding. After participants placed all 10 items with their respective confidence ratings and completed the global judgment, they were given feedback on their performance in terms of the items that they correctly placed, the number of points they received (out of 55 possible), and the percentage of points they received. After receiving feedback, participants repeated this procedure with unique items in grids for seven further study-test cycles (for a total of eight trials).

Finally, participants in the divided attention conditions also completed a tone discrimination task during the study period. These participants were instructed that during the study phase they would hear a series of tones. Tones were presented auditorily through headphones and were one of two pitches: low pitch (400 Hz) and high pitch (900 Hz). Each tone was played for a duration of 1 s and the order of presentation was random for each participant with the constraint that no pitch was played more than three times consecutively. Participants completed a 1-back tone discrimination task such that they were required to determine whether the most current tone they heard was the "same" or "different" than the tone immediately preceding it. The corresponding keys were labeled as such on the keyboard. Before each study-test cycle, a blank grid appeared on the screen and the first tone was played. Participants were instructed that they were not required to respond to this first tone. After 3 s, the first item (in the Seq-DA) or all ten items (in the Sim-DA) appeared along with the second tone. Participants then had to make their first decision ("same" or "different" than the first tone). After that, the remaining tones were played in 3-s intervals, totaling 11 tones by the end of the study period (one preceding the presentation of items and ten concurrently with item presentation). In the Seq-DA condition, tones were played for the first second of each item's 3-s presentation duration. For both conditions, participants were required to make their tone discrimination response within a 3-s window before the subsequent tone was played. Participants were able to change their response within that 3-s interval, and their final response was used in later analyses.

Results

Given the nature of these data, we first analyzed tone discrimination in the divided attention conditions followed by memory performance as a function of encoding condition. Then, in order to examine the effects of item value on memory, we used hierarchical linear modeling (HLM). Explained in more detail at the beginning of the Memory Selectivity section, HLM is a powerful technique that allowed us to examine the relationship between our variables (i.e., the relationship between item value and recall probability for any given item, and how each encoding condition *and* task experience may have changed this probability). This technique has been used successfully in prior work as a useful analytical approach (Middlebrooks et al., 2016, 2017; Siegel & Castel, 2018a, 2018b, 2019). However, it does not provide any comparison directly examining mean condition differences (e.g., differences in the overall averages between encoding conditions). In contrast, a mean-based analytic technique (e.g., ANOVA) is unable to detect any direct relationships between item value and recall probability but is able to determine whether there were differences between encoding conditions on average. As such, the utilization of these analyses in conjunction allowed us to appropriately examine differences in overall memory and metacognitive accuracy using analyses of variance and differences in how item value influenced these measures between conditions using HLM. Finally, we examined local metacognitive accuracy by calculating correlations between confidence ratings and relocation accuracy, and global metacognitive accuracy by calculating correlations between the global estimates and the number of items recalled on a trial.

Tone Discrimination Performance

Tone discrimination performance was analyzed to ensure that participants' attention was adequately divided during encoding. Firstly, we examined each participants' tone discrimination performance individually to ensure that participants were not simply ignoring the auditory task in order to focus on the visuospatial memory task. We set an inclusion criterion such that, to be included in the experiment, participants had to (a) have responded on at least 50% of tones and (b) have tone discrimination accuracy greater than 50% averaged across all eight grids.

To determine whether tone discrimination accuracy during encoding varied as a function of presentation format or across grids, we conducted a 2 (Presentation format: simultaneous, sequential) × 8 (Trial: 1, 2, ..., 8) repeated-measures analysis of variance (ANOVA). For all experiments in the current study, we used Greenhouse-Geisser corrections to correct for sphericity violations when necessary. This analysis revealed no main effect of presentation format, such that tone accuracy was equivalent between the simultaneous (M = .63, SD = .10) and sequential (M = .62, SD = .17), $F(1, 46) = 0.03$, $p = .87$, $\eta^2 = .001$ presentation formats. There was a main effect of trial, $F(7, 322) = 19.74$, $p < .001$, $\eta^2 = .30$. Bonferroni-corrected paired-samples t-tests indicated that tone accuracy on Trial 1 (M = .35, SD = .27) was significantly lower than all other trials ($M_{Trials\ 2\text{-}8}$ = .67, SD = .15), ps < .001. Additionally, accuracy on Trial 2 (M = .56, SD = .27) was lower than Trial 4 (M = .69, SD = .22), Trial 5 (M = .71, SD = .17), and Trial 6 (M = .70, SD = .19), ps < .05. No other follow-up comparisons were significant, ps > .28. Further, there was no interaction between presentation format and trial, $F(7, 322) = 1.20$, $p = .30$, $\eta^2 = .02$.

Finally, to determine whether performance differed from chance (i.e., 50%) throughout the task, we conducted one-sample t-tests on tone discrimination performance for Trial 1, Trial 2, and the average of Trials 3-8 (due to the previously described significant differences) collapsing across presentation format conditions. These analyses revealed that tone discrimination accuracy was lower than chance on Trial 1, $t(47) = 3.94$, $p < .001$, not significantly different than chance on Trial 2, $t(47) = 1.49$, $p = .14$, and significantly higher than chance on Trials 3-8, $t(47) = 8.45$, $p < .001$. These results suggest that there was no difference in tone discrimination accuracy between presentation conditions and that participants' performance was consistently above chance after the second trial.

Memory Performance

We first analyzed overall memory performance between encoding conditions across trials ignoring value and then how memory performance may have differed as a function of the value of items.

Overall. Relocation accuracy (i.e., the proportion of items correctly placed) for each presentation format and attention condition across grids is depicted in Figure 4.1. To analyze these data, we first examined relocation accuracy without regard to item value across the task using a 2 (Presentation format: simultaneous, sequential) × 2 (Attention: full, divided) × 8 (Trial: 1, 2, ..., 8) repeated measures ANOVA on relocation accuracy. There was a main effect of presentation format, such that the simultaneous conditions ($M = .59$, $SD = .23$) had higher performance than the sequential conditions ($M = .39$, $SD = .17$), $F(1, 92) = 26.60$, $p < .001$, $\eta^2 = .16$. There was also a main effect of attention, with full attention conditions ($M = .62$, $SD = .19$) recalling more items than the divided attention conditions ($M = .39$, $SD = .18$), $F(1, 92) = 50.31$, $p < .001$, $\eta^2 = .29$. A main effect of trial was also found, $F(7, 644) = 7.29$, $p < .001$, $\eta^2 = .07$, with Bonferroni-corrected paired-samples *t*-tests indicating that performance on Trial 1 was worse than all subsequent trials, *p*s < .04, and performance on Trial 2 was worse than Trials 5, 6,

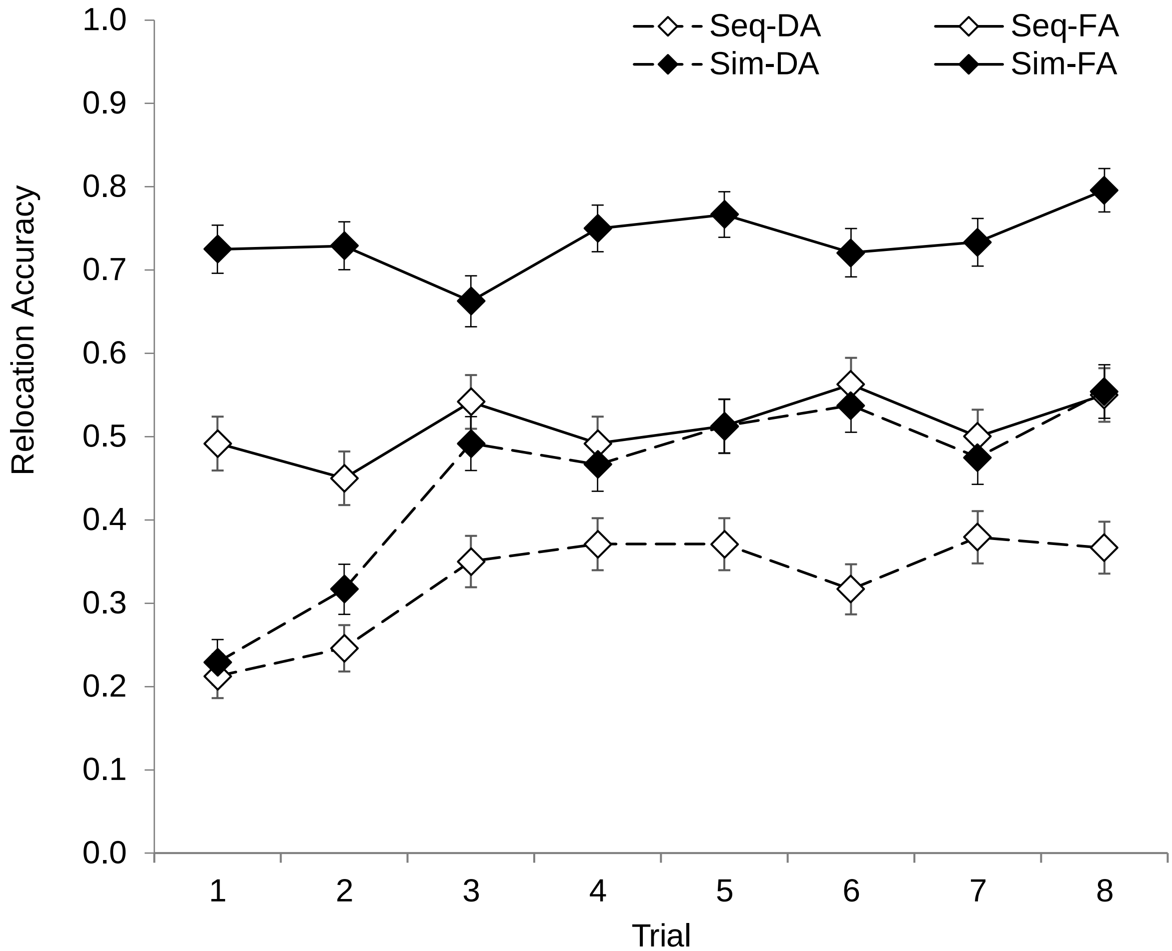

Figure 4.1. Relocation accuracy as a function of presentation format and attention across trials. Error bars represent ±1 standard error. *Sim*: simultaneous presentation format, *Seq*: sequential presentation format, *FA*: full attention, *DA*: divided attention.

and 8, *p*s < .04. All other follow-up comparisons were insignificant, *p*s > .09.

In addition to these main effects, we found a significant interaction between attention and trial, $F(7, 644) = 3.45$, $p = .001$, $\eta^2 = .04$. To decompose this interaction, we conducted one-way ANOVAs analyzing relocation accuracy across trials within each presentation format. In the full attention conditions, there was no main effect of trial, $F(7, 329) = 0.95$, $p = .47$. In the divided attention conditions, there was a main effect of trial, $F(7, 329) = 9.44$, $p < .001$, with follow-up paired-samples *t*-tests indicating that relocation accuracy was significantly lower on Trial 1 than on all subsequent trials, *p*s < .01, accuracy on Trial 2 lower than those of Trials 3, 4, and 8, with no other significant comparisons, *p*s > .05. Finally, there was no significant interaction between presentation format and trial, $F(7, 644) = 0.65$, $p = .72$, $\eta^2 = .01$, no interaction between presentation format and attention, $F(1, 92) = 2.32$, $p = .13$, $\eta^2 = .01$, and no three-way interaction between the variables, $F(7, 644) = 1.72$, $p = .10$, $\eta^2 = .02$. These results demonstrate that, in general, there was better memory performance in simultaneous and full attention conditions relative to sequential and divided attention conditions, respectively. Further, while the divided attention conditions improved performance across trials, performance in the full attention conditions was consistent throughout the task.

By Item Value. Relocation accuracy as a function of item-value and encoding condition is depicted in Figure 4.2. In order to compare selectivity between groups and across trials, we used an HLM to analyze relocation accuracy as a function of item value. HLM has been used in previous studies investigating memory selectivity (Castel, Murayama, Friedman, McGillivray, & Link, 2013; Middlebrooks & Castel, 2018; Middlebrooks et al., 2017; Middlebrooks, McGillivray, Murayama, & Castel, 2016; Raudenbush & Bryk, 2002; Siegel & Castel, 2018a, 2018b, 2019). The post-hoc binning of items into low, medium, and high value groups may not accurately reflect participants' valuations of to-be-learned stimuli (e.g., Participant 1 may consider items with values 6-10 to be of "high" value, while Participant 2 may only consider items with values 8-10 as such). In contrast, HLM treats item value as a continuous variable, allowing for a more precise investigation of the relationship between relocation accuracy and item value. Further, by first clustering data within each

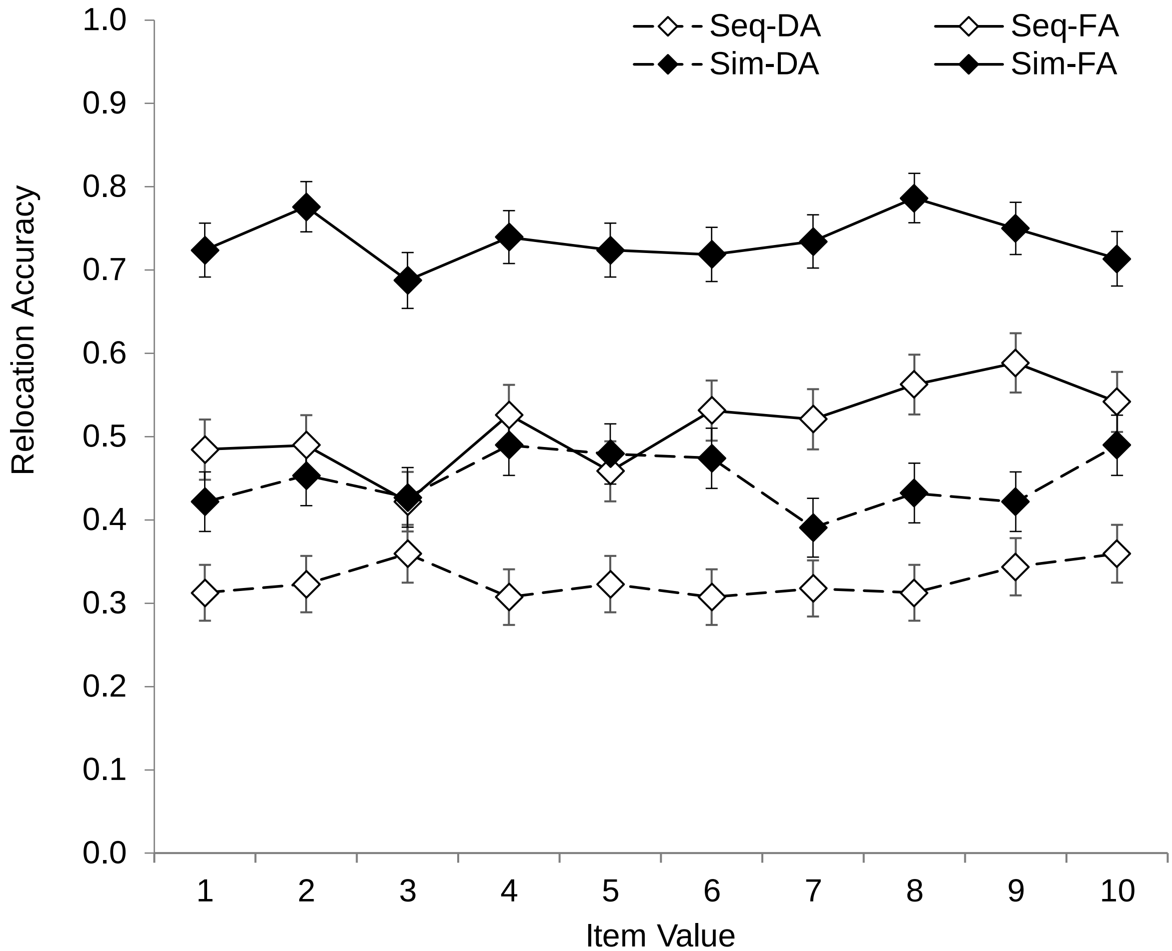

Figure 4.2. Relocation accuracy as a function of presentation format, attention, and item value averaged across trials. Error bars represent ±1 standard error. *Sim*: simultaneous presentation format, *Seq*: sequential presentation format, *FA*: full attention, *DA*: divided attention.

participant and then examining possible condition differences, HLM accounts for both within- and between-subject differences in strategy use, the latter of which would not be evident when conducting standard analyses of variance. Thus, HLM allows for a more fine-grained analysis of participants' value-based strategies.

In a two-level HLM, relocation accuracy (using a Bernoulli distribution, 0 = not recalled, 1 = recalled; level 1 = items; level 2 = participants) was modeled as a function of item value, trial, and the interaction between those two variables. Item value and trial were entered into the model as group-mean centered variables (with item value anchored at the mean value of 5.5 and trial anchored at the mean value of 4.5). The encoding conditions (0 = Sim-FA, 1 = Sim-DA, 2 = Seq-FA, 3 = Seq-DA) were included as level-2 predictors. In this analysis, participants in the Sim-FA condition were treated as the comparison group, while Comparison 1 compared Sim-FA and Sim-DA, Comparison 2 compared Sim-FA and Seq-FA, and Comparison 3 compared Sim-FA and Seq-DA.

Table 4.1 presents the tested model and estimated regression coefficients in the current study. Firstly, and most surprisingly, there was no significant effect of value on relocation accuracy for participants in the Sim-FA condition, $\beta_{10} = 0.01$, $p = .79$. This effect was consistent for the other encoding conditions as indicated by the lack of significance of the comparison coefficients, $\beta_{11} = -.01$, $p = .84$, $\beta_{12} = .05$, $p = .08$, and $\beta_{13} = .004$, $p = .86$. For the Sim-FA condition, trial was also a significant predictor of relocation accuracy, $\beta_{20} = 0.06$, $p = .03$, indicating a moderate increase in memory performance across trials. This relationship between trial and relocation accuracy was significantly stronger in the Sim-DA condition, $\beta_{21} = .12$, $p = .02$, and not significantly different than the Sim-FA condition in either the Seq-FA, $\beta_{22} = -.0.02$, $p = .52$, or Seq-DA conditions, $\beta_{23} = .03$, $p = .44$. Finally, there was no interaction between item value and trial in the Sim-FA condition, $\beta_{30} = .01$, $p = .47$, or indeed any of the other conditions, $\beta_{31} = -.0001$, $p > .99$, $\beta_{32} = -.0004$, $p = .97$, and $\beta_{33} = .004$, $p = .70$. The results from this HLM indicate that, regardless of the encoding condition, participants were not selective in their memory performance throughout the task.

Metacognitive Measures

Of particular interest in the current study were the overall global predictions and local confidence ratings provided by participants. We first analyzed whether the magnitude of such predictions varied as a function of encoding condition and task experience and then the degree to which participants were accurate in their assessments of their performance (i.e., their metacognitive accuracy via correlational analyses). In terms of metacognitive accuracy, we analyzed average correlations between trial-level relocation accuracy and global trial judgments (global metacognitive accuracy) and average correlations between local, item-level accuracy and local confidence ratings (local metacognitive accuracy).

Overall Global Predictions. First, we examined how global trial-level predictions varied between encoding conditions and across trials while ignoring value and relocation accuracy. We conducted a 2 (Presentation format: simultaneous, sequential) × 2 (Attention: full, divided) × 8 (Trial: 1, 2, ..., 8) mixed-subjects ANOVA on global predictions (i.e., how many items, out of a total of 10, participants estimated they correctly placed) and found a significant interaction between attention presentation format and trial, $F(7, 644) = 3.11$, $p = .003$, $\eta_2 = .03$. To decompose this interaction, one-way ANOVAs examining global predictions across trials within each presentation format were conducted. In the simultaneous conditions, there was a main effect of trial, $F(7, 329) = 3.28$, $p = .002$, $\eta_2 = .07$, with Bonferroni-corrected follow-up paired-samples *t*-tests indicating that global confidence on Trial 1 was lower than those of Trials 5 and 8, *p*s < .02. No other comparisons were significant, *p*s > .08. In the sequential conditions, there was no main effect of trial, $F(7, 329) = 0.39$, $p = .91$, $\eta_2 = .01$.

Resulting from the original 2 × 2 × 8 ANOVA was also a significant interaction between attention and trial, $F(7, 644) = 3.97$, $p < .001$, $\eta_2 = .04$. To decompose this interaction, one-way

ANOVAs examining global predictions across trials within each attention condition were conducted. In the full attention conditions, there was no main effect of trial, $F(7, 329) = 0.86$, $p = .54$, $\eta^2 = .02$. In the divided attention conditions, there was a significant main effect of trial, $F(7, 329) = 4.89$, $p < .001$, $\eta^2 = .09$, with Bonferroni-corrected paired-samples *t*-tests indicating lower global predictions on Trial 1 relative to Trials 5, 6, and 8, *p*s < .01. No other comparisons were significant, *p*s > .06. Finally, this omnibus ANOVA revealed that there were main effects of presentation format, $F(1, 92) = 26.35$, $p < .001$, $\eta^2 = .15$, and attention, $F(1, 92) = 51.29$, $p < .001$, $\eta^2 = .30$, such that global predictions were higher in the simultaneous format ($M = 5.27$, $SD = 2.34$) relative to the sequential format ($M = 3.54$, $SD = 1.70$), and the full attention ($M = 5.61$, $SD = 2.15$) relative to the divided attention condition ($M = 3.20$, $SD = 1.53$). There was no main effect of trial, $F(7, 644) = 1.53$, $p = .15$, $\eta^2 = .02$, no interaction between presentation format and attention, $F(1, 92) = 2.10$, $p = .15$, $\eta^2 = .01$, and no three-way interaction between these variables, $F(7, 644) = 3.05$, $p = .37$, $\eta^2 = .01$. These results indicate that global predictions were generally higher for simultaneous and full attention conditions, and that simultaneous and divided attention condition predictions were higher at the end relative to the beginning of the task.

Global Metacognitive Accuracy. Next, to examine metacognitive accuracy at an individual-level, we computed global prediction-performance Pearson's correlations within each encoding condition. That is, each participants' prediction for their overall relocation accuracy (i.e., how many items out of the 10 possible) on Trial 1 was paired with their subsequent memory performance on Trial 1, their prediction for Trial 2 paired with their subsequent performance on Trial 2, and so on for all eight lists. Pearson's correlations were conducted using these eight pairings for each participant resulting in a single global prediction-performance correlation coefficient for each participant. For this value, positive correlations indicated high metacognitive accuracy (i.e., a positive relationship between predictions and actual performance), negative correlations indicated poor metacognitive accuracy, and no correlation indicated a lack of relationship between predictions and performance.

The average magnitude of global prediction-performance correlations is depicted in Figure 4.3. One participant was excluded from the Sim-FA condition due to providing the same prediction on each trial, thus preventing the ability to calculate a correlation. To determine whether this measure varied as a function of encoding condition, a 2 (Presentation format: simultaneous, sequential) × 2 (Attention: full, divided) between-subjects ANOVA was conducted on average global correlation coefficients. There was a main effect of presentation format, such that global correlation coefficients were significantly higher in the simultaneous conditions (M = .66, SD = .23) than the sequential conditions (M = .47, SD = .34), $F(1, 91) = 10.39$, $p = .002$, $\eta^2 = .10$. There was no main effect of attention, $F(1, 91) = 0.02$, $p = .90$, $\eta^2 < .001$, and no interaction between presentation format and attention, $F(1, 91) = 1.77$, $p = .19$, $\eta^2 = .02$. This analysis suggests that global metacognitive accuracy was higher when encoding was simultaneous relative to sequential but did not depend on whether attention was full or divided.

Overall Local Confidence. Next, we analyzed how local item-level judgments may have varied as a function of encoding condition and trial. We conducted a 2 (Presentation format: simultaneous, sequential) × 2 (Attention: full, divided) × 8 (Trial: 1, 2, ..., 8) mixed-subjects ANOVA on average local confidence ratings (i.e., the average of the individual item confidence ratings that participants provided on each trial) and found a significant interaction between presentation format and trial, $F(7, 644) = 2.33$, $p = .02$, $\eta^2 = .02$. To decompose this interaction, one-way ANOVAs examining local confidence ratings across trials

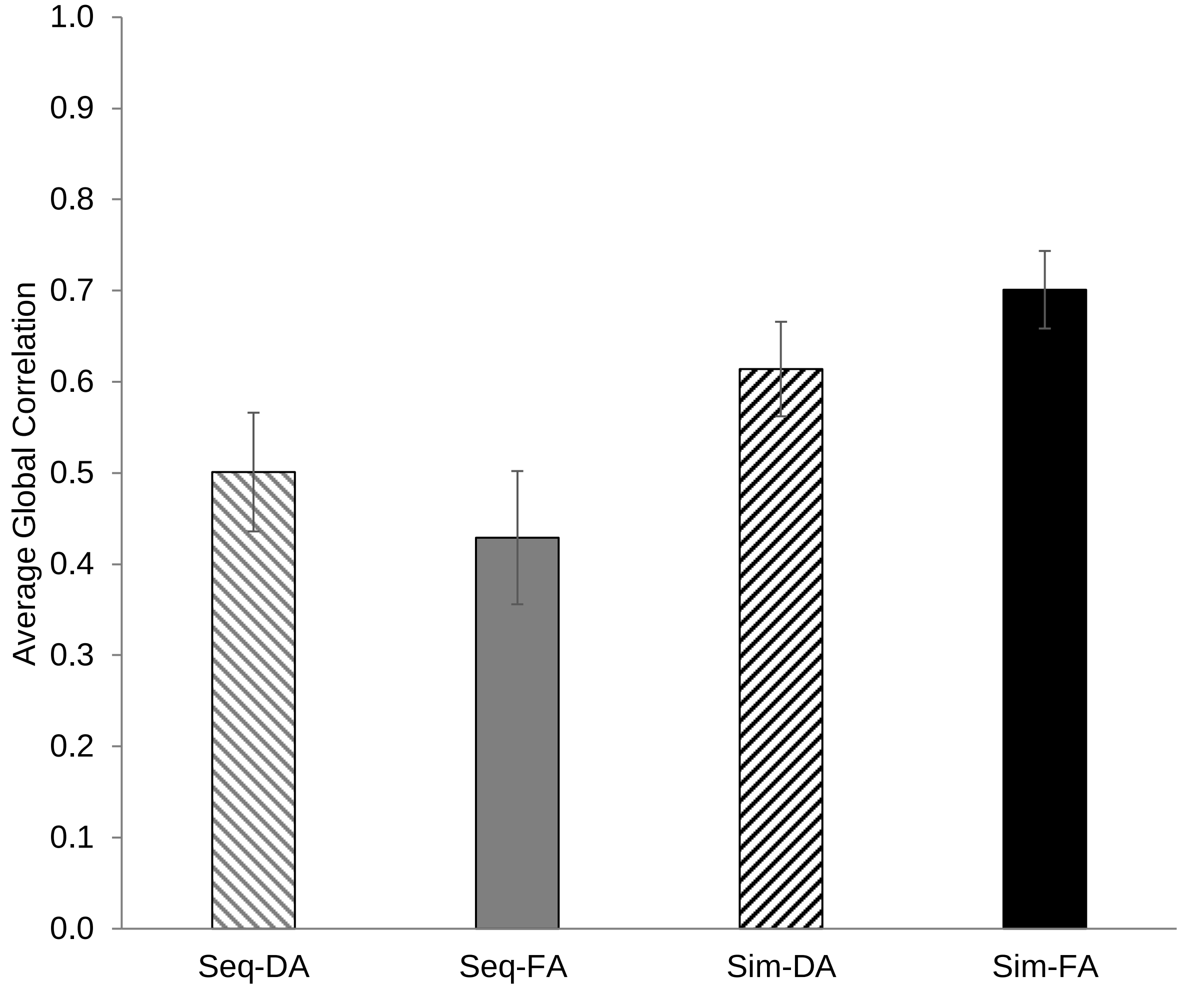

Figure 4.3. Average global correlation between the number of items predicted and number of items actually recalled in each encoding condition. Error bars represent ±1 standard error. *Sim*: simultaneous presentation format, *Seq*: sequential presentation format, *FA*: full attention, *DA*: divided attention.

within each presentation format were conducted. In the simultaneous conditions, there was a main effect of trial, $F(7, 329) = 4.95$, $p < .001$, $\eta_2 = .10$, with follow-up Bonferroni-corrected paired-samples *t*-tests indicating lower local confidence ratings on Trial 1 and Trial 4 relative to Trial 8, *p*s < .04, with no other significant comparisons, *p*s > .05. In the sequential conditions, there was no main effect of trial, $F(7, 329) = 1.86$, $p = .08$, $\eta^2 = .04$.

Resulting from the original 2 × 2 × 8 ANOVA was also a significant interaction between attention and trial, $F(7, 644) = 6.06$, $p < .001$, $\eta^2 = .06$. To decompose this interaction, one-way ANOVAs examining global predictions across trials within each attention condition were conducted. In the full attention conditions, there was no main effect of trial, $F(7, 329) = 0.31$, $p = .95$, $\eta^2 = .01$. In the divided attention conditions, $F(7, 329) = 12.18$, $p < .001$, $\eta^2 = .21$, follow-up Bonferroni-corrected paired-samples *t*-tests indicated lower local confidence ratings on Trial 1 relative to Trials 2-8, *p*s < .03, on Trial 2 relative to Trial 8, $p = .02$, and no other significant comparisons, *p*s > .10. Finally, this omnibus ANOVA revealed there were main effects of presentation format, $F(1, 92) = 20.68$, $p < .001$, $\eta^2 = .13$, and attention, $F(1, 92) = 42.88$, $p < .001$, $\eta^2 = .28$, such that local confidence ratings were higher in the simultaneous format ($M = 6.47$, $SD = 2.10$) relative to the sequential format ($M = 5.02$, $SD = 1.64$), and the full attention ($M = 6.79$, $SD = 1.78$) relative to the divided attention condition ($M = 4.70$, $SD = 1.67$). There was a main effect of trial, $F(7, 644) = 5.89$, $p < .001$, $\eta^2 = .06$, which was not further explored due to the previously described two-way interactions involving the trial variable. Further, there was no interaction between presentation format and attention, $F(1, 92) = 0.64$, $p = .42$, $\eta^2 = .004$, and no three-way interaction between these variables, $F(7, 644) = 1.49$, $p = .17$, $\eta^2 = .01$. These results indicate that, consistent with global predictions, local confidence ratings were generally higher for simultaneous and full attention conditions and that simultaneous and divided attention condition predictions were higher at the end relative to the beginning of the task.

Local Confidence by Item Value. We also examined local confidence ratings as a function of item value using the same HLM described in the Memory Performance by Item Value section with confidence ratings as the outcome variable (ranging from 1 *not at all* *confident* to 10 *extremely confident*) in a non-logistic multilevel model. Firstly, there was no significant effect of value on confidence ratings for participants in the Sim-FA condition, β_{10} = 0.02, $p = .64$. This effect was consistent for the Sim-DA and Seq-DA encoding conditions as indicated by the lack of significance of the comparison coefficients, $\beta_{11} = .04$, $p = .34$, and β_{13} = .04, $p = .38$, respectively. However, the comparison between Sim-FA and Seq-FA was significant, $\beta_{12} = .13$, $p = .02$, and reconducting the model with the Seq-FA as the comparison group to obtain the simple slope indicated that item value was a positive predictor of confidence ratings in this condition, $\beta = .24$, $p < .001$. Returning to the original analysis, for the Sim-FA condition, trial was not a significant predictor of confidence ratings, $\beta_{20} = 0.04$, $p = .42$, nor was it for the Seq-FA, $\beta_{22} = -.10$, $p = .23$, or the Seq-DA conditions, $\beta_{23} = .09$, $p = .23$. There was a significant difference, however, between the Sim-FA and Sim-DA conditions, $\beta_{21} = .30$, $p = .01$; reconducting the analysis with Sim-DA as the comparison group revealed a positive relationship between trial and confidence ratings for this condition, $\beta = .34$, $p < .001$. Finally, from the original HLM, there was no interaction between item value and trial in the Sim-FA condition, β_{30} = -.01, $p = .20$, or indeed any of the other conditions, $\beta_{31} = .02$, $p = .22$, $\beta_{32} = .02$, $p = .26$, and β_{33} = .03, $p = .054$. The results from this HLM indicate that the only condition whose local confidence ratings were sensitive to item value was the Seq-FA condition where participants provided higher confidence ratings for higher value items. In addition, the only condition whose confidence ratings varied across trials was the Sim-DA condition where participants provided higher overall confidence ratings as they gained task experience.

Local Metacognitive Accuracy. Finally, we analyzed local metacognitive accuracy with respect to encoding condition. For each participant, we calculated point-biserial correlations between the local item confidence (i.e., how confident they were that an item was correctly relocated) and the binary relocation accuracy for that item (i.e., 0 = not correctly relocated, 1 = correctly relocated). The result consisted of eight point-biserial correlation coefficients for each participant representing their local metacognitive accuracy on each trial. Again, positive values indicated high local metacognitive accuracy (i.e., a positive relationship between confidence ratings and the likelihood that an item was recalled), negative values indicated a negative relationship and poor local metacognitive accuracy, and no correlation indicated a lack of relationship between confidence ratings and relocation accuracy.

The average magnitude of local prediction-performance correlations is depicted in Figure 4.4. Again, one participant was excluded from the Sim-FA condition due to providing the same confidence rating for every item on every trial, thus preventing the ability to calculate a correlation. To determine whether this measure varied as a function of encoding condition, a 2 (Presentation format: simultaneous, sequential) × 2 (Attention: full, divided) between-subjects ANOVA was conducted on average local correlation coefficients. There was a main effect of presentation format, such that local correlation coefficients were higher for sequential conditions (M = .60, SD = .14) relative to simultaneous conditions (M = .52, SD = .16), $F(1, 91) = 6.61$, p = .01, η^2 = .07. There was no main effect of attention, $F(1, 91) = 2.23$, p = .14, η^2 = .02, and no interaction between presentation format and attention, $F(1, 91) = 0.53$, p = .47, η^2 = .01. In contrast to the analyses on global correlations, the sequential presentation formats led to higher metacognitive local accuracy than did the simultaneous formats. Again, attention did not influence local metacognitive judgments in the current experiment.

Summary of Results

Tone discrimination accuracy was equivalent between presentation formats and

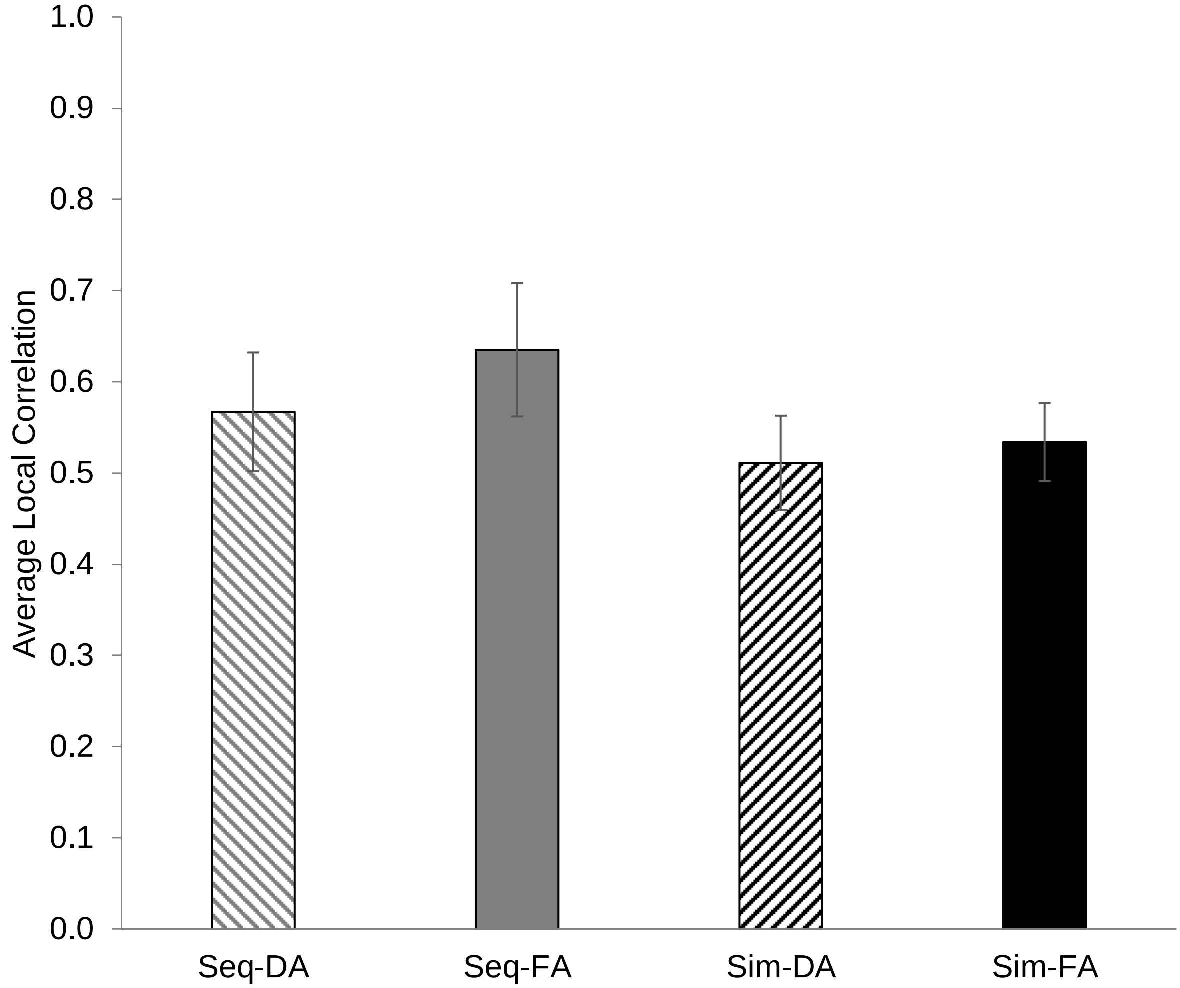

Figure 4.4. Average local correlation between the confidence ratings and relocation accuracy. Error bars represent ±1 standard error. *Sim*: simultaneous presentation format, *Seq*: sequential presentation format, *FA*: full attention, *DA*: divided attention.

significantly above chance after the second trial. In general, there was better memory performance in simultaneous relative to sequential conditions and in full relative to divided attention conditions. Participants in the divided attention conditions increased their memory performance across the task. Surprisingly, there was no effect of item value on memory, as participants displayed no selectivity. In terms of metacognitive measures, participants provided higher estimates of the number of items they thought they correctly recalled (i.e., global predictions) and higher average item confidence ratings (i.e., local confidence) in the simultaneous and full relative to sequential and divided attention conditions. These metacognitive assessments were only correct for the global predictions where participants in the simultaneous conditions were more accurate than those of the sequential condition in their predictions. On the other hand, for local confidence ratings, participants in the sequential conditions were more accurate than those in the simultaneous conditions. Whether attention was full or divided during encoding did not seem to affect either types of metacognitive accuracy.

Discussion

The results from Experiment 5 were largely consistent with prior work and our hypotheses. Memory accuracy was higher when information was presented simultaneously and under full attention conditions, relative to sequentially and divided attention conditions, suggesting that reducing participants' attentional control during encoding reduces memory performance. This may be due to various factors including higher working memory load in the sequential presentation format and divided attention conditions (Ariel et al., 2009; Middlebrooks & Castel, 2018; Siegel & Castel, 2018a, 2018b) and a reduced ability to engage in memory-aiding relational processing (Jaswal & Logie, 2011; Lilienthal, Hale, & Myerson, 2014; Taylor, Thomas, Artuso, & Eastman, 2014). Participants in divided attention conditions required adequate task experience to reach maximum memory performance, which is also consistent with prior findings suggesting that overall performance increases across trials in dual-task conditions as participants receive feedback, adjust their strategies, and generally become more familiar with the task (Castel, McGillivray, & Friedman, 2012; Middlebrooks & Castel, 2018; Siegel & Castel, 2018b).

In contrast to previous work demonstrating impaired metacognitive accuracy under conditions of divided attention (Barnes & Dougherty, 2007; Beaman et al., 2014; Kelley & Sahakyan, 2003; Sacher et al., 2009), the findings in Experiment 5 suggest relative equivalence on both local and global judgments of memory performance between full and divided attention conditions. In general, the magnitude of the metacognitive measures provided by participants in the divided attention conditions reflected their reduced memory performance, suggesting an awareness of the detrimental effect of divided attention during study on later recall. These measures were adjusted accurately on both a local and global scale, as indicated by the lack of divided attention effect on both metacognitive accuracy measures. Presentation format, however, did significantly influence metacognitive accuracy. Despite providing higher local confidence ratings and higher estimates of the number of items they would recall, the simultaneous presentation format only led to more accurate ratings of global performance, as indicated by prediction-performance correlations. Although the sequential conditions resulted in lower memory accuracy, participants were more accurate in their local confidence ratings on individual items.

These results produce an interesting dichotomy between item-level and trial-level metacognitive knowledge as a function of how the information was encountered. Previous research has suggested that the particular presentation format of information may result in different processing orientations. Sequentially presented information isolates individual items which may lead to a local-processing orientation such that participants may be more focused on the individual items themselves and related details. In contrast, simultaneously presented information may emphasize the global configuration, leading to a global-processing orientation in which more focus is dedicated to the entire array and spatial relations between items (Blalock

& Clegg, 2010; Taylor et al., 2014). Our results suggest that this orientation to processing locally or globally during encoding not only affects memory performance, but also metacognitive knowledge about one's performance during retrieval. That is, the sequential presentation may lead to a more local-processing orientation, which results in lower memory performance overall, but better knowledge of one's memory of individual items, as more attentional resources were focused on individual items during encoding. On the other hand, the simultaneous format may allow participants to better engage in relational processing, improving memory performance overall (Jaswal & Logie, 2011; Lilienthal, Hale, & Myerson, 2014) and also producing more accurate knowledge about their memory on the trial as a whole.

Most surprising was the lack of selectivity towards high-value items in any of the encoding conditions. The effect of information importance on memory is robust, even in the face of reduced attentional resources; maintained prioritization in memory is found in cognitively healthy older adults (Castel et al., 2002; Siegel & Castel, 2018a, 2019), younger adults under dual-task conditions (Middlebrooks, Kerr, & Castel, 2017; Siegel & Castel, 2018b), individuals with lower working memory capacity (Hayes et al., 2013; Robison & Unsworth, 2017) and even, to some extent, children with and without attention-deficit/hyperactivity disorder (ADHD; Castel et al., 2011) and older adults with Alzheimer's disease (Castel, Balota, & McCabe, 2009; Wong, Irish, Savage, Hodges, Piguet, & Hornberger, 2019). Further, this prioritization ability has been demonstrated in recognition (Elliott & Brewer, 2019; Gruber & Otten, 2010; Gruber, Ritchey, Wang, Doss, & Ranganath, 2016; Hennessee, Castel, & Knowlton, 2017; Hennessee, Patterson, Castel, & Knowlton, 2019; Spaniol, Schain, & Bowen, 2013), cued recall (e.g., Griffin, Benjamin, Sahakyan, & Stanley, 2019; Schwartz, Siegel, & Castel, 2020; Wolosin, Zeithamova, & Preston, 2012), and free recall memory paradigms (e.g., Castel et al., 2002; Cohen, Rissman, Hovhannisyan, Castel, & Knowlton, 2017; Nguyen, Marini, Zacharczuk, Llano, & Mudar, 2019; Stefanidi, Ellis, & Brewer, 2018), as well as with more naturalistic, real-world materials like severe medication interactions (Friedman, McGillivray, Murayama, & Castel, 2015; Hargis & Castel, 2018), potentially life-threatening allergies (Middlebrooks, McGillivray, Murayama, & Castel, 2016), and important faces (DeLozier & Rhodes, 2015; Hargis & Castel, 2017). Behavioral and eye tracking work suggests that the effect of value on memory is reflective of both automatic, bottom-up and strategic, top-down control processes, with value automatically and involuntarily capturing attention (Anderson, 2013; Sali, Anderson, & Yantis, 2014) and explicitly directing controlled, goal-oriented attention (Ariel & Castel, 2014; Ludwig & Gilchrist, 2002, 2003; for a review, see Chelazzi, Perlato, Santandrea, & Della Libera, 2013). Neuroimaging work reveals similar findings demonstrating that neural activity occurs in typical reward processing regions like the ventral tegmental area (VTA) and the nucleus accumbens (NAcc) as well as frontotemporal regions involved in executive functioning like the left inferior frontal gyrus and left posterior lateral temporal cortex (Adcock et al., 2006; Carter et al., 2009; Cohen, Rissman, Suthana, Castel, & Knowlton, 2014, 2016).

Given this wealth of past work, it is remarkable (or even perhaps implausible) that the participants in Experiment 5 displayed no selectivity whatsoever. This finding occurred despite the task being very similar to previous work using the same paradigm (Siegel & Castel, 2018a, 2018b), with the only major difference being the addition of the metacognitive measures during retrieval. Even in the condition that allowed participants to most effectively implement their strategies by affording them the highest level of attentional control, the simultaneous-full attention condition (Ariel et al., 2015; Middlebrooks & Castel, 2018; Siegel & Castel, 2018b), selectivity was essentially nonexistent, with a value-relocation accuracy regression slope of 0.01.

It would be reasonable to hypothesize then, when considering the results of Experiment 5 with previous work, that the potential underlying cause of this lack of prioritization may be due to the addition of the metacognitive measures. Given the unexpectedness of this finding, we sought to replicate this result in Experiment 6a to ensure that this lack of selectivity was actually representative of a true effect and not an artifact specific to the particular experimental design and/or participant sample.

Experiment 6a: Do Differences in Metacognitive Accuracy Persist Within-Subjects?

As described, previous work has indicated that the format in which information gets encountered may cause participants to adopt different processing orientations (Blalock & Clegg, 2010; Jaswal & Logie, 2011; Lilienthal et al., 2014; Taylor et al., 2014). The results from Experiment 5 suggest that these processing orientations during encoding may lead to differences in metacognitive resolution; sequentially presented information induces a local-processing orientation causing more accurate knowledge about one's memory for individual items, while simultaneously presented information prompts a global-processing orientation producing more accurate knowledge of one's memory performance on a whole trial. In Experiment 6a, we wanted to examine whether the differences in local and global metacognitive accuracy could be eliminated by experiencing both presentation formats in a within-participant design. We hypothesized that presenting information both sequentially and simultaneously on different trials would discourage the adoption of a predominantly local- or global-processing orientation. Instead, participants may take a more "middle of the road" approach with resources devoted equivalently to monitoring memory for both individual items and whole trial performance.

To test this hypothesis, we used a modified version of the visuospatial selectivity task from Experiment 5. Participants again completed eight study-test trials of the visuospatial grid task, but presentation format was manipulated within-subjects, such that half of participants received the first four trials of sequentially presented items and the last four trials of simultaneously presented items. The other half of participants received the opposite order. As the attention manipulation did not produce significant results on selectivity or the accuracy of metacognitive ratings, this variable was dropped in Experiment 6a and all participants studied under full attention conditions. Participants also provided a standardized measure of working memory capacity via performance on the Operation Span task (Ospan; Oswald, McAbee, Redick, & Hambrick, 2015) conducted after the completion of all eight visuospatial memory trials. While previous work has generally found that working memory capacity is unrelated to memory selectivity (Castel, Balota, & McCabe, 2009; Cohen, Rissman, Suthana, Castel, & Knowlton, 2014; Middlebrooks, Kerr, & Castel, 2018; Siegel & Castel, 2018b; cf. Griffin et al., 2019; Robison & Unsworth, 2017), there is reason to believe that working memory capacity may be related to metacognitive ability in a positive manner (Shimamura, 2000; Thomas, Bonura, Taylor, & Brunyé, 2012; Touron, Oransky, Meier, & Hines, 2010). Thus, this measure was included in an exploratory manner to examine whether participants' visuospatial memory and selectivity performance and/or metacognitive accuracy may vary with working memory capacity.

Accordingly, the goals of Experiment 6a were three-fold: 1) to replicate the unexpected null effect of value on memory performance in the presence of metacognitive judgments during retrieval, 2) to determine whether the differences in global and local metacognitive accuracy as a function of presentation format would be reduced or eliminated in a within-subjects design, and 3) to determine whether working memory capacity may be related to memory/selectivity performance or metacognitive accuracy in this task.

Method

Participants

The participants in Experiment 6a were 50 UCLA undergraduate students who participated for course credit (38 females, M_{age} = 21.44 years, SD_{age} = 5.97, age range: 18-30). In terms of the highest education level obtained, participants reported the following: 68% had some college, 18% had an associate degree, 12% had a bachelor's degree, and 2% had a graduate degree. Participants were all fluent in English and did not report any significant visual impairment. None of the participants in Experiment 5 participated in Experiment 6a.

Sample size for this experiment was based on power analyses utilizing the effect sizes between presentation formats in global (η^2 = .10) and local (η^2 = .07) metacognitive accuracy. These effect sizes were converted to Cohen's *d*s (d_{global} = .53, d_{local} = .66; Cohen, 1988) and entered into the G*Power 3.1 program (Faul, Erdfelder, Lang, & Buchner, 2007). These power analyses indicated that, to reach a desired power level of .95 with the previously obtained effect sizes in a within-subjects design, sample sizes of 32 and 49 for the global and local metacognitive differences, respectively, would be required if such an effect was to persist in the current design. As such, to adopt a conservative approach, we set our desired sample size at 50 for Experiment 6a and proceeded with data collection.

Materials and Procedure. The materials used in Experiment 6a were identical to those used in Experiment 5 (i.e., 80 simple black-and-white line drawings of everyday household items). As in the previous experiment, 10 items were randomly selected, paired with point values 1 to 10, and placed within a 5 × 5 grid to form the eight unique grids used as the study materials in this experiment.

The procedure was very similar to Experiment 5 with a few key exceptions. Firstly, there was no divided attention manipulation, only two full attention conditions (simultaneous and sequential formats). Secondly, the presentation format conditions were manipulated within-subjects. Half of the participants were randomly assigned to complete the four simultaneous trials first and then the four sequential trials (Sim-Seq) and the other half completed these trials in the opposite order (Seq-Sim). For both presentation orders, participants were instructed that the first four trials would contain all items shown at the same time (or one at a time in the Seq-Sim order) and then the last four trials with items shown one at a time (or all at the same time for the Seq-Sim order). Other than these exceptions, the procedure was identical with participants receiving instructions about the upcoming task, studying eight unique item-location grids (four sequential and four simultaneous), completing the item-relocation test with local item confidence ratings and global trial predictions, and receiving feedback on their performance.

In addition, after their participation in the visuospatial memory task, participants also completed a shortened version of the Ospan task (Oswald et al., 2015) as a measure of working memory capacity. The Ospan task instructs participants to keep a string of letters in mind while solving arithmetic problems and provides a single measure of working capacity ranging from 0 (low working memory capacity) to 30 (high working memory capacity). For a full description of the shortened OSpan task, please see Oswald and colleagues (2015). This measure was included to examine whether participants' visuospatial memory and selectivity performance and/or metacognitive accuracy may vary with working memory capacity. Finally, the experiment was concluded once participants had completed all eight trials of the visuospatial memory task and the OSpan task.

Results

The same analytical approach taken in Experiment 5 was also applied to the data from Experiment 6a. We analyzed memory performance as a function of presentation format, item value, and trial and then analyzed the local and global metacognitive measures. Finally, we correlated memory and metacognitive measures with the working memory OSpan task.

Memory Performance

We analyzed memory performance between presentation formats across trials ignoring value and then how memory performance may have differed as a function of the value of items.

Overall. We conducted a 2 (Presentation format: simultaneous, sequential) × 4 (Trial: 1, 2, 3, 4) within-subjects ANOVA on relocation accuracy and found a main effect of format such that participants had higher accuracy in the simultaneous (M = .72, SD = .16) relative to the sequential format (M = .53, SD = .14), $F(1, 49) = 72.44$, $p < .001$, $\eta_2 = .60$. There was also a main effect of trial, $F(3, 147) = 2.75$, $p = .045$, $\eta_2 = .05$, but follow-up Bonferroni-corrected paired-samples t-tests indicated no significant differences between trials, ps > .19. There was no interaction between format and trial, $F(3, 147) = 0.41$, $p = .75$, $\eta_2 = .01$. Overall, participants had better memory performance when information was presented simultaneously relative to sequentially, and this effect did depend on task experience.

By Item Value. In contrast to Experiment 5, HLM was not used as no between-subjects (i.e., group-level) variables were included in the current experiment's paradigm. Instead, a simple, level-1 logistic regression predicting the binary relocation accuracy variable from presentation format, value, and trial was used (Figure 4.5). The regression equation was of the form: Relocation Accuracy = $b_0 + b_1$ (Trial) + b_2 (Value) + b_3 (Format) + b_4 (Trial × Value) + b_5 (Trial × Format) + b_6 (Value × Format) + b_7 (Trial × Value × Format). The categorical

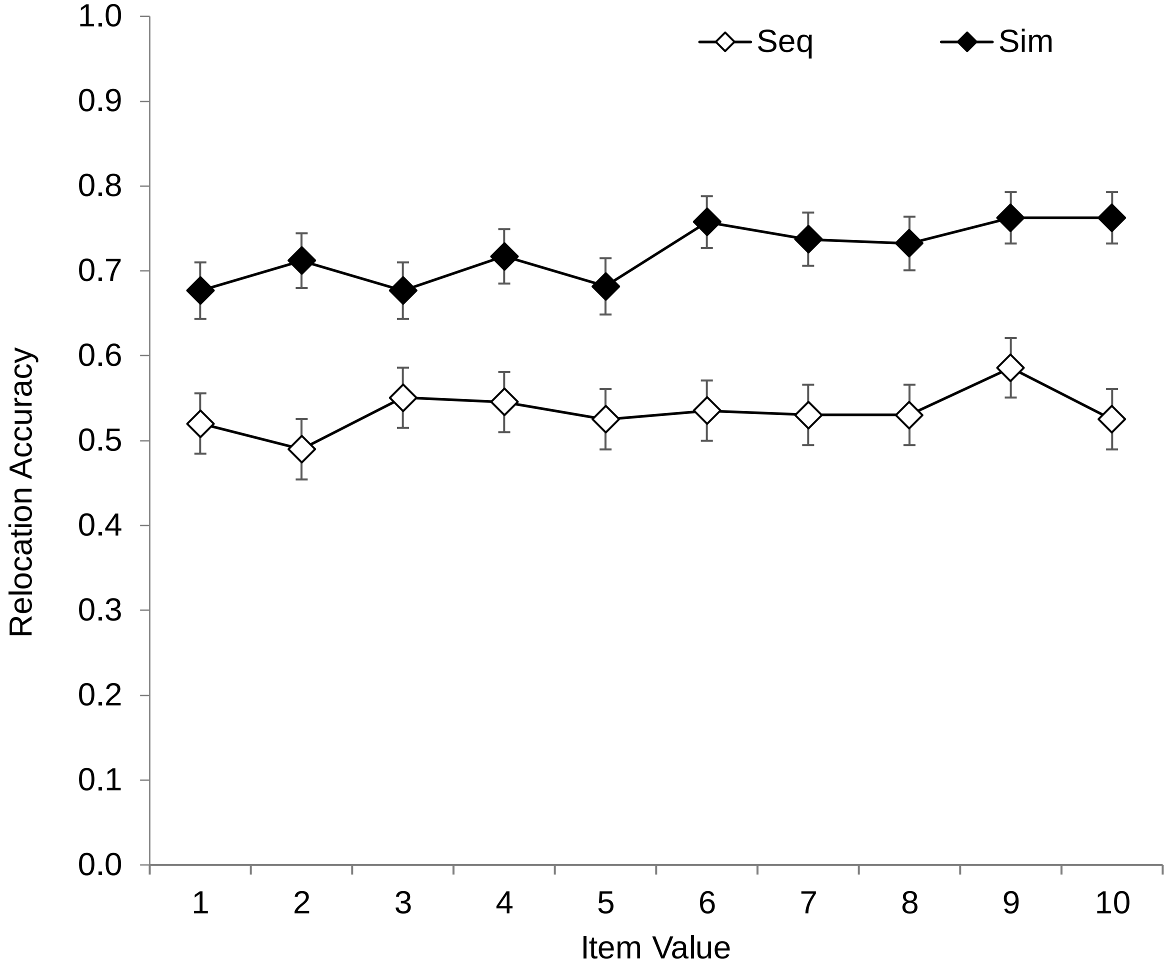

Figure 4.5. Relocation accuracy as a function of presentation format and item value averaged across grids. Error bars represent ±1 standard error. *Sim*: simultaneous presentation format, *Seq*: sequential presentation format.

presentation format variable was included as the dummy coded variable "Format" with values of 0 (*simultaneous*) or 1 (*sequential*). The continuous predictor variables Trial and Value were mean centered when entered into the model.

The model was a significant predictor of relocation accuracy, McFadden $R^2 = .03$, $\chi^2(2532) = 82.20$, $p < .001$. Neither trial nor value were significant predictors of relocation accuracy, $b_1 = .05$, $p = .35$, and $b_2 = .01$, $p = .66$. Presentation format was a significant predictor, $b_3 = -.73$, $p < .001$, indicating that there was higher accuracy in the simultaneous relative to the sequential format, replicating the ANOVA result from the previous section. None of the two-way interaction terms were significant, *p*s > .54, and neither was the three-way interaction term, $b_7 = .02$, $p = .44$. As such, the only significant finding from this analysis is that simultaneously presented information was recalled at a higher rate than sequentially presented information. Crucially, the value of items was not a significant predictor of memory performance.

Metacognitive Measures

We first analyzed whether the magnitude of local ratings and global predictions varied as a function of encoding condition and task experience and then the degree to which participants were accurate in their assessments of their performance (i.e., their metacognitive accuracy via correlational analyses) using prediction/rating-memory correlations.

Overall Global Predictions. We conducted a 2 (Presentation format: simultaneous, sequential) × 4 (Trial: 1, 2, 3, 4) within-subjects ANOVA on global predictions (i.e., how many items participants thought they correctly placed on each trial) and found a main effect of format such that participants had said they recalled more items in the simultaneous ($M = 6.17$, $SD = 1.82$) relative to the sequential format ($M = 4.40$, $SD = 1.36$), $F(1, 49) = 73.32$, $p < .001$, $\eta^2 = .60$. There was no main effect of trial, $F(3, 147) = 1.64$, $p = .18$, $\eta^2 = .03$, and no interaction between format and trial, $F(3, 147) = 0.63$, $p = .60$, $\eta^2 = .01$. Thus, the simultaneous presentation format produced higher global predictions than the sequential presentation format, and this effect did not vary across trials.

Global Metacognitive Accuracy. The average magnitude of global prediction-performance correlations is depicted in Figure 4.6. To determine whether this measure varied as

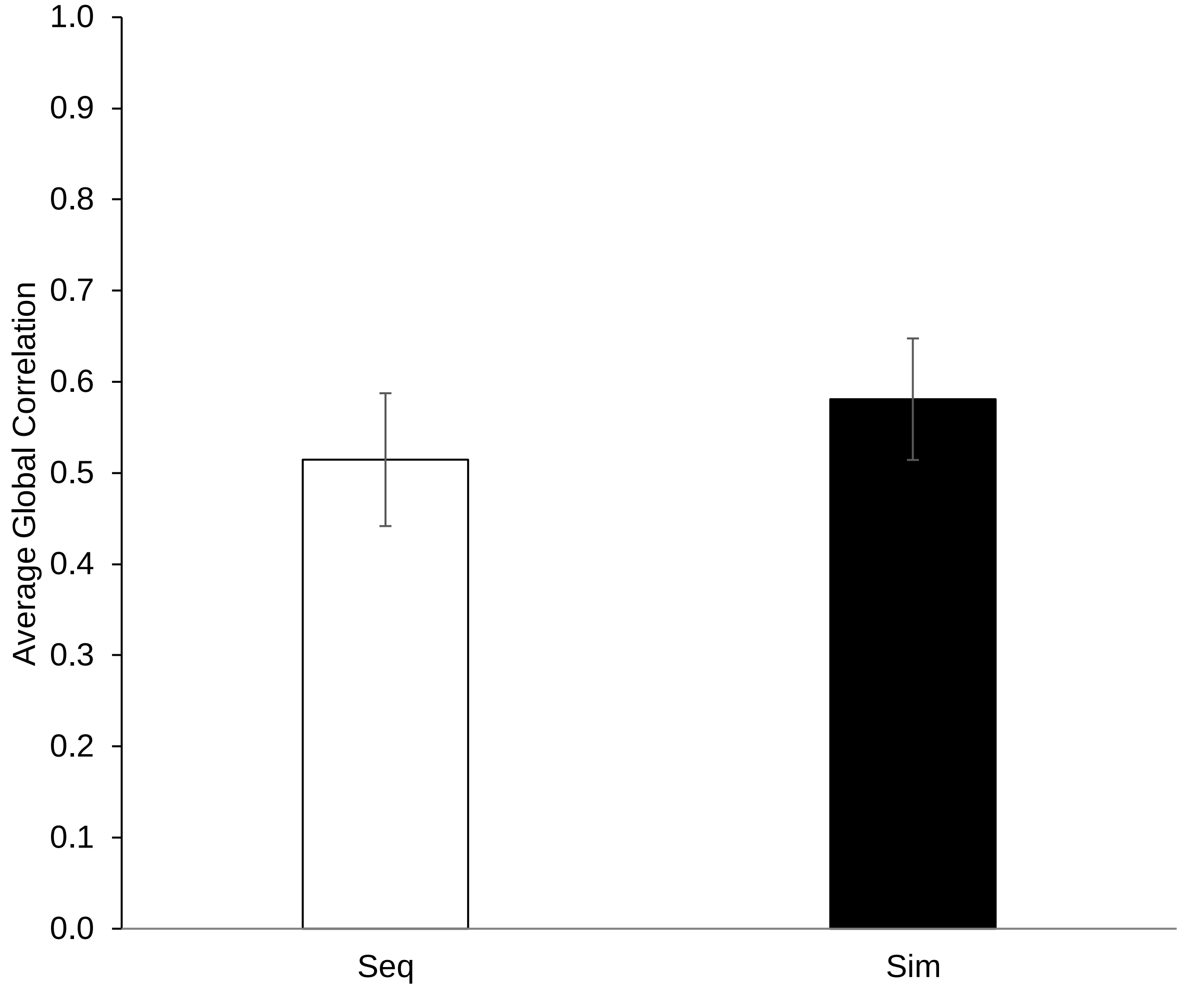

Figure 4.6. Average global correlation between the number of items predicted and number of items actually recalled in each presentation format. Error bars represent ±1 standard error. *Sim*: simultaneous presentation format, *Seq*: sequential presentation format.

a function of presentation format, a paired-samples *t*-test was conducted on average global correlation coefficients between formats. Three participants were excluded from the analysis for providing the same prediction on at least one block of four trials preventing the ability to calculate a correlation. There was no significant difference between the magnitude of correlation coefficients between the simultaneous (M = .58, SD = .46) and sequential formats (M = .52, SD =

.51), $t(46) = 0.87$, $p = .39$, Cohen's $d = .13$, suggesting that global metacognitive accuracy in this experiment did not vary as a function of presentation format.

Overall Local Confidence. We conducted a 2 (Presentation format: simultaneous, sequential) × 4 (Trial: 1, 2, 3, 4) mixed-subjects ANOVA on average local confidence ratings (i.e., the average of the individual item confidence ratings that participants provided on each trial) and found a main effect of format such that there were higher local confidence ratings in the simultaneous ($M = 7.53$, $SD = 1.52$) relative to the sequential format ($M = 5.88$, $SD = 1.53$), $F(1, 49) = 87.54$, $p < .001$, $\eta^2 = .64$. There was also a main effect of trial, $F(3, 147) = 4.08$, $p = .01$, $\eta^2 = .08$. Bonferroni-corrected paired-samples *t*-tests suggested that average ratings on Trial 1 were significantly lower than Trials 2 and 3, *p*s < .04, with no other significant comparisons. There was not a significant interaction between format and trial, $F(3, 147) = 0.36$, $p = .79$, $\eta^2 = .01$. The local confidence ratings were higher in simultaneous relative to sequential conditions and in the middle relative to the beginning and end of the task.

Local Confidence by Item Value. We conducted the same regression as the memory by item value analysis (although in simple linear regression form, not logistic regression due to the continuous dependent variable) with confidence ratings as the outcome variable (ranging from 1 *not at all confident* to 10 *extremely confident*). The regression equation was of the form: Confidence rating = b_0 + b_1 (Trial) + b_2 (Value) + b_3 (Format) + b_4 (Trial × Value) + b_5 (Trial × Format) + b_6 (Value × Format) + b_7 (Trial × Value × Format). The tested model and unstandardized coefficients are presented in Table 4.2. The model was a significant predictor of relocation accuracy, $R^2 = .06$, $F(7, 2552) = 24.08$, $p < .001$. Neither trial nor value were significant predictors of confidence ratings, $b_1 = .15$, $p = .07$, and $b_2 = .02$, $p = .64$. Presentation format was a significant predictor, $b_3 = -1.64$, $p < .001$, indicating that there were higher confidence ratings in the simultaneous relative to sequential formats, replicating the ANOVA result from the previous section. None of the two-way interaction terms were significant, *p*s > .50, and neither was the three-way interaction term, $b_7 = .05$, $p = .19$. So, the only significant finding from this analysis was that simultaneously presented information was given higher confidence ratings than sequentially presented information. Crucially, the value of items was not a significant predictor of confidence ratings.

Local Metacognitive Accuracy. For each participant, we calculated point-biserial correlations between the local item confidence (i.e., how confident they were that an item was correctly relocated) and the binary relocation accuracy for that item (i.e., 0 = not correctly relocated, 1 = correctly relocated). The average magnitude of local prediction-performance correlations is depicted in Figure 4.7 (no exclusions were necessary). Correlation coefficients averaged across trials were examined between presentation formats using a paired samples *t*-test. There was no significant difference in magnitude of correlation coefficients in the simultaneous ($M = .58$, $SD = .17$) and sequential formats ($M = .61$, $SD = .17$), $t(49) = 0.79$, $p = .44$, Cohen's $d = .11$. As such, there was no difference in local metacognitive accuracy between presentation formats in this experiment.

Correlations with OSpan

In addition to the previously described analyses mirroring those conducted in Experiment 5, we also correlated the newly collected OSpan measure (ranging from 0 indicating low working memory capacity to 30 indicating high working memory capacity) with the various memory and metacognitive measures collected in the current experiment. OSpan was not significantly correlated with relocation accuracy, $r = -.09$, $p = .53$, or the selectivity index (SI), $r = .08$, $p = .60$, a measure that represents participants' selectivity towards high-value items

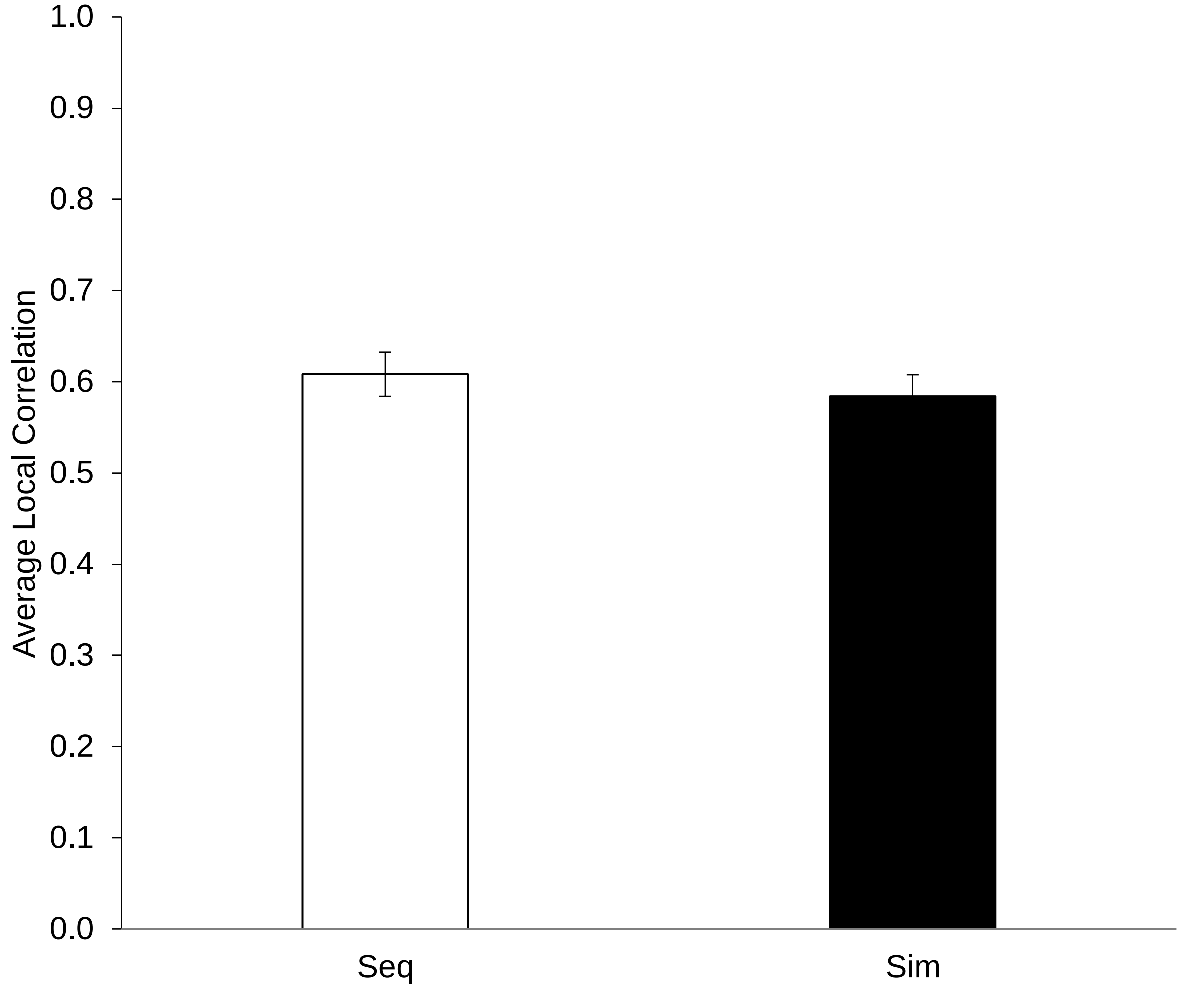

Figure 4.7. Average local correlation between the confidence ratings and relocation accuracy. Error bars represent ±1 standard error. *Sim*: simultaneous presentation format, *Seq*: sequential presentation format.

(producing SI values close to 1) or low-value items (producing SI values close to -1; see Castel, Benjamin, Craik & Watkins, 2002 for more information on SI calculations). OSpan was also not significantly correlated with the obtained metacognitive measures as it was unrelated to the average magnitude of global predictions, $r = -.01$, $p = .93$, and the average magnitude of local confidence ratings, $r = .03$, $p = .82$. Finally, no significant correlations were found between

OSpan and participants' average local, $r = .21$, $p = .14$, or global metacognitive accuracy, $r = .02$, $p = .92$. We also conducted these correlations conditionalized by presentation format and produced the exact same results (i.e., no significant correlation between OSpan and any of the measures). These analyses suggest that working memory capacity, as measured by OSpan, was not associated with the memory or metamemory measures in the current paradigm.

Between-Experiment Comparisons of Metacognitive Accuracy

We also conducted exploratory analyses to determine how local and global metacognitive accuracy may differ depending on whether participants experienced viewing both formats (as in Experiment 6a) or only one of the formats (as in Experiment 5). We hypothesized that experiencing both sequentially and simultaneously presented information on different trials would discourage the adoption of a predominantly local- or global-processing orientation with participants, instead encouraging participants to take a more "middle of the road" approach. As half of participants in Experiment 6a were first shown items sequentially in the first block and simultaneously in the second block (the "Seq-Sim" condition), we would expect that the local-processing orientation adopted during the first block would carry over into the second, increasing local metacognitive accuracy relative to when participants were only presented simultaneous information for all trials in Experiment 5 (the "Sim-Only" condition for the following analyses).

On the other hand, for the half of participants who were presented items simultaneously in the first block and sequentially in the second block in Experiment 6a (i.e., the "Sim-Seq" condition), the global-processing orientation adopted during the first block may carry over into the second block, increasing global metacognitive accuracy relative to participants who were only presented sequential information for all trials in Experiment 5 (the "Seq-Only" condition for the following analyses. In addition to these hypotheses, it is unclear whether these predicted increases in metacognitive accuracy due to experiencing both presentation formats would result in maintained or lower metacognitive accuracy for the unpracticed orientation in the second block; that is, global metacognitive accuracy may suffer when local metacognitive accuracy is increased on simultaneous trials and local metacognitive accuracy may suffer when global metacognitive accuracy is increased on sequential trials, representing a tradeoff between these two types of monitoring. These hypotheses are explored in the between-experiment analyses described below.

Seq-Sim versus Sim-Only Comparisons. To examine whether local correlation accuracy improved from Experiment 5 to Experiment 6a for simultaneously presented items, we compared the magnitude of correlation coefficients from the 24 participants in the Sim-FA condition (23 data points because of the one exclusion described in Experiment 5 due to the same confidence ratings provided for every item) with the 25 participants in Experiment 6a in the Seq-Sim format (i.e., experienced the first block of trials sequentially, and the second block simultaneously, but with the following analyses examining only simultaneous trials). Local accuracy on these simultaneous trials was compared using an independent-samples *t*-test, as the Shapiro-Wilk tests for normality (the most powerful normality assumption test; Razali & Wah, 2011) was not violated in Experiment 5, $W = .97$, $p = .79$, or Experiment 6a, $W = .97$, $p = .55$, indicating normal distributions for both samples. The one-tailed, independent-samples *t*-test suggested there was higher local accuracy in Experiment 6a ($M = .62$, $SD = .16$) relative to Experiment 5 ($M = .53$, $SD = .18$), $t(46) = 1.68$, $p = .0499$. This result suggests that having experienced the sequential format before the simultaneous format resulted in higher local metacognitive accuracy on simultaneous trials (as in Experiment 6a) relative to experiencing solely the simultaneous format (as in Experiment 5).

We also wanted to examine whether experiencing sequentially presented items may have led to a decrease in global metacognitive accuracy on later simultaneous trials representing a tradeoff between these two measures. We compared global metacognitive correlation coefficients from the Sim-FA condition in Experiment 5 (again the 23 data points were included) and from the Seq-Sim condition in Experiment 6a (including only Block 2 trials of simultaneously presented items). The Shapiro-Wilk tests for normality were violated in Experiment 5, $W = .91$, $p = .03$, and Experiment 6a, $W = .81$, $p < .001$, indicating a non-normal distribution of global metacognitive accuracy coefficients in simultaneous trials of both experiments. Due to the non-normality of distributions, the Mann-Whitney test was used as the nonparametric equivalent of the independent-samples *t*-test when distributions violate normality assumptions (Fay & Proschan, 2010; Nachar, 2008). The one-tailed Mann-Whitney test comparing mean ranks of global metacognitive accuracy on simultaneous trials indicated no significant difference between Experiment 5 (*Mean rank* = 25.30, $M = .70$, $SD = .20$) and Experiment 6a (*Mean rank* = 23.76, $M = .57$, $SD = .45$), $U = 269.00$, $p = .35$. This finding indicates that global metacognitive accuracy on simultaneous trials did not differ depending on whether participants had experienced the sequential format prior to the simultaneous format (as in Experiment 6a) or if they had only experienced the simultaneous format (as in Experiment 5).

Sim-Seq versus Seq-Only Comparisons. To examine whether global correlation accuracy improved from Experiment 5 to Experiment 6a for sequentially presented items, we compared the magnitude of correlation coefficients from the 24 participants in the Seq-FA condition (all data points were included) with the 25 participants in Experiment 6a in the Sim-Seq format (i.e., experienced the first block of trials simultaneously, and the second block sequentially, but with the following analyses examining only sequential trials). While the

Shapiro-Wilk test for normality was not violated in Experiment 5, *W* = .95, *p* = .21, it was violated in Experiment 6a, *W* = .75, *p* < .001, indicating a non-normal distribution of global metacognitive accuracy coefficients in sequential trials in Experiment 6a. As such, we used the one-tailed Mann-Whitney test comparing mean ranks of global metacognitive accuracy between experiments which indicated a significant difference, with higher global metacognitive accuracy in Experiment 6a (*Mean rank* = 29.22, *M* = .54, *SD* = .60) relative to Experiment 5 (*Mean rank* = 20.60, *M* = .43, *SD* = .36), *U* = 194.50, *p* = .02. This finding suggests that having experienced the simultaneous format before the sequential format resulted in higher global metacognitive accuracy on sequential trials (as in Experiment 6) relative to experiencing solely the sequential format (as in Experiment 5).

Finally, we also wanted to examine whether experiencing simultaneously presented items may have led to a decrease in local metacognitive accuracy on later sequential trials, thus representing a tradeoff between these two measures. We compared local metacognitive correlation coefficients from the Seq-FA condition in Experiment 5 (again all 24 data points were included) and from the Sim-Seq condition in Experiment 6a (including only Block 2 trials of sequentially presented items). Further, the Shapiro-Wilk test for normality was violated in Experiment 5, *W* = .88, *p* = .01, but not in Experiment 6a, *W* = .97, *p* = .70, indicating a non-normal distribution of local metacognitive accuracy coefficients in simultaneous trials in Experiment 5, so the Mann-Whitney test was used again. The one-tailed Mann-Whitney test comparing mean ranks between experiments suggested no significant difference in local metacognitive accuracy between Experiment 5 (*Mean rank* = 28.25, *M* = .64, *SD* = .09) relative to Experiment 6a (*Mean rank* = 21.88, *M* = .59, *SD* = .15), *U* = 222.00, *p* = .06. This finding indicates that local metacognitive accuracy on sequential trials did not differ depending on whether participants experienced the simultaneous format prior to the sequential format (as in Experiment 6a) or if they only experienced the sequential format (as in Experiment 5).

Summary of Results

Memory performance and magnitude of estimates largely mirrored the results from Experiment 5 with higher memory accuracy, global predictions, and local confidence ratings on simultaneous relative to sequential trials. The unexpected null effect of value on relocation accuracy in Experiment 5 was also replicated, with participants again demonstrating no selectivity towards high-value information in either encoding condition. Critically, in contrast to Experiment 5, there was no difference in the accuracy of the local or global estimates of performance between presentation formats. The addition of the OSpan working memory capacity measure revealed no association with memory performance, selectivity, or metacognitive measures in this task. Importantly, between-experiment comparisons indicated that participants who experienced the sequential format prior to the simultaneous format had higher local metacognitive accuracy on simultaneous trials as compared to those who only experienced the simultaneous format. On the other hand, participants who experienced the simultaneous format prior to the sequential format had higher global metacognitive accuracy than those who only experienced the sequential format. These respective increases in metacognitive accuracy in Experiment 6a did not come at the cost of the other type of metacognitive accuracy; that is, global metacognitive accuracy did not suffer when local metacognitive accuracy was increased on simultaneous trials and local metacognitive accuracy did not suffer when global metacognitive accuracy was increased on sequential trials.

Discussion

The goals of Experiment 6a were to replicate the lack of selectivity in the presence of metacognitive judgments observed in Experiment 5, to determine whether the differences in global and local metacognitive accuracy may be reduced or eliminated when participants experienced both presentation formats, and to examine how individual working memory capacity may be related to memory, selectivity, and metacognitive ability.

Firstly, we again found no relationship between item value and relocation accuracy, in stark contrast to a myriad of previous work demonstrating higher memory for higher value information with various levels of attentional control during encoding, in various attentional and memory disorders, in different memory domains and paradigms, and with both curated and naturalistic materials (e.g., Castel et al., 2002, 2009, 2011; Cohen et al., 2014, 2016; DeLozier & Rhodes, 2015; Elliott & Brewer, 2019; Friedman et al., 2015; Gallo, Hargis, & Castel, 2019; Griffin et al., 2019; Hargis & Castel, 2017, 2018; Hayes et al., 2013; Hennessee et al., 2017, 2019; Middlebrooks & Castel, 2018; Middlebrooks et al., 2016, 2017; Robison & Unsworth, 2017; Schwartz et al., 2020; Siegel & Castel, 2018a, 2018b, 2019; Spaniol et al., 2013; Stefanidi et al., 2018; Wong et al., 2019). Participants in Experiment 6a again displayed no selectivity with an item value and relocation accuracy slope of .01, almost identical to the corresponding value in Experiment 5. This result adds further evidence that the presence of a metacognitive monitoring task impairs selectivity where other previous manipulations have failed. This novel finding is further explored in Experiment 7a and interpreted in the General Discussion as a potential novel form of judgment of learning (JOL) reactivity, in which making metacognitive assessments is not an independent and separate process, but actually affects subsequent memory performance (Janes, Rivers, & Dunlosky, 2018; Mitchum, Kelley, & Fox, 2016; Rhodes & Tauber, 2011; Soderstrom, Clark, Halamish, & Bjork, 2015; Tauber & Witherby, 2019; Witherby & Tauber, 2017; cf. Double, Birney, & Walker, 2018; Tauber & Rhodes, 2012). The current study suggests that JOL reactivity not only results in changes in memory, but also the effectiveness of goal-relevant strategies. As further elaborated on below, the addition of local and global assessments to this paradigm may have drawn metacognitive resources away from prioritization during encoding and towards estimation accuracy during retrieval.

Secondly, the differences in metacognitive accuracy observed in Experiment 5, when participants were only exposed to one presentation format (either sequential or simultaneous), were eliminated when participants in Experiment 6a encountered both formats in separate trials during the task; the advantage of the sequential format with higher correlations between local item confidence ratings and relocation accuracy, and the advantage of the simultaneous format with higher correlations between global trial predictions and the number of items recalled were no longer present. Further, between-experiment comparisons suggested that having experienced the sequential format prior to the simultaneous format led to higher local metacognitive accuracy on simultaneous trials than only experiencing the simultaneous format. Conversely, experiencing the simultaneous format prior to the sequential led to higher global metacognitive accuracy than experiencing only the sequential format. These increases in local and global accuracy did not occur at a cost of the other form of accuracy, suggesting that the experience of both presentation formats did not result in a tradeoff in metacognitive monitoring resources (indicating a switch from a local-to-global or global-to-local processing orientation); rather, the results indicate that the specific orientation adopted by participants from the first block of trials persisted into the second block and, importantly, did not hinder the adoption of the other orientation usually produced by the second block of trials.

As such, when participants experienced both presentation formats, they were less likely to prioritize local over global features (or vice versa), instead implementing a more comprehensive, “middle of the road” metacognitive monitoring approach, indicated by higher local and global monitoring accuracy. It is important to note that the between-experiment findings should be interpreted with caution. Future work is needed to more explicitly determine the underlying mechanism that is suggested by the between-experiment analyses, perhaps directly comparing participants randomly assigned to conditions where they either experience only one or both formats and examining differences in local and global metacognitive accuracy. What is clear is that the differences in metacognitive monitoring accuracy as a function of presentation format found in Experiment 5 were eliminated in Experiment 6a when format was manipulated within-subjects, suggesting that instead of adopting a predominantly local-processing or global-processing orientation during encoding, participants may take both item-level and trial-level metacognitive information more effectively into account and produce equally accurate estimates of their own performance on these measures.

Finally, consistent with various other studies examining VDR, working memory capacity measured in the current study via the OSpan task was not associated with any memory or selectivity measures (Castel et al., 2009; Cohen et al., 2014; Middlebrooks et al., 2017; Siegel & Castel, 2018b; cf. Griffin et al., 2019; Robison & Unsworth, 2017). This was the case regardless of presentation format. Despite prior work indicating that metacognitive monitoring processes may be positively associated with working memory capacity (Shimamura, 2000; Thomas et al., 2012; Touron et al., 2010), the results obtained in Experiment 6a suggest that, at least in the context of a visuospatial VDR task, neither local nor global metacognitive monitoring ability was related to working memory capacity. This result presents a novel finding by suggesting that the metacognitive mechanisms necessary for monitoring memory of local and global features of information may be unassociated with the amount of information one can hold in working memory. This result should be expanded upon in future work to explore more in-depth the relationship between working memory capacity and metacognitive monitoring ability by utilizing different materials (e.g., individual verbal and verbally associated information as in Ariel et al., 2015) and measures of working memory capacity (e.g., symmetry span and reading span as in Robison and Unsworth, 2017) in order to produce consistent and generalizable results. What can be concluded from the current study, however, is that much like memory and selectivity represent dissociable cognitive processes (Castel, 2008; Siegel & Castel, 2019), working memory capacity and metacognitive monitoring ability also appear to rely on separate, distinct mechanisms. This potential dissociation is further tested in Experiment 7a in which older adults', who typically have lower working memory capacity (e.g., Park et al., 2002), global and local metacognitive monitoring is compared to their younger adult counterparts.

Experiment 6b: Age-Related Similarities and Differences in Local and Global Metacognitive Monitoring in a Visuospatial Value-Directed Task

Another primary goal of the current set of experiments was to determine how aging may affect metacognitive accuracy for information of differing importance. This type of metacognitive monitoring may be interesting to study in the context of cognitively healthy older adults for a number of reasons. In general, older adults have been shown to generally be equally as selective as younger adults in both verbal and visuospatial memory tasks (Ariel et al., 2015; Castel et al., 2002, 2013; Siegel & Castel, 2018b, 2019). Despite lower memory capacity for individual items/features and even further impaired ability to remember associations (Castel & Craik, 2003; Naveh-Benjamin, 2000), older have shown intact prioritization ability in both verbal (Ariel et al., 2015) and visuospatial (Siegel & Castel, 2018a) associative memory contexts. These findings suggest that older adults are metacognitively aware of their reduced memory capacity and subsequently adjust their strategies to account for such decline demonstrating a dissociation between age-related deficits in memory and equivalence in metacognitive monitoring. Other work has also shown that metacognitive processes associated with memory may experience little to no age-related decline in some circumstances (Castel et al., 2002; Castel et al., 2016; Hertzog & Dunlosky, 2011; Shaw & Craik, 1989), which may be especially important for aging across the lifespan due to an increase in memory errors with age (Hertzog & Dixon, 1994).

Although there may be negligible differences in local-item JOL accuracy between younger and older adults (Connor, Dunlosky, & Hertzog, 1997; Hertzog et al., 2002, 2010; Lovelace, 1990; Lovelace & Marsh, 1985; Rabinowitz, Ackerman, Craik, & Hinchley, 1982; Robinson, Hertzog, & Dunlosky, 2006), the particular type of metacognitive judgement (local, global) may indeed differentially impact older adults' memory accuracy more so than younger adults. In contrast to item-by-item JOLs, older adults may be less accurate and, in particular, more overconfident when making global predictions about their performance on an entire set of to-be-remembered materials (Bruce, Coyne, & Botwinick, 1982; Connor et al., 1997; Hertzog, Saylor, Fleece, & Dixon, 1994; Siegel & Castel, 2019; Touron, Oransky, Meier, & Hines, 2010). Evidently, older adults may have difficulty applying the information they have gained from item-level monitoring during memory encoding to later make global metacognitive assessments.

Further, in the visuospatial domain, some work has provided evidence of age-related deficits in metacognitive judgements of location features (e.g., monitoring memory for where an item was located), but not item identity features (e.g., monitoring memory for whether an item was previously presented), suggesting that the effect of aging on metamemory, in the context of visuospatial information, may be even more nuanced (Thomas et al., 2012). Apart from metacognitive differences, older adults may be equally as accurate in predicting their selectivity in a value-directed remembering task, but less accurate in predicting their overall memory capacity (Siegel & Castel, 2019). As such, the monitoring of memory for differentially important information is worthy of investigation in order to clarify age-related differences and similarities in the metacognitive processes associated with prioritization in memory.

The goal of Experiment 6b, then, was to examine differences in local and global metacognitive accuracy between younger and older adults. We were interested in whether older adults, who may have maintained prioritization ability (Ariel et al., 2015; Castel et al., 2002, 2013; Siegel & Castel, 2018a) and metacognitive abilities (Castel et al., 2016; Hertzog & Dunlosky, 2011), would exhibit similar tradeoffs in metacognitive resources between selective encoding and local/global memory monitoring similar to younger adults. As such, older adult participants were collected online using CloudResearch Prime Panels (www.cloudresearch.com), an online data collection platform that has been empirically shown to be representative of the United States population and thus provides an easily accessible and reliable source of older adult data (Chandler, Rosenzweig, Moss, Robinson, & Litman, 2019). Older adults in Experiment 6b completed eight visuospatial VDR trials of the same within-subjects design as younger adults in Experiment 6a (four trials of the simultaneous format and four trials of the sequential format in counterbalanced orders) with the goal of examining differences in local and global metacognitive accuracy dependent on presentation format and whether selectivity towards high-value items would be eliminated with the addition of the metacognitive judgments. We also conducted post-hoc between-experiment comparisons between younger and older adults in Experiments 8a and 8b to identify potential age-related differences in overall memory and metacognitive accuracy.

Method

Participants

The participants in Experiment 6b were older adults who were recruited online via Prime Panels on CloudResearch (formerly known as Turkprime; www.cloudresearch.com). Similar to other online data collection platforms like Amazon Mechanical Turk (MTurk), CloudResearch's Prime Panels allows for researchers to target and collect large, diverse samples of participants in a way that is both time and resource efficient. Importantly, this efficiency does not appear to come at the cost of data quality, as Prime Panels participants have been shown to produce similar rates of passing attention checks and similar effect sizes as other online and in-lab samples, while being more demographically diverse and representative of the U.S. population (Chandler et al., 2019). Prime Panels also has the advantage of having a larger proportion of older adults, with over 23% of participants over the age of 60 relative to only 3.3% of MTurk participants meeting the same criterion (Chandler et al., 2019; Huff & Tingley, 2015). As such, Prime Panels, despite obvious limitations inherent to online data collection (e.g., less monitoring of participants during a task), offers a compelling alternative to in-lab experimentation by providing a useful tool to efficiently obtain quality older adult data.

Given the power analyses conducted based on the data obtained from Experiment 5, 50 older adults were recruited via CloudResearch's Prime Panels and were randomly assigned evenly into the two between-subjects' conditions (i.e., Sim-Seq and Seq-Sim). Participants were restricted to be age 65+, reside in the United States, and have at least a high school degree. Further, to ensure participants were attending to the task, a measure of participants' focus on the experiment was used as an exclusion criterion. The focus measure was the proportion of time of which a participant's computer mouse was present on the experiment browser page with 1 representing 100% attention on the task and 0 representing 0% attention on the task. Participants were excluded from the experiment if they had a focus less than 75% for the duration of the experiment. Data were collected until 50 participants met this criterion.

The final sample of consisted of 50 older adult participants (30 females, M_{age} = 70.64 years, SD_{age} = 4.02, age range: 64-82) who reported the following highest levels of education: 22% high school degree, 16% associate degree, 14% some college, 26% bachelor's degree, and 22% graduate degree. All participants were residents of the United States at the time of collection and were self-reported fluent in English. Participants were compensated $2.00 for their participation in the task which lasted approximately 20 min.

Materials and Procedure

The materials were identical to Experiment 6a using the same 80 black-and-white line drawings randomly distributed in eight grids (ten per grid) for each participant. The procedure was also identical to Experiment 5a with participants randomly assigned in even groups to complete four simultaneous trials and then four sequential trials (Sim-Seq) or vice-versa (Seq-Sim). All participants were instructed that they would be presented with ten items placed within a 5 × 5 grid and would be later tested on that information via a relocation test. Participants were further instructed that each item would be paired with a point value from 1 to 10 and that their goal was to maximize their point score on each trial. Participants completed all eight study-test cycles according to their particular order (Sim-Seq or Seq-Sim). The OSpan measure collected in Experiment 6a was not collected in this experiment.

Results

The same analytical approach taken in Experiment 6a was also applied to the data from Experiment 6b. We analyzed memory performance as a function of presentation format, item value, and trial and then analyzed the local and global metacognitive measures. Finally, we conducted between experiment analyses to investigate age-related differences in memory, overall judgments, and metacognitive accuracy.

Memory Performance

We analyzed memory performance between presentation formats across trials ignoring value and then how memory performance may have differed as a function of the value of items.

Overall. We conducted a 2 (Presentation format: simultaneous, sequential) × 4 (Trial: 1, 2, 3, 4) within-subjects ANOVA on relocation accuracy and found a main effect of format such that older adults had higher accuracy in the simultaneous (M = .56, SD = .22) relative to sequential format (M = .48, SD = .20), $F(1, 49) = 8.81$, $p = .01$, $\eta^2 = .15$. There was no main effect of trial, $F(3, 147) = 2.17$, $p = .09$, $\eta^2 = .04$, and no interaction between format and trial, $F(3, 147) = 0.52$, $p = .67$, $\eta^2 = .01$. Overall, participants had better memory performance when information was presented simultaneously relative to sequentially, and this effect did depend on task experience.

By Item Value. A level-1 (non-hierarchical) logistic regression predicting the binary relocation accuracy variable from presentation format, value, and trial was conducted (Figure 4.8). The regression equation was of the form: Relocation Accuracy = $b_0 + b_1$ (Trial) + b_2 (Value) + b_3 (Format) + b_4 (Trial × Value) + b_5 (Trial × Format) + b_6 (Value × Format) + b_7 (Trial × Value × Format). The categorical presentation format variable was included as the dummy coded variable "Format" with values of 0 (*simultaneous*) or 1 (*sequential*). The continuous predictor variables Trial and Value were mean centered when entered into the model.

The model was a significant predictor of relocation accuracy, McFadden $R^2 = .01$, $\chi^2(3992) = 30.70$, $p < .001$. Neither trial nor value were significant predictors of relocation

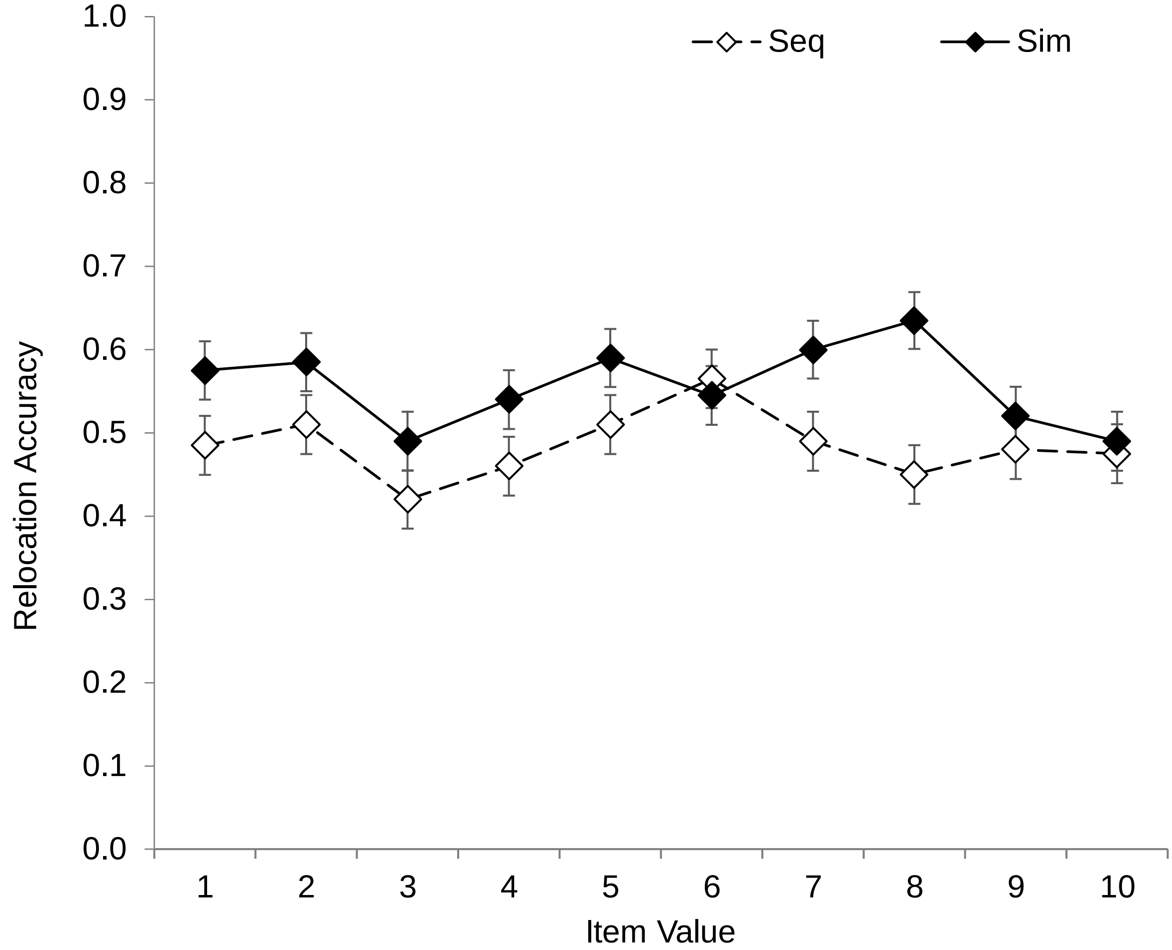

Figure 4.8. Relocation accuracy as a function of presentation format and item value averaged across grids. Error bars represent ±1 standard error. *Sim*: simultaneous presentation format, *Seq*: sequential presentation format.

accuracy, $b_1 = .06$, $p = .15$, and $b_2 = -.01$, $p = .57$. Presentation format was a significant predictor, $b_3 = -.29$, $p < .001$, indicating that there was higher accuracy in the simultaneous relative to sequential formats, replicating the ANOVA result from the previous section. None of the two-way interaction terms were significant, *p*s > .44, and neither was the three-way interaction term, $b_7 = -.01$, $p = .74$. As such, the only significant finding from this analysis is that simultaneously presented information was recalled at a higher rate than sequentially presented information. Again, the value of items was not a significant predictor of memory performance.

Metacognitive Measures

We first analyzed whether the magnitude of local ratings and global predictions varied as a function of encoding condition and task experience and then the degree to which participants were accurate in their assessments of their performance (i.e., their metacognitive accuracy via correlational analyses) using prediction/rating-memory correlations.

Overall Global Predictions. We conducted a 2 (Presentation format: simultaneous, sequential) × 4 (Trial: 1, 2, 3, 4) within-subjects ANOVA on global predictions (i.e., how many items participants thought they correctly placed on each trial) and found a main effect of format such that participants had said they recalled more items in the simultaneous (M = 4.83, SD = 2.34) relative to the sequential format (M = 3.99, SD = 2.19), $F(1, 49) = 18.65$, $p < .001$, $\eta^2 = .28$. There was no main effect of trial, $F(3, 147) = 0.18$, $p = .91$, $\eta^2 = .004$, and no interaction between format and trial, $F(3, 147) = 0.43$, $p = .73$, $\eta^2 = .01$. Thus, the simultaneous presentation format produced higher global predictions than the sequential presentation format, and this effect did not vary across trials.

Global Metacognitive Accuracy. The average magnitude of global prediction-performance correlations is depicted in Figure 4.9. To determine whether this measure varied as a function of presentation format, a paired-samples t-test was conducted on average global correlation coefficients between formats. Nine participants were excluded from the analysis for providing the same prediction on at least one block of four trials preventing the ability to calculate a correlation. There was no significant difference between the magnitude of correlation coefficients between the simultaneous (M = .52, SD = .46) and sequential formats (M = .59, SD =

.45), $t(39) = 0.86$, $p = .39$, Cohen's $d = .14$, suggesting that global metacognitive accuracy in this experiment did not vary as a function of presentation format.

Overall Local Confidence. We conducted a 2 (Presentation format: simultaneous, sequential) × 4 (Trial: 1, 2, 3, 4) mixed-subjects ANOVA on average local confidence ratings (i.e., the average of the individual item confidence ratings that participants provided on each trial) and found a main effect of format such that there were higher local confidence ratings in the simultaneous ($M = 5.88$, $SD = 2.57$) relative to the sequential format ($M = 5.07$, $SD = 2.39$), $F(1, 49) = 11.51$, $p = .001$, $\eta^2 = .19$. There was also no main effect of trial, $F(3, 147) = 0.89$, $p = .45$, $\eta^2 = .02$, and no significant interaction between format and trial, $F(3, 147) = 2.07$, $p = .11$, $\eta^2 = .04$. So, local confidence ratings were higher in simultaneous relative to sequential conditions with no changes across trials.

Local Confidence by Item Value. We conducted the same regression as the memory by item value analysis (although in simple linear regression form, not logistic regression due to the continuous dependent variable) with confidence ratings as the outcome variable (ranging from 1 *not at all confident* to 10 *extremely confident*). The regression equation was of the form: Confidence rating = $b_0 + b_1$ (Trial) + b_2 (Value) + b_3 (Format) + b_4 (Trial × Value) + b_5 (Trial × Format) + b_6 (Value × Format) + b_7 (Trial × Value × Format). The tested model and unstandardized coefficients are presented in Table 4.2. The model was a significant predictor of confidence ratings, $R^2 = .01$, $F(7, 3998) = 7.95$, $p < .001$. Neither trial nor value were significant predictors of confidence ratings, $b_1 = -.11$, $p = .15$, and $b_2 = -.01$, $p = .73$. Presentation format was a significant predictor, $b_3 = -.80$, $p < .001$, indicating that there were higher confidence ratings in the simultaneous relative to sequential formats, replicating the ANOVA result from the

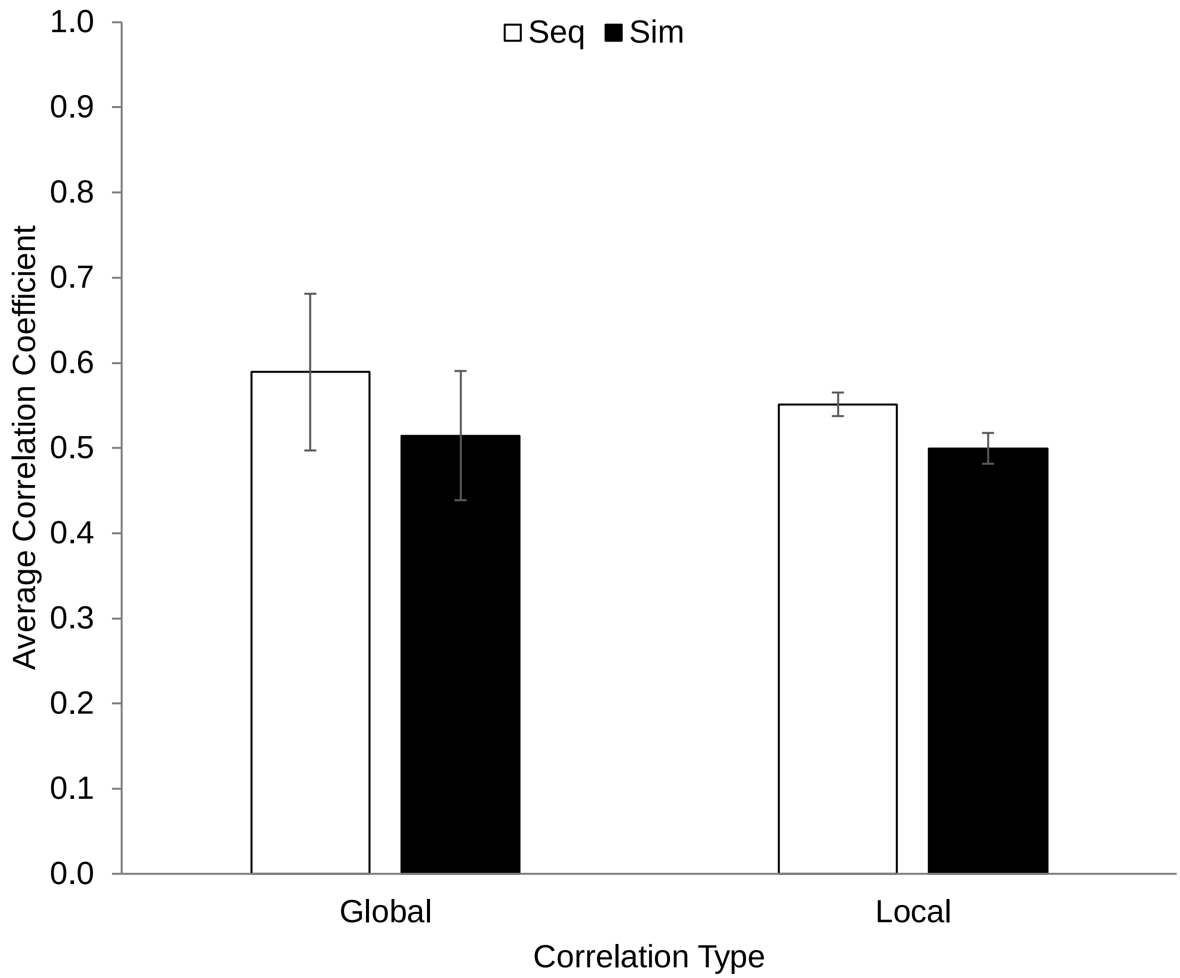

Figure 4.9. Average global and local correlations as a function of presentation format. Error bars represent ±1 standard error. *Sim*: simultaneous presentation format, *Seq*: sequential presentation format.

previous section. There was also a significant interaction between format and trial, $b_5 = .28$, $p = .01$. To decompose this interaction, separate linear regressions analyzing the effect of trial on confidence within each format were conducted. In the simultaneous format, the model including the trial predictor was not significant, $R_2 = .001$, $F(1, 1998) = 6.47$, $p = .01$. In the sequential format, however, the model was significant, $R_2 = .003$, $F(1,1998) = 7.95$, $p < .001$, with trial being a significantly positive predictor of confidence ratings, $b_1 = .03$, $p = .01$. Returning to the original regression, there were no other significant two-way or three-way interactions, *p*s > .68. These findings indicate that confidence ratings were higher in the simultaneous relative to the sequential format and that confidence ratings in the sequential format increased across trials. Crucially, the value of items was not a significant predictor of confidence ratings in either format.

Local Metacognitive Accuracy. For each participant, we calculated point-biserial correlations between the local item confidence (i.e., how confident they were that an item was correctly relocated) and the binary relocation accuracy for that item (i.e., 0 = not correctly relocated, 1 = correctly relocated). The average magnitude of local prediction-performance correlations is depicted in Figure 4.9 (five exclusions were made due to the inability to calculate correlations for participants whose ratings did not vary). Correlation coefficients averaged across trials were examined between presentation formats using a paired samples *t*-test. There was no significant difference in magnitude of correlation coefficients in the simultaneous ($M = .50$, $SD = .22$) and sequential formats ($M = .55$, $SD = .18$), $t(43) = 0.91$, $p = .37$, Cohen's $d = .14$, indicating no difference in local metacognitive accuracy between presentation formats for older adults.

Between-Experiment Comparisons of Age Differences

To examine how our dependent measures may have varied between age groups in Experiment 6a (younger adults) and 6b (older adults), we conducted 2 (Age group: younger adults, older adults) × 2 (Presentation format: simultaneous, sequential) mixed-subjects ANOVAs on relocation accuracy, global prediction magnitude, global metacognitive accuracy, local confidence magnitude, and local metacognitive accuracy. Younger adults ($M = .63$, $SD = .13$) had higher relocation accuracy than older adults ($M = .52$, $SD = .19$), $F(1, 98) = 10.22$, $p =$

.002, η^2 = .09. There was a main effect of format, $F(1, 98) = 62.18$, $p < .001$, η^2 = .36, but also an interaction between age group and format, $F(1, 98) = 11.97$, $p < .001$, η^2 = .07. To decompose this interaction, the effect of age group on relocation accuracy was examined within each presentation format using Bonferroni-corrected independent samples *t*-tests. In the simultaneous format, younger adults had higher relocation accuracy than older adults, $t(98) = 4.16$, $p < .001$, but in the sequential format there was no difference between age groups, $t(98) = 1.41$, $p = .32$.

Younger adults ($M = 5.28$, $SD = 1.43$) also provided higher global predictions than older adults ($M = 4.41$, $SD = 2.16$), $F(1, 98) = 5.69$, $p = .02$, η^2 = .06. Again, there was a main effect of format, $F(1, 98) = 84.78$, $p < .001$, η^2 = .44, but also an interaction between age group and format, $F(1, 98) = 11.00$, $p = .001$, η^2 = .06. Bonferroni-corrected independent samples *t*-tests revealed higher global predictions for younger adults relative to older adults in the simultaneous format, $t(98) = 3.21$, $p = .004$, but no difference in the sequential format, $t(98) = 1.11$, $p = .54$. In terms of the accuracy of global predictions, there was no main effect of age group on the average global correlation ($M_{younger} = .54$, $SD_{younger} = .37$, $M_{older} = .56$, $SD_{older} = .33$), $F(1, 85) = 0.07$, p = .79, η^2 = .001, no main effect of format, $F(1, 85) = 0.003$, $p = .95$, $\eta^2 < .001$, and no interaction, $F(1, 85) = 1.49$, $p = .23$, η^2 = .02, indicating age equivalence in global metacognitive accuracy.

In terms of local confidence ratings, younger adults ($M = 6.70$, $SD = 1.39$) provided higher local confidence ratings on average relative to older adults ($M = 5.47$, $SD = 2.34$), $F(1, 98) = 10.20$, $p = .002$, η^2 = .09. There was a main effect of format, $F(1, 98) = 69.10$, $p < .001$, η^2 = .39, but also an interaction between age and format, $F(1, 85) = 8.30$, $p = .01$, η^2 = .05. Bonferroni-corrected independent samples *t*-tests revealed higher local confidence ratings for younger adults relative to older adults in the simultaneous format, $t(98) = 3.91$, $p < .001$, but no difference in the sequential format, $t(98) = 2.00$, $p = .10$. Finally, there was a significant difference between age groups in local correlation accuracy ($M_{younger}$ = .60, $SD_{younger}$ = .13, M_{older} = .52, SD_{older} = .15), $F(1, 92) = 6.76$, $p = .01$, $\eta^2 = .07$. There was no main effect of format, $F(1, 92) = 1.48$, $p = .23$, $\eta^2 = .02$, and no interaction, $F(1, 92) = 0.05$, $p = .82$, $\eta^2 = .001$. Taken together, these findings indicate that younger adults recalled more items correctly, had higher local confidence ratings, and higher global estimates than did older adults. For the metacognitive measures, there were no age differences in global metacognitive accuracy, but older adults were less accurate in their local confidence ratings relative to younger adults.

Summary of Results

Similar to younger adults in Experiment 6a, older adults in Experiment 6b had higher memory accuracy, global predictions, and local confidence ratings on simultaneous relative to sequential trials. Older adults also displayed no selectivity towards high-value information in either encoding condition and there was no difference in the accuracy of the local or global estimates of performance between presentation formats. Between-experiment age comparisons indicated that older adults were less accurate in their memory for items in the simultaneous format, but equally as accurate under sequential format conditions. Older adults also predicted they would remember less information overall relative to younger adults resulting in equivalent global metacognitive accuracy. However, despite providing lower local confidence ratings overall, older adults were less locally metacognitively accurate than younger adults, as indicated by smaller average correlations between confidence ratings and relocation accuracy.

Discussion

The results from older adults in Experiment 6b are largely similar to the findings obtained from younger adults. Overall visuospatial memory was more accurate under simultaneous format conditions relative to sequential format conditions, also consistent with prior work in younger adults (Blalock & Clegg, 2010; Lecerf & de Ribaupierre, 2005; Middlebrooks & Castel, 2018). The addition of metacognitive judgments in the current experiment also resulted in a lack of selectivity, whereas previous work employing the same visuospatial VDR task without these ratings found that older adults could engage in value-based encoding strategies even under cognitively demanding conditions like associative binding and sequential presentation formats (Ariel et al., 2015; Siegel & Castel, 2018a). So, despite displaying equivalent or even greater selectivity than younger adults in some circumstances (Castel, 2008), the results from the current study suggest older adults are also potentially susceptible to this tradeoff in metacognitive resources between prioritization during encoding and accurate local/global memory monitoring – the mechanism underlying this tradeoff in older adults is further explored in Experiment 7b. Finally, older adults also appear to be able to take a more "middle of the road" approach to their processing orientation during encoding as evidenced by equivalent local and global metacognitive accuracy. This finding suggests some cognitive flexibility on behalf of older adults whose metacognitive accuracy did not suffer as a function of a particular presentation format first or when switching between formats. Future work should extend this finding by comparing older adults who only experience one presentation format to those who experience both to more directly investigate how different processing orientations may be adopted under these circumstances and whether older adults' metacognitive accuracy can benefit from experiencing multiple formats, as was done in the between-experiments comparisons for younger adults in Experiments 5 and 6a.

As revealed by the between-experiments age comparisons, younger adults were more accurate overall in their item-location binding than older adults, replicating previous work demonstrating an associative deficit in visuospatial memory (Chalfonte & Johnson, 1996; Siegel

& Castel, 2018a; Thomas et al., 2012). When examining memory as a function of presentation format, however, age-related differences were only present for simultaneously presented information, but not sequentially presented information. This finding conflicts with previous work (Siegel & Castel, 2018a) which found age-related deficits in both format types. The age of older adult participants who were presented information sequentially in Siegel and Castel (2018a) was higher on average (M = 78.75, SD = 8.01) than the older adults in the current experiment (M = 70.64 years, SD = 4.02), $t(72) = 5.82$, $p < .001$. As such, it is likely that the younger-older adults in the current experiment may have relatively less age-related memory capacity decline resulting in negligible differences between age groups for both presentation formats in the current study. In any case, despite an almost 50-year difference on average between younger adults and older adults in Experiments 6a and 6b, older adults had equivalent memory accuracy in the cognitively demanding sequential format which should not go unrecognized. In the simultaneous format, goal-related strategies may be more easily implemented (Ariel et al., 2009; Dunlosky & Thiede, 2004; Middlebrooks & Castel, 2018), but older adults may be less likely to self-initiate the use of such strategies (Ariel et al., 2015), perhaps allowing younger adults to more effectively encode item-locations in the current study, but providing no such benefit to older adults. Given that older adults may be able to use effective strategies to improve memory if explicitly instructed to do so (e.g., Dunlosky, Kubat-Silman, & Hertzog, 2003; Hertzog, Price, & Dunlosky, 2012; Naveh-Benjamin, Brav, & Levy, 2007), future research should explore how older adults' item-location memory in simultaneous presentation conditions may be enhanced by direct instructions of effective mnemonic strategies like elaborative and relational encoding, which could potentially reduce or eliminate age-related differences for this information.

One of the main goals of the current experiment was to examine the age-related similarities and differences in metacognitive accuracy. The findings from the between-experiment analyses of local and global metacognitive accuracy are inconsistent with previous work which has found negligible age-related differences in local JOL accuracy (Connor et al., 1997; Hertzog et al., 2002, 2010; Lovelace, 1990; Lovelace & Marsh, 1985; Rabinowitz et al., 1982; Robinson et al., 2006) and age-related overconfidence in global assessments of performance (Bruce et al., 1982; Connor et al., 1997; Hertzog et al., 1994; Siegel & Castel, 2019; Touron et al., 2010). Several factors may be contributing to this inconsistency. Firstly, the demanding nature of the associative memory task used in the current study (e.g., item-location binding) may not only impair older adults' memory to a greater extent than younger adults, as detailed in the associative deficit hypothesis (Naveh-Benjamin, 2000; Naveh-Benjamin & Mayr, 2018), but also older adults' local metacognitive abilities. This could be directly tested by examining age-related differences in metacognitive accuracy for individual stimuli (e.g., JOLs for single words) compared to associative stimuli (e.g., JOLs for word pairs) with results from the current study predicting less metacognitive accuracy for associated information in older adults.

Secondly, local metacognitive ratings in the current study were made during retrieval (i.e., how confident participants were in relocating an item), not during encoding when typical JOLs are made (i.e., making a judgment about how likely an item is to be later recalled when initially studying). While older adults may be able to equally assess how likely they are to remember a piece of information *before* they attempt to retrieve it (i.e., during learning), the results from the current study suggest that *after* the attempted retrieval has occurred, accuracy may suffer, resulting in age-related decrements in the strength of confidence-memory relationships. As of yet, the mechanism driving this difference in pre-retrieval and post-retrieval metacognitive accuracy remains unclear, but one may speculate that the process of retrieving information from memory is particularly draining for older adults who may already have fewer available cognitive resources (Castel & Craik, 2003; Craik & Byrd, 1982), leading to less accurate confidence ratings which may also rely on cognitive resources. This, however, remains to be clarified by future work.

Finally, with regards to age equivalence in global metacognitive accuracy in the current experiment, receiving explicit feedback on the number of items correctly relocated after each trial may have provided older adults with schematic support on which to anchor their subsequent global prediction. Prior work has shown that older adults' memory may be equivalent to younger adults in some circumstances when schematic knowledge can be applied (Castel, 2005; Mather, Johnson, & De Leonardis, 1999; McGillivray & Castel, 2010), and given that older adults' memory performance was relatively consistent across trials, it is possible that older adults may have relied on the feedback from the previous trial to inform their predictions about the current trial. In fact, other work has shown that pre-trial predictions may be more highly correlated with previous trial performance than current trial performance (Hertzog, Dixon, & Hultsch, 1990) and that this effect exists to an equivalent extent in both younger and older adults (Siegel & Castel, 2019; Tauber & Rhodes, 2012), implying reliance on previous feedback to generate current predictions. The global metacognitive accuracy results of the current study may then have been due to an equivalent reliance on feedback by younger and older adults to monitor global memory performance, resulting in negligible age differences in this measure. Future work can further disentangle these findings by providing feedback on some trials but not others and examining how the accuracy of global predictions between age groups in these different conditions. In sum, these findings suggest there are circumstances in which older adults may be less accurate than younger adults in monitoring the strength of local, item-level information, but equally as accurate on global, trial-level monitoring, representing a novel dissociation between these two types of metacognitive ability.

Experiment 7a: How Will Selectivity Vary on Trials With and Without Metacognitive Judgments?

Experiments 5 and 6 demonstrated that regardless of the level of attentional control during encoding, the collection of metacognitive measures during retrieval appears to impair goal-related prioritization processes. As described, this stands in contrast to an abundance of prior work demonstrating maintained memory selectivity in almost all previous memory domains and paradigms. We hypothesized then that the addition of the metacognitive monitoring measures may draw metacognitive resources away from selectively encoding items and towards making accurate judgments during retrieval. Both of these processes depend on metacognitive monitoring and control; selectivity involves accurately monitoring performance across trials and adjusting performance on subsequent trials to improve (Castel, 2008; Castel et al., 2012; Dunlosky, Ariel, & Thiede, 2011; Siegel & Castel, 2019), while providing local and global estimates of performance involves accurately assessing both item-level and trial-level memory quality/strength (Rouault, Dayan, & Fleming, 2019; Schraw, 1994). As such, it may be the case that the limited nature of metacognitive resources leads to a tradeoff in the allocation of these resources – that is, in the absence of metacognitive judgments, participants direct resources towards selectively encoding information based on information importance (indicating a main goal of memory prioritization), but when local and global performance estimates are present, resources are diverted away from prioritization and towards providing accurate estimates (indicating a main goal of estimation accuracy).

In Experiment 7a, participants completed half of trials with metacognitive estimates and half of trials without estimates. All participants were shown information simultaneously (there was no sequential format included) in order to afford participants the best opportunity to exhibit selectivity as quickly and effectively as possible by allowing the most control over encoding strategies, as indicated by prior work (Ariel et al., 2009; Dunlosky & Thiede, 2004; Middlebrooks & Castel, 2018; Thiede & Dunlosky, 1999). Participants were randomly assigned to one of three block orders: 1) four trials of the visuospatial VDR with metacognitive judgments and then four trials without judgments (i.e., the Judgment-No Judgment condition or "J+/J-"), 2) four trials without ratings and then four trials with ratings (i.e., the No Judgment-Judgment condition or "J-/J+"), or 3) four trials with ratings and four trials without ratings in a randomized order (the Random condition or "RAND"). Thus, all participants completed four trials with metacognitive judgments and four without, but the order of trials varied between conditions. Importantly, in the J+/J- and J-/J+ conditions, participants were aware of whether the subsequent trial would include metacognitive estimates during test, as they were explicitly instructed before each block of four trials. In the RAND condition, participants were told that some trials would include both local and global judgments while some others would not, but that the order would be randomized, and they would not be aware prior to studying the items in the grid.

The goal of Experiment 7a was to test a few main hypotheses. Firstly, consistent with Experiments 5 and 6, we expected that participants in all three conditions would be more selective in trials without metacognitive judgments than in trials with judgments. This result would provide more conclusive evidence that the addition of the metacognitive judgments directly impairs study prioritization, representing a tradeoff in metacognitive resources between memory prioritization and estimation accuracy. Secondly, we were interested in participants' ability to switch between trials with judgments and those without dependent upon their encoding condition. For example, we hypothesized that participants in the J+/J- condition would not be selective on the first block of J+ trials due to the presence of judgments and that selectivity on the second block of J- trials would start relatively low and gradually increase throughout the block as they gained experience, similar to participants increasing selectivity after completing multiple trials and adjusting strategies in the presence of feedback in other VDR tasks (Castel, 2008; Middlebrooks et al., 2017; Siegel & Castel, 2018a). In contrast, we hypothesized that participants in the J-/J+ would exhibit typical selectivity in the first block of trials, consistent with prior work in the visuospatial VDR domain (Siegel & Castel, 2018a, 2018b), and that the selectivity would be reduced or eliminated when transitioning to the J+ trials. Alternate hypotheses would suggest that participants may be less reactive to changes in the presence of judgments during testing, such that the initial selectivity of participants in the J-/J+ persists into the block of J+ trials, while the lack of initial selectivity of participants in the J+/J- trials may not only delay, but also eliminate selectivity in J- trials.

Finally, we considered three potential outcomes for the RAND condition: 1) no selectivity on either J+ or J- trials, 2) equivalent selectivity on J+ and J- trials, and 3) higher selectivity on J- relative to J+ trials. In this condition, participants do not know during the encoding of items whether there will be metacognitive ratings during retrieval. As such, the role of judgment expectation on encoding strategies is likely to be diminished in this condition. Firstly, if selectivity is not obtained on either trial type, this would suggest that, when they are unaware of whether a trial will require them to use metacognitive resources during retrieval in providing judgments, they opt to reserve such resources for the retrieval phase, as selectively encoding items would require and potentially drain the resource pool. This finding would suggest that participants are explicitly allocating resources in a controlled, top-down manner by prioritizing metacognitive accuracy over selective memory.

On the other hand, if equivalent (and positive) selectivity is obtained on both trial types, this would suggest that participants are explicitly focusing on selectively prioritizing items when they are unsure if a trial will require metacognitive judgments. In this case, we would also expect metacognitive accuracy to be lower than the other encoding orders, as metacognitive resources that would be allocated to providing accurate judgments would instead be allocated to strategic encoding. This would also suggest that the primary mechanism underlying this tradeoff is of a controlled, top-down manner with participants explicitly prioritizing selective encoding over metacognitive accuracy.

Lastly, participants in the RAND condition may exhibit higher selectivity in J- trials relative to J+ trials. This finding would suggest that the shift in metacognitive resources from selectivity remembering to providing accurate judgments is more likely to be a bottom-up, automatically driven process, as the allocation of participants' metacognitive resources would be determined on a trial-by-trial basis. That is, selectivity would be exhibited on J- trials as resources would not have to subsequently allocated to metacognitive judgments during retrieval, and participants would not be selective on J+ trials in which selective encoding processes would be disrupted by the surprise inclusion of judgments. In this sense, the tradeoff in metacognitive resources would be very much automatically driven by the trial type as opposed to some top-down controlled strategy to divide metacognitive resources between encoding and retrieval tasks.

Method

Participants

The participants in Experiment 7a were 72 UCLA undergraduate students who participated for course credit (58 females, M_{age} = 20.53 years, SD_{age} = 2.05, age range: 18-30). In terms of the highest education level obtained, participants reported the following: 85% had some college, 6% had an associate degree, and 9% had a bachelor's degree. Participants were all fluent in English and did not report any significant visual impairment. None of the participants in Experiment 7a participated in Experiments 5 or 6.

Materials and Procedure. The materials used in Experiment 7a were identical to those used in Experiment 5 and 2 (i.e., 80 simple black-and-white line drawings of everyday household items). As in the previous experiments, 10 items were randomly selected, paired with point values from 1 to 10, and placed within a 5 × 5 grid to form the eight unique grids used as the study materials in this experiment.

The procedure was very similar to Experiments 5 and 6 with a few key exceptions. Firstly, information was presented simultaneously to all participants in Experiment 7a. Participants were randomly assigned in even groups (n = 24 per condition) to one of three between-subjects block orders: Judgments-No Judgments (J+/J-), No Judgments-Judgments (J-/J+), or Random (RAND). All participants were instructed that they would be presented with ten items placed within a 5 × 5 grid and would be later tested on that information via a relocation test. Participants were further instructed that each item would be paired with a point value from 1 to 10 and that their goal was to maximize their point score on each trial.

Participants in the J+/J- condition were told that they would complete a total of eight trials, with the first four trials including local confidence ratings and global trial predictions and the last four trials without these judgments. Participants in the J-/J+ condition were told the opposite in that they would first complete four trials with no local or global judgments and then the last four trials including these judgments. Participants in the J+/J- and J-/J+ were also reminded before each block of trials whether that block would contain metacognitive ratings. Participants in the RAND condition were instructed that some trials would include both local confidence ratings and global estimates, but that these would be randomized throughout the task and that they would not know prior to each trial whether that trial would involve metacognitive judgments during the test. Unbeknownst to participants, exactly four trials were J+ and four trials were J- in the RAND condition. The order of J+ and J- trials was completely randomized for each participant such that one participant may have had the following order of trials "J+, J-, J-, J-, J+, J-, J+, J+", while another may have had the following order "J+, J+, J-, J-, J-, J+, J-, J+". After completing a total of four of each trial type (a total of eight trials) with testing and feedback on each trial, the experiment concluded. The OSpan measure of working memory capacity collected in Experiment 6a was not included in the current experiment.

Results

The same analytical approaches taken in the previous experiments were also applied to the data from Experiment 7a. We analyzed memory performance as a function of block order and item value and then analyzed the local and global metacognitive measures.

Memory Performance

Relocation accuracy was examined as a function of block order, trial type, and item value. Given that trial type was not consistent between the block orders (i.e., the first four trials had the metacognitive judgments in the J+/J- condition, but it was the last four trials for the J-/J+, and a random set of four trials in the RAND condition), the influence of these factors on relocation accuracy was analyzed separately.

Overall. We first conducted a 3 (Block order: J+/J-, J-/J+, RAND) × 4 (Trial: 1, 2, 3, 4) repeated measures ANOVA on relocation accuracy. Two participants were excluded from this analysis for missing data (one participant in the J+/J- condition and one in the RAND condition). There was no main effect of block order, $F(2, 65) = 0.57$, $p = .57$, $\eta^2 = .02$, such that there were no significant differences in relocation accuracy between the J+/J- ($M = .76$, $SD = .18$), J-/J+ ($M = .80$, $SD = .12$), and RAND ($M = .79$, $SD = .17$) conditions. Further, the ANOVA also indicated no main effect of trial, $F(7, 455) = 1.24$, $p = .28$, $\eta^2 = .02$ and no significant interaction between block order and trial, $F(14, 455) = 1.31$, $p = .20$, $\eta^2 = .04$.

Then, to determine whether differences existed in relocation accuracy between J+ and J- trials, we conducted a 3 (Block order: J+/J-, J-/J+, RAND) × 2 (Trial type: J+, J-) repeated measures ANOVA. There was no main effect of block order consistent with the previous ANOVA, $F(2, 67) = 0.52$, $p = .60$, $\eta^2 = .02$. There was also no main effect of trial type, $F(1, 67) = 0.25$, $p = .62$, $\eta^2 = .004$, such that there was no significant difference in relocation accuracy on J+ ($M = .78$, $SD = .18$) and J- ($M = .78$, $SD = .17$) trials. Finally, there was no significant interaction between block order and trial type, $F(2, 67) = 0.17$, $p = .84$, $\eta^2 = .01$. So, overall relocation accuracy did not depend on the presence of metacognitive judgments or on the order in which these trials with and without judgments were presented.

By Item Value. Relocation accuracy as a function of item-value, trial type, and block order is depicted in Figure 4.10. The primary research question of Experiment 7a was to examine how selectivity would change depending on the presence of metacognitive judgments and how the order of blocks with and without judgments would impact this selectivity. We used an HLM

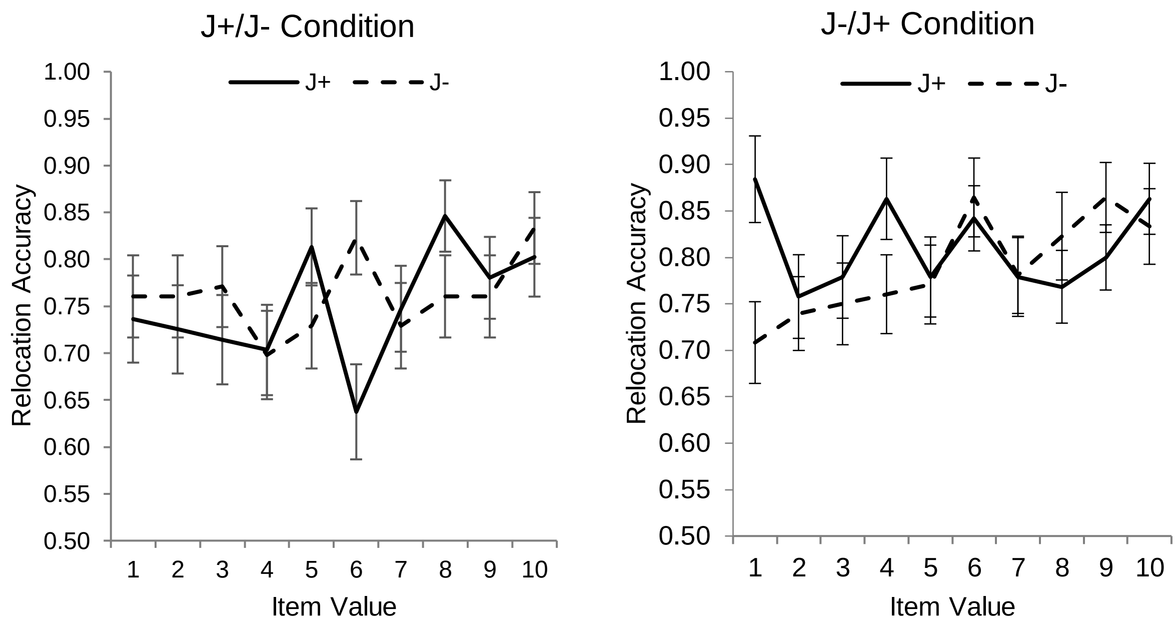

Figure 4.10. Relocation accuracy as a function of block order, trial type, and item value averaged across grids. Error bars represent ±1 standard error. *J+*: judgment present trials, *J-*: judgment absent trials.

to analyze relocation accuracy as a function of item value and trial type between block orders. In a two-level HLM, relocation accuracy was modeled as a function of item value, trial type, and block order. Item value was a level-1 predictor and was entered into the model as a group-mean centered variable (with item value anchored at the mean value of 5.5). Trial type was also a level-1 predictor and was entered into the model as a dummy coded variable (0 = J- or judgment absent trials, 1 = J+ or judgment present trials). Block order (J+/J-, J-/J+, RAND) was also included as dummy coded level-2 predictors. In this analysis, the J+/J- condition was treated as the dummy coded comparison group, while Comparison 1 compared the J+/J- and J-/J+ conditions and Comparison 2 compared the J+/J- and RAND conditions.

Firstly, there was no effect of item value on relocation accuracy in the J+/J- condition on J- trials, $\beta_{10} = .02$, $p = .56$. The coefficients for the comparison coefficients for the J-/J+ and RAND orders were not significant, $\beta_{11} = .07$, $p = .13$, and $\beta_{12} = .02$, $p = .15$. Further, there was no significant effect of trial type on relocation accuracy in the J+/J- order, $\beta_{20} = -.03$, $p = .87$, which did not significantly differ for the J-/J+, $\beta_{21} = .27$, $p = .37$, or RAND conditions, $\beta_{22} = .17$, $p = .57$.

Importantly, however, a significant interaction between encoding order and the value-trial type relationship was obtained. While the HLM revealed that there was no significant interaction between trial type and value for the J+/J- condition, $\beta_{30} = .04$, $p = .42$, or the RAND condition, $\beta_{32} = -.06$, $p = .30$, this relationship was significantly different in the J-/J+ condition, $\beta_{31} = -.13$, $p = .04$. To decompose this apparent three-way interaction, we conducted follow-up logistic regressions predicting relocation accuracy as a function of item value and trial type within each block order. These were simple, level-1 logistic regressions, due to the lack of between-subjects factors, and took the following form: Relocation Accuracy = $b_0 + b_1$ (Value) + b_2 (Trial Type) + b_3 (Value × Trial Type). Value was again entered into the models as group-mean centered variables and trial type was still entered into the model as a dummy coded variable (0 = J- or judgment absent trials, 1 = J+ or judgment present trials).

In the J+/J- and RAND conditions, this model (and thus item value) was not a significant predictor of relocation accuracy, McFadden $R^2 = .002$, $\chi^2(1866) = 5.12$, $p = .16$, and McFadden $R^2 = .001$, $\chi^2(1876) = 2.31$, $p = .51$, respectively. This indicates that in these encoding orders, there was no difference in the relationship between value and relocation accuracy on J+ or J- trials. However, the model was a significant predictor of relocation accuracy in the J-/J+ condition, McFadden $R^2 = .01$, $\chi^2(1906) = 12.68$, $p = .01$. The coefficient for value was significant, $b_1 = .09$, $p < .001$, indicating a positive effect of item value in the J- trials on relocation accuracy. The coefficient for trial type was not significant, $b_2 = .12$, $p = .31$, but there was a significant interaction between value and trial type, $b_3 = -.10$, $p = .01$, indicating a difference in the value-relocation accuracy relationship on J+ trials. To further decompose this interaction, a level-1 logistic regression predicting relocation accuracy as a function of item value within each trial type in the J-/J+ condition was conducted (regression equations of the form: Relocation Accuracy = $b_0 + b_1$ (Value)). In the J+ trials, the model was not significant, McFadden $R_2 = .00004$, $\chi_2(948) = 0.04$, $p = .85$. However, in the J- trials, the model was significant, McFadden $R_2 = .01$, $\chi_2(958) = 11.19$, $p < .001$, with the coefficient for item value significantly positive, $b_1 = .09$, $p < .001$.

Taken together, these results indicate that neither value nor trial type were significant predictors of relocation accuracy in the J+/J- or RAND block orders. However, in the J-/J+ block order, participants were more accurate with each increase in item value in J- trials (i.e., in the first block), but there was no effect of value on relocation accuracy on the J+ trials (i.e., in the second block).

Metacognitive Measures

Metacognitive measures were only provided on half of trials (i.e., J+ trials) for participants in each block order. As such, trial number was not included as a variable in the following analyses and only the trials in which judgments were provided were analyzed. As in the previous experiments, we first analyzed whether the magnitude of global predictions and local ratings varied as a function of block order and then the degree to which participants were accurate in their assessments of their performance (i.e., their metacognitive accuracy via correlational analyses) using prediction/rating-memory correlations.

Overall Global Predictions. To determine whether global predictions varied as a function of block order, a one-way between-subjects ANOVA was conducted on average predictions. There was no main effect of block order on overall global predictions, $F(2,69) = 0.24$, $p = .79$, $\eta^2 = .01$, indicating that the number of items participants predicted that they correctly placed did not differ as a function of block order.

Global Metacognitive Accuracy. To determine whether global metacognitive accuracy (i.e., the average correlation between the actual number of items correctly relocated and the predicted number) varied as a function of block order, a one-way between-subjects ANOVA was conducted on average global correlation coefficients between block orders. Four participants each from the J+/J- and J-/J+ conditions and three from the RAND condition were excluded from this analysis due to providing the same prediction on each trial preventing the ability to calculate a correlation (total $N = 61$). There was no main effect of block order, $F(2, 58) = 1.00$, $p = .38$, $\eta^2 = .03$, indicating a lack of difference in global metacognitive accuracy between block orders.

Overall Local Confidence. We analyzed the overall magnitude of local confidence ratings between block order using a one-way between-subjects ANOVA. There was no main effect of block order, $F(2, 69) = 1.12$, $p = .33$, $\eta^2 = .03$, indicating that the magnitude of local confidence ratings did not differ significantly between block orders.

Local Confidence by Item Value. To determine if confidence ratings varied as a function of item value between block orders, we conducted another HLM with confidence ratings as the continuous outcome variable (ranging from 1 *not at all confident* to 10 *extremely confident*). In a two-level HLM, local confidence ratings were modeled as a function of item value and block order. Item value was a level-1 predictor and was entered into the model as a group-mean centered variable (with item value anchored at the mean value of 5.5). The block orders (0 = J+/J-, 1 = J-/J+, 2 = RAND) were included as level-2 predictors. In this analysis, participants in the J+/J- condition were treated as the comparison group, while Comparison 1 compared the J+/J- and J-/J+ conditions and Comparison 2 compared the J+/J- and RAND conditions. There was no significant effect of value on confidence ratings for participants in the J+/J- condition, β_{10} = .04, *p* = .19. This effect was consistent for the J-/J+ and RAND block orders as indicated by the lack of significance of the comparison coefficients, β_{11} = -.004, *p* = .94, and β_{12} = -.03, *p* = .46, respectively. These findings suggest that local confidence ratings did not vary as a function of block order or item value in the current experiment.

Local Metacognitive Accuracy. Finally, we analyzed overall local confidence ratings (i.e., the average correlation between individual item confidence ratings and the relocation accuracy of that item) as a function of block order using another one-way between-subjects ANOVA. Like the global metacognitive accuracy measure, four participants each from the J+/J- and J-/J+ conditions and four from the RAND condition were excluded from this analysis due to an inability to calculate correlations (total *N* = 60). There was no main effect of block order, *F*(2, 57) = 0.79, *p* = .46, η^2 = .03, indicating that local metacognitive accuracy was equivalent between block orders.

Summary of Results

Overall memory performance did not depend on the type of trial or the order of these trials, as participants' overall relocation accuracy was equivalent between judgment present and absent trials and equivalent between the different block orders. Crucially, the degree of memory selectivity depended on the trial type and order of trials. When participants completed a block of trials with metacognitive judgments first, they displayed no selectivity on that block *and* the following block without metacognitive judgments. In the inverse of that condition, participants were selective on the first block of judgment absent trials, but this selectivity disappeared on the second block of trials when judgments were added. In the randomized order of conditions in which participants were unaware of whether a trial would include judgments during retrieval, participants were not selective on judgment present or judgment absent trials. Finally, block order did not influence the accuracy of either global or local judgments.

Discussion

The goal of Experiment 7a was to more directly examine how the presence of metacognitive judgments affects memory selectivity to determine whether an explicit tradeoff exists between prioritizing memory selectivity or metacognitive accuracy, or alternatively if resources could be effectively split between these two processes. The results clearly indicated that participants' selectivity is directly impaired by providing metacognitive judgments. Importantly, memory accuracy overall did not depend on the presence of metacognitive judgments or the order in which trials with and without judgments were presented. Consistent with prior work (e.g., Middlebrooks et al., 2017; Siegel & Castel, 2018b), when the first set of trials did not include metacognitive judgments, participants were able to selectively prioritize high-value information indicating that participants were aware of and effectively able to implement goal-related encoding strategies. However, these same participants apparently abandoned their value-based encoding strategies in favor of metacognitive accuracy on the second block, as selectivity did not persist into these judgment present trials. On the other hand, when first completing judgment present trials, participants were unable or unwilling to shift resources to implement value-based encoding strategies when faced with the second block of judgment absent trials, suggesting that they may have been still prioritizing metacognitive accuracy over selectivity despite not being required to provide judgments. As such, the results from the current set of experiments provide convincing evidence that a tradeoff exists between the allocation of finite metacognitive resources in the current task. That is, participants can allocate metacognitive resources to prioritizing high-value information or accurately assessing their memory, but not both. Further, the shifting of resources from metacognitive monitoring to prioritization may prove difficult to participants, while a shift in the other direction from monitoring to prioritization appears to be more effectively implemented. In Experiment 8, we investigated the precise mechanism underlying this shift by examining whether local or global judgments on their own require adequate metacognitive resources to impair selectivity or whether the combination of judgments triggers this apparent shift.

Experiment 7b: Do Older Adults Maintain Selectivity on Judgment Absent Trials?

As was conducted in Experiments 6a and 6b, we sought to determine whether the same pattern of results would be found in an older adult sample. In Experiment 7b, older adults were recruited online via Amazon MTurk and completed the visuospatial VDR task described in Experiment 7a (participants were randomly assigned in even groups into J+/J- and J-/J+ conditions). We considered four potential outcomes. Firstly, older adults may perform similar to younger adults and exhibit the tradeoff observed in Experiment 7a, such that selectivity is prioritized in the absence of metacognitive judgments, but that this relationship inverts when required to make local and global judgments resulting in a lack of memory sensitivity to item value. Secondly, older adults, with fewer available cognitive resources (Castel & Craik, 2003; Craik & Byrd, 1982), may be less able to flexibly shift their metacognitive resources between tasks and may persist with the metacognitive task prioritized in the first block of trials into the second block (i.e., metacognitive accuracy in J+/J- trials and selective encoding in J-/J+ trials). Thirdly, older adults may actually be more effective in allocating metacognitive resources between tasks and be both selective and relatively accurate on local and global judgments. Finally, older adults may find the task very cognitively demanding and not display any selectivity and impaired metacognitive accuracy.

Method

Participants

In Experiment 7b, older adult participants were collected online through Amazon MTurk which is an online marketplace in which workers (participants) complete human intelligence tasks (HITs) for compensation. Prior work investigating MTurk suggests that it is as reliable as traditional, in-lab testing, even when testing older adults, strengthening its efficacy as a psychological research tool (Buhrmester, Kwang, & Gosling, 2011; Bui, Myerson, & Hale, 2015; Paolacci, Chandler, & Ipeirotis, 2010; cf. Chandler, Rosenzweig, Moss, Robinson, & Litman, 2019). Some advantages of using MTurk as a research tool include access to a large, diverse participant pool which may be more representative of the general United States population than traditional undergraduate samples and convenience samples from the local older adult community, increasing external validity (Mason & Suri, 2012; Thomas & Clifford, 2017).

The participants in Experiment 7b were collected via a human intelligence task (HIT) posted on Amazon MTurk. The age of MTurk workers who were able to participate in the task was restricted to ages 55-85. Similar to Prime Panels participants collected in Experiment 6b, participants in the current experiment were excluded if they had a focus less than 75% for the duration of the experiment. Data were collected until there were 48 participants in each block order met this criterion. The final sample of participants in Experiment 7b consisted of 96 MTurk workers ($n_{J+/J-}$ = 48, $n_{J-/J+}$ = 48). The older adults (70 females, M_{age} = 62.55 years, SD_{age} = 4.81, age range: 55-76) reported the following highest levels of education: 12% high school degree, 17% associate degree, 24% some college, 33% bachelor's degree, and 14% graduate degree. All participants were residents of the United States at the time of collection and were self-reported fluent in English. Participants were compensated $2.00 for their participation in the task which lasted approximately 15 min.

Materials and Procedure

The materials were identical to Experiment 7a. The procedure was nearly identical, except only two block orders were used: J+/J- and J-/J+. The RAND condition from Experiment 7a was omitted from Experiment 7b due to the similarity in the pattern of results with the J+/J- condition. Older adult participants were randomly assigned to these conditions and completed eight unique trials of the visuospatial VDR task with and without metacognitive judgments according to their block order condition.

Results

The same analytical approaches taken in Experiment 7a were applied to the data from Experiment 7b. We analyzed memory performance as a function of block order and item value, and then analyzed the local and global metacognitive measures.

Memory Performance

Overall. Relocation accuracy was examined as a function of block order, trial type, and trial. We first conducted a 2 (Block order: J+/J-, J-/J+) × 8 (Trial: 1, 2, ..., 8) repeated-measures ANOVA on relocation accuracy. There was no main effect of block order, $F(1, 94) = 0.17$, $p = .68$, $\eta^2 = .002$, such that there were no significant differences in relocation accuracy between the J+/J- ($M = .67$, $SD = .20$) and J-/J+ ($M = .65$, $SD = .19$) conditions. There was a main effect of trial, $F(7, 658) = 2.19$, $p = .03$, $\eta^2 = .02$. However, Bonferroni-corrected follow-up paired-samples *t*-tests indicated no significant differences between trials, *p*s > .05. There was no interaction between block order and trial, $F(7, 658) = 1.58$, $p = .14$, $\eta^2 = .02$.

Then, to determine whether differences existed in relocation accuracy between J+ and J- trials, we conducted a 2 (Block order: J+/J-, J-/J) × 2 (Trial type: J+, J-) repeated-measures ANOVA. There was no main effect of block order consistent with the previous ANOVA, $F(1, 94) = 0.17$, $p = .68$, $\eta^2 = .002$. There was also no main effect of trial type, $F(1, 95) = 1.77$, $p = .19$, $\eta^2 = .02$, such that there was no significant difference in relocation accuracy on J+ ($M = .65$, $SD = .20$) and J- ($M = .67$, $SD = .21$) trials. Finally, there was no significant interaction between block order and trial type, $F(1, 94) = 2.45$, $p = .12$, $\eta^2 = .03$. Thus, overall relocation accuracy did not depend on the presence of metacognitive judgments or the order in which these trials with and without judgments were presented.

By Item Value. Relocation accuracy as a function of item-value, trial type, and block order is depicted in Figure 4.11. We used the same HLM as in Experiment 7a to analyze relocation accuracy as a function of item value and trial type between block orders with the level-2 variable block order only having two levels in this experiment. Item value was a level-1 predictor and was entered into the model as a group-mean centered variable (with item value anchored at the mean value of 5.5). Trial type was also a level-1 predictor and was entered into the model as a dummy coded variable (0 = J- or judgment absent trials, 1 = J+ or judgment present trials). Block order was included as dummy coded level-2 predictor. In this analysis, the J+/J- condition was treated as the dummy coded comparison group (0 = J+/J-, 1 = J-/J+)

Firstly, there was no effect of item value on relocation accuracy in the J+/J- condition on J- trials, $\beta_{10} = .02$, $p = .47$, which was not significantly different in the J-/J+ condition, $\beta_{11} = .02$, $p = .55$. Further, there was no effect of trial type on relocation accuracy in the J+/J- order, β_{20} =

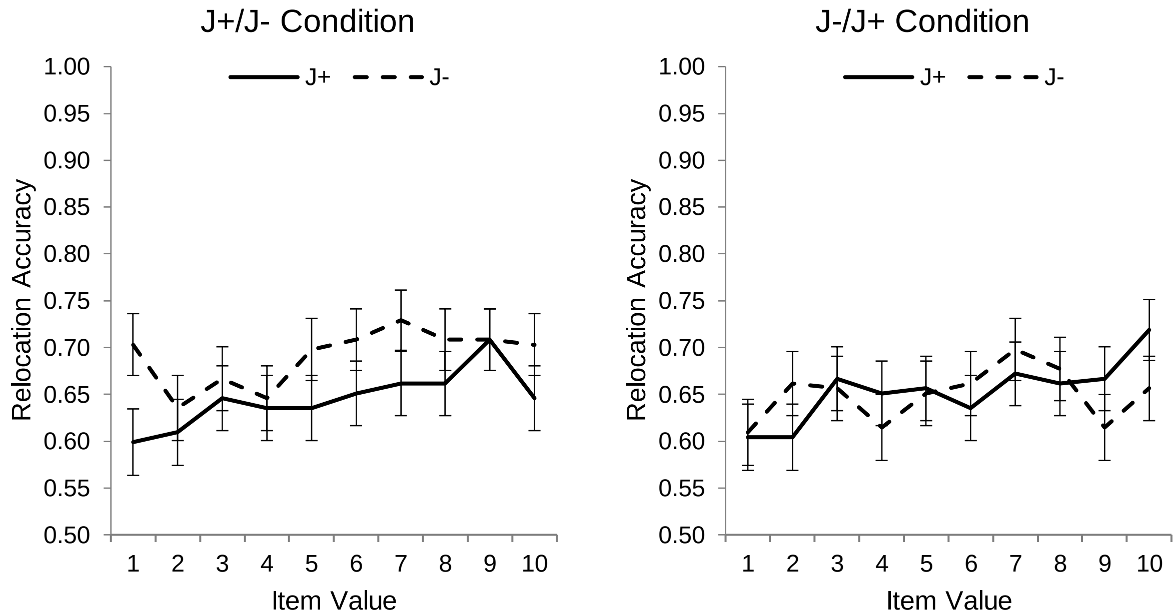

Figure 4.11. Relocation accuracy as a function of block order, trial type, and item value averaged across grids. Error bars represent ±1 standard error. *J+*: judgment present trials, *J-*: judgment absent trials.

.01, p = .95, which did not significantly differ for the J-/J+ condition, β_{21} = -.31, p = .06. Finally, there was no significant interaction between value and trial type for the J+/J- condition, β_{30} = .02, p = .29, which did not significantly differ for the J-/J+ condition, β_{31} = -.03, p = .51. In sum, these results suggest that there was no effect of value on relocation accuracy in either of the encoding orders or trial types.

Metacognitive Measures

Metacognitive measures were only provided on half of trials (i.e., J+ trials) for participants in each block order. As such, trial number was not included as a variable in the following analyses and only the trials in which judgments were provided were analyzed. As in the previous experiments, we first analyzed whether the magnitude of global predictions and local ratings varied as a function of block order and then the degree to which participants were accurate in their assessments of their performance (i.e., their metacognitive accuracy via correlational analyses) using prediction/rating-memory correlations.

Overall Global Predictions. To determine whether global predictions varied as a function of block order and across trials, a 2 (Block order: J+/J-, J-/J+) × 4 (Trial: 1, 2, 3, 4) repeated-measures ANOVA was conducted on average global predictions. There was no main effect of block order on overall global predictions, $F(1, 94) = 0.22$, $p = .64$, $\eta^2 = .002$. There was also no main effect of trial, $F(3, 282) = 1.02$, $p = .39$, $\eta^2 = .01$, and no interaction between block order and trial, $F(3, 282) = 0.04$, $p = .99$, $\eta^2 < .001$. These results indicate that the number of items participants predicted that they correctly placed did not differ as a function of block order or trial.

Global Metacognitive Accuracy. To determine whether global metacognitive accuracy (i.e., the average correlation between the actual number of items correctly relocated and the predicted number) varied as a function of block order, a one-way between-subjects ANOVA was conducted on average global correlation coefficients between block orders. Two participants each from the J+/J- and J-/J+ conditions were excluded from this analysis due to providing the same prediction on each trial preventing the ability to calculate a correlation ($n = 92$ in this analysis). There was a significant main effect of block order, $F(1, 90) = 4.72$, $p = .03$, $\eta^2 = .05$, such that older adults more accurately predicted their global performance in the J+/J- block order ($M = .65$, $SD = .44$) than did older adults in the J-/J+ block order ($M = .44$, $SD = .51$).

Overall Local Confidence. We then analyzed the overall magnitude of local confidence ratings between block order and across trials using a 2 (Block order: J+/J-, J-/J+) × 4 (Trial: 1, 2, 3, 4) repeated-measures ANOVA. There was no main effect of block order, $F(1, 94) = 0.17$, $p =$

.68, η_2 = .002, no main effect of trial, $F(3, 282) = 0.46$, $p = .71$, η_2 = .01, and no interaction, $F(3, 282) = 0.10$, $p = .96$, η_2 = .001, indicating that the magnitude of local confidence ratings did not differ significantly between block orders or across trials.

Local Confidence by Item Value. To determine if confidence ratings varied as a function of item value between block orders, we conducted another HLM with confidence ratings as the continuous outcome variable (ranging from 1 *not at all confident* to 10 *extremely confident*). In a two-level HLM, local confidence ratings were modeled as a function of item value and block order. Item value was a level-1 predictor and was entered into the model as a group-mean centered variable (with item value anchored at the mean value of 5.5). The block orders (0 = J+/J-, 1 = J-/J+) were included as level-2 predictors. In this analysis, participants in the J+/J- condition were treated as the comparison group, while Comparison 1 compared the J+/J- and J-/J+ conditions. There was no significant effect of value on confidence ratings for participants in the J+/J- condition, β_{10} = .06, $p = .13$. This effect was consistent for the J-/J+ condition as indicated by the lack of significance of the comparison coefficient, β_{11} = .001, p = .99, suggesting that local confidence ratings did not vary as a function of block order or item value in the current experiment.

Local Metacognitive Accuracy. Finally, we analyzed overall local confidence ratings (i.e., the average correlation between individual item confidence ratings and the relocation accuracy of that item) as a function of block order using another one-way between-subjects ANOVA. Like the global metacognitive accuracy measure, two participants each from the J+/J- and J-/J+ conditions were excluded from this analysis due to an inability to calculate correlations (n = 92 for this analysis). There was no main effect of block order, $F(1, 90) = 0.67$, $p = .42$, η_2 = .01, indicating that local metacognitive accuracy was equivalent between block orders.

Between-Experiment Comparisons of Age Differences

To examine how our dependent measures may have varied between age groups in Experiments 7a (younger adults) and 7b (older adults), we conducted 2 (Age group: younger adults, older adults) × 2 (Block order: J+/J-, J-/J+) between-subjects ANOVAs on relocation accuracy, global prediction magnitude, global metacognitive accuracy, local confidence magnitude, and local metacognitive accuracy. Levene's tests for equality of variance indicated no significant difference in variance in any of the dependent measures, *p*s > .05. Younger adults (M = .78, SD = .15) had higher relocation accuracy than older adults (M = .66, SD = .19), $F(1, 139) = 13.45$, $p < .001$, $\eta^2 = .09$, but there was no main effect of block order, $F(1, 139) = 0.24$, $p = .63$, $\eta^2 = .002$, and no interaction between age group and block order, $F(1, 139) = 1.00$, $p = .32$, $\eta^2 = .01$.

Younger adults (M = 6.48, SD = 2.15) also provided higher global predictions than older adults (M = 5.42, SD = 2.20), $F(1, 139) = 7.29$, $p = .01$, $\eta^2 = .05$, with no main effect of block order, $F(1, 139) = 0.74$, $p = .39$, $\eta^2 = .01$, and no interaction, $F(1, 139) = 0.10$, $p = .75$, $\eta^2 < .001$. Younger adults (M = .64, SD = .37) and older adults (M = .54, SD = .49) did not differ in the average correlation coefficient representing their global metacognitive accuracy, $F(1, 128) = 1.38$, $p = .24$, $\eta^2 = .01$, with no significant main effect of block order, $F(1, 128) = 2.80$, $p = .10$, $\eta^2 = .02$, and no interaction, $F(1, 128) = 0.75$, $p = .39$, $\eta^2 = .01$.

In terms of local confidence ratings, younger adults (M = 7.79, SD = 1.57) provided higher item confidence ratings on average relative to older adults (M = 6.52, SD = 2.18), $F(1, 139) = 12.56$, $p < .001$, $\eta^2 = .08$, but there was no main effect of block order, $F(1, 139) = 1.10$, $p = .30$, $\eta^2 = .01$, and no interaction between age and block order, $F(1, 139) = 0.29$, $p = .59$, $\eta^2 = .002$. Despite providing higher overall confidence ratings, there was no significant difference between age groups in local metacognitive accuracy correlations ($M_{younger}$ = .55, $SD_{younger}$ = .27, M_{older} = .54, SD_{older} = .22), $F(1, 128) = 0.01$, $p = .92$, $\eta_2 < .001$. There was also no main effect of block order, $F(1, 128) = 0.54$, $p = .46$, $\eta_2 = .004$, and no interaction, $F(1, 128) = 2.51$, $p = .12$, $\eta_2 = .02$. Taken together, these findings indicate that younger adults recalled more items correctly, had higher local confidence ratings, and higher global estimates than older adults. However, in terms of the metacognitive measures, there were no age differences found suggesting equivalence between younger and older adults in the accuracy of their local and global metacognitive judgments.

Summary of Results

Older adults' memory performance did not vary as a function of block order, trial type, or item value. Similarly, the magnitude of global predictions and local confidence ratings did not depend on these factors. Interestingly, completing metacognitive judgments in the first block impaired older adults' global metacognitive accuracy relative to those that completed them in the second block. There was no effect, however, of block order on local metacognitive accuracy. Finally, between-experiment comparisons indicated that older adults, while recalling less information overall, were equally as accurate in their global and local metacognitive judgments, adjusting them to account for their poorer memory ability relative to younger adults.

Discussion

The results from Experiment 7b provide some interesting differences with younger adults under the same experimental paradigm in Experiment 7a. Unlike younger adults who were selective on trials without metacognitive ratings when they occurred before trials with ratings, older adults were not selective in any trial type in the current experiment. This finding contradicts previous work using the same visuospatial VDR paradigm (Siegel & Castel, 2018b) and other work examining verbal memory prioritization in older adults (Ariel et al., 2015; Castel et al., 2002, 2013; Siegel & Castel, 2019), who typically exhibit equivalent or even superior selectivity relative to their younger adult counterparts, despite remembering less information overall. Like the older adults in Experiment 6b who were not selective in either presentation format, these results add further evidence that the presence of metacognitive judgments during encoding may disrupt older adults' selective encoding processes perhaps to an even greater extent than in younger adults. That is, even on trials when older adults were not yet required to make local and global judgments, they still did not display any memory sensitivity to item value, while younger adults were.

The current experiment findings suggest that even the awareness that metacognitive judgments will have to be made on a second block of trials may have influenced older adults' ability to engage in value-based encoding strategies, suggesting that older adults may be less flexibly able to shift metacognitive resources when task demands change. Future research could directly test this assertion by varying the type of instruction given to older adults. That is, some would be informed that metacognitive judgments would have to be provided while others would not be informed of this. After a certain amount of trials, the judgments could be introduced with explanation to the naïve group and selectivity on the first set of judgment absent trials could be compared. Results from the current study support the prediction that those aware of metacognitive judgments from the beginning would display no impaired memory selectivity relative to those informed later on, as all metacognitive resources could be directed to selective encoding strategies in this second group. It would also be interesting to investigate whether earlier knowledge of forthcoming metacognitive judgments improves or impairs memory and metacognitive accuracy compared to naïve participants. For example, heightened scrutiny of one's own performance even on judgment absent trials may lead to more accurate insight but actively direct resources away from the execution of encoding strategies for cognitively limited older adults.

Evidence from the current study is consistent with that obtained in other domains of executive functioning when multiple task demands are present. Older adults, with fewer available cognitive resources (Castel & Craik, 2003; Craik & Byrd, 1982), are less effective in task-switching, an important form of executive control, exhibiting greater switch costs especially under high memory load (Cepeda, Kramer, & Gonzalez de Sather, 2001; Kramer, Hahn, & Gopher, 1999; Mayr, 2001). This is further evidenced by older adults tendency to continue pursuing outdated task goals (e.g., producing higher frequency of perseveration errors on the Wisconsin Card Sorting Task, a standard test of executive functioning; Ashendorf & McCaffrey, 2008; Axelrod & Henry, 1992; Rhodes, 2004) and the presence of switch costs even when task switching is no longer necessary (DiGirolamo et al., 2001; Mayr & Liebscher, 2001). Interpreted in the context of the current task, older adults appear to (either implicitly or explicitly) prioritize metacognitive accuracy over selective encoding, demonstrating limitations on their ability to adaptively shift resources with changing task demands.

Older adults' maintained focus on the metacognitive judgments was not all in vain, however. Between-experiment comparisons suggested that older adults were equally as accurate in their local and global judgments as younger adults. This finding stands in contrast to results from Experiment 6b in which older adults were equally as metacognitively accurate on global predictions, but less metacognitively accurate in their local confidence ratings. One potential reason for this discrepancy is the age profile of the older adults in the two experiments. Older adults recruited on Prime Panels in Experiment 6b were significantly older (M_{age} = 70.64 years,

SD_{age} = 4.02) than those recruited on Amazon MTurk in the current experiment (M_{age} = 62.55 years, SD_{age} = 4.81), $t(144) = 10.17$, $p < .001$, perhaps representing two distinct age groups: younger-older adults and older-older adults. As we experience cognitive decline relatively linearly with increasing age (e.g., Park et al., 2002; Salthouse, 2010; Verhaeghen & Salthouse, 1997), perhaps these observed differences in local metacognitive accuracy are reflective of this slope, with younger-older adults not yet experiencing deficits that are observed in the older-older adult participants on this measure. As such, more work is needed to resolve these contrasting findings in order to make more definitive conclusions about age-related local metacognitive differences in aging.

Converging evidence is provided, however, for the notion that global metacognitive ability (the ability to predict how many items out of an entire set are correctly remembered) remains intact with age, providing contrasting results with previous work showing age-related deficits (Bruce et al., 1982; Connor et al., 1997; Hertzog et al., 1994; Siegel & Castel, 2019). As previously discussed, older adults' ability to rely on schematic support in the form of feedback from the previous trial may have driven these results by allowing them to anchor their predictions on their performance from the previous trial, as described by the memory-for-past-tests heuristic (Finn & Metcalfe, 2008; King, Zechmeister, & Shaughnessy, 1980), which may be utilized similar between younger and older adults (Tauber & Rhodes, 2012). As memory performance was relatively stable across trials, this would result in accurate metacognitive judgments, allowing older adults to achieve the same level of global metacognitive accuracy as younger adults. If this is indeed the case, these results provide further evidence that older adults can rely on schema-related knowledge to boost performance and reduce age-related deficits in some circumstances (Castel, 2005; Mather et al., 1999; McGillivray & Castel, 2010). More evidence is needed, however, to determine if older adults are indeed reliant on feedback to make predictions in the current paradigm and more clearly elucidate the effects of aging on differing types of metacognitive accuracy.

Experiment 8: Which Type of Judgment is Causing Selectivity Impairments?

Experiments 5-7 provided consistent support for the notion that the addition of a metacognitively demanding task may consume resources that would otherwise be used to selectively encode and remember important information. In each of these experiments, when metacognitive judgments were requested, participants provided both local, item-level confidence ratings and global, trial-level predictions. When requested in conjunction, these two types of judgments clearly result in decrements to memory selectivity. However, what remains to be seen is whether it is the combination of these judgments that produces this deficit or if one type (either local or global judgments) is predominantly responsible.

In Experiment 8, we sought to clarify this distinction by probing participants for either local confidence ratings only *or* global trial predictions only and examining relative selectivity. If both conditions remain selective despite their respective metacognitive ratings, we can conclude that the conjunction of both local and global ratings impairs prioritization. If one condition is selective and the other is not, the judgment type that is present in the impaired condition may be considered primarily responsible for reducing selectivity. Finally, if memory in both conditions is not sensitive to item value, then it can be inferred that either type of metacognitive judgment may sufficiently detract from selective encoding resources and impair prioritization ability.

Furthermore, we also examined whether participants' retrieval strategies were differentially affected by the presence of different judgment types by analyzing the order in which they output items. In VDR paradigms, participants typically retrieve items of high value earlier in the test phase than items of lower value (Middlebrooks & Castel, 2018; Schwartz et al., 2020; Stefanidi et al., 2018). In the context of the current task, as participants were required to place all ten items before proceeding to the next trial, we were able to analyze the order in which information was outputted and whether this varied as a function of judgment type and value. If participants' output order in either judgment condition is not sensitive to item value, it would provide further evidence that these judgments are interfering with value-based encoding or retrieval strategies. Thus, participants in Experiment 8 were randomly assigned to complete eight trials of the same visuospatial VDR task while completing either local, item-level confidence ratings *or* global, trial-level predictions during the test phase of each trial.

Method

Participants

The participants in Experiment 8 were 48 UCLA undergraduate students who participated for course credit (35 females, M_{age} = 20.50 years, SD_{age} = 2.03, age range: 18-31). In terms of the highest education level obtained, participants reported the following: 69% had some college, 16% had an associate degree, and 15% had a bachelor's degree. Participants were all fluent in English and did not report any significant visual impairment. None of the participants in Experiment 8 participated in Experiments 5-7.

Materials and Procedure. The materials used in Experiment 8 were identical to those used in Experiments 5-7 (i.e., 80 simple black-and-white line drawings of everyday household items). As in the previous experiments, 10 items were randomly selected, paired with point values from 1 to 10, and presented simultaneously within a 5 × 5 grid to form the eight unique grids used as the study materials. The procedure was very similar to the previous experiments with one key exception. Participants were randomly assigned in equal groups (*n* = 24 per condition) to complete trials with either only local, item-level confidence ratings (i.e., "How confident are you that this item was presented in this location?" on a scale from 1 = *not at all confident* to 10 = *extremely confident*) when relocating each item during the testing phrase or only global, trial-level predictions (i.e., "Of the 10 items that you placed, how many do you think were correctly placed?" ranging from 0 to 10) after placing all 10 items. Feedback was provided after each of the eight trials on the number and proportion of points received.

Results

We analyzed memory performance as a function of judgment condition (Local Only, Global Only) and item value. Local and global metacognitive measures (overall magnitude and correlations with memory) were not analyzed in this experiment because no between condition analyses were possible as participants in each condition only completed one type of judgment. We also analyzed output order as a function of judgment type and item value for more insight into participants' retrieval strategies.

For comparison purposes, a sample of previously published data from Siegel and Castel (2018b) was used. This sample consisted of 24 UCLA undergraduate students who completed eight trials of the visuospatial VDR task with simultaneously presented items and no metacognitive judgments during recall. As such, the procedure for this sample was identical to the first four trials of participants in the J-/J+ condition in Experiments 7a and 7b, but did not have any explicit instruction or requirement to produce metacognitive judgments and completed a total of eight trials similar to participants in the current experiment. As such, this sample was used as the control group in the current experiment (i.e., the "No Judgments" condition) to assess how selectivity was affected in the Local Only and Global Only conditions relative to participants who did not make any metacognitive judgments.

Memory Performance

Overall. We conducted a 3 (Judgment type: no judgment, local only, global only) × 8 (Trial: 1, 2, ..., 8) repeated-measures ANOVA on relocation accuracy which revealed no main effect of judgment type such that there were no significant differences in overall memory between the no judgment (M = .70, SD = .15), local only (M = .73, SD = .15), and global only (M = .73, SD = .20) conditions, $F(2, 69) = 0.38$, $p = .69$, $\eta^2 = .01$. There was also no main effect of trial, $F(7, 483) = 0.38$, $p = .91$, $\eta^2 = .003$, and no interaction between judgment type and trial, $F(14, 483) = 1.62$, $p = .07$, $\eta^2 = .02$. So, there was no difference in the amount of information correctly relocated between judgment type conditions.

By Item Value. Relocation accuracy as a function of judgment type, item value, and trial is depicted in Figure 4.12. We used the same HLM as in the previous experiments to analyze relocation accuracy as a function of item value and trial type between judgment types. Item value and trial were level-1 predictors and were entered into the model as group-mean centered variables. Judgment type was included as a dummy coded level-2 predictor. In this analysis, the No Judgment condition was treated as the dummy coded comparison group with Comparison 1 between the No Judgment and Local Only conditions and Comparison 2 between the No Judgment and Global Only Conditions.

There was a positive effect of item value on relocation accuracy in the No Judgment condition, $\beta_{10} = .11$, $p < .001$, which was not significantly different from the Global Only condition, $\beta_{12} = -.04$, $p = .35$. However, there was a marginally significant difference in the Local Only condition, $\beta_{11} = -.08$, $p = .052$. Rerunning the model with the Local Only condition as the

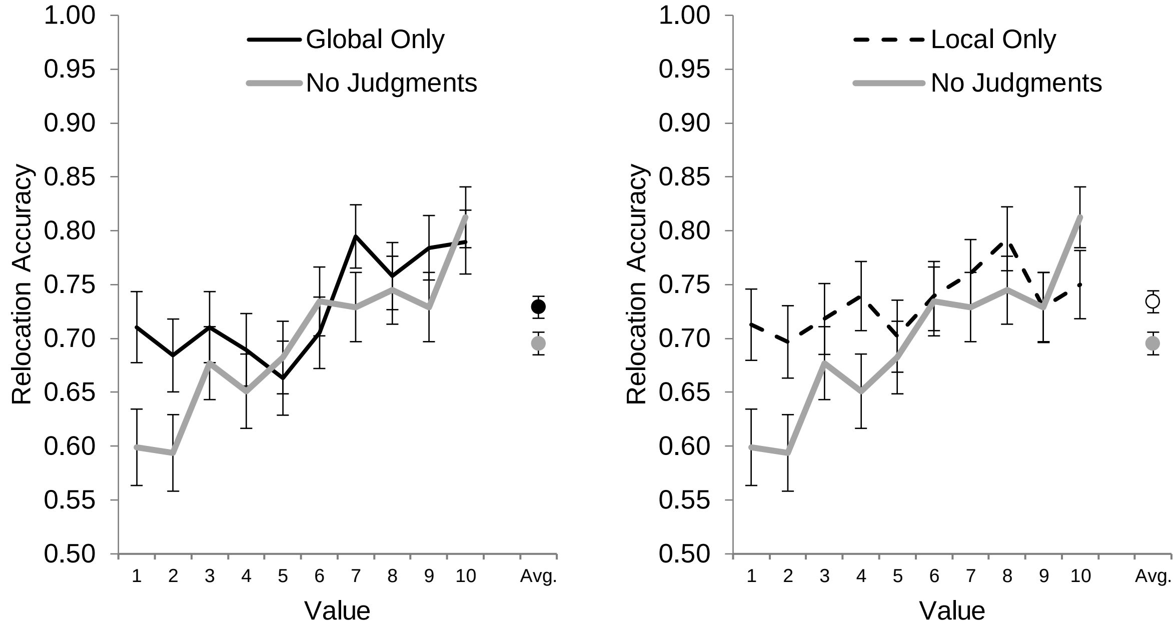

Figure 4.12. Relocation accuracy as a function of item value when only global judgments (left) and local judgments (right) were made. Error bars represent ±1 standard error.

comparison group to calculate the simple slope revealed that value was not a significant predictor of relocation accuracy in this condition, $\beta = .03$, $p = .22$. Returning to the original HLM, there was no effect of trial on relocation accuracy in the No Judgment condition, $\beta_{20} = -.04$, $p = .28$, which was not significantly different for the Local Only condition, $\beta_{21} = .01$, $p = .89$, or the Global only condition, $\beta_{22} = .07$, $p = .25$. Finally, there was no significant interaction between value and trial for the No Judgment, $\beta_{30} = -.0002$, $p = .82$, which did not significantly differ for the other two conditions, $\beta_{31} = -.0003$, $p = .98$, and $\beta_{32} = -.004$, $p = .74$. In sum, these results suggest that there was a positive relationship between value and relocation accuracy for the No Judgement and Global Only conditions, but no effect of value on relocation accuracy in the Local Only condition.

Output Order. To examine the order in which participants replaced each item into the test grid, we conducted the same HLM in the previous section with output order as the continuous dependent variable. No intercept was included in the model as the average output order for each condition is equal (i.e., 5.5) and the model would otherwise not converge. Also, the effect of trial on output order was not interpreted as average output order was equivalent across trials. The trial term was included, however, to examine the interaction between value and trial. Output order ranged from 1 (the first item placed during the recall phase) to 10 (the last item placed during the recall phase), with lower scores indicating an earlier output and higher scores indicating a later output. Given that participants were able to move items around in the grid at their discretion (i.e., an item was not "locked in" after its first placement), we used the final output position for each item. For example, if participants placed all ten items and then shifted the item that they had placed fourth to a new location, that item would then become the last item placed and receive an output order score of 10.

In the No Judgment condition, there was a significant effect of value on output order, $\beta_{10} = -.19$, $p < .001$, such that as item value increased, output order decreased (i.e., higher value items were output earlier on in the test phase). This did not significantly differ for the Global Only condition, $\beta_{11} = .08$, $p = .25$, but was significantly less negative for the Local Only condition, $\beta_{12} = .14$, $p = .048$. Rerunning the analysis with the Local Only condition as the comparison group revealed no significant effect of value on output order for this condition, $\beta = -.06$ $p = .27$. Returning to the original HLM, there was no interaction between value and trial for the No Judgment condition, $\beta_{30} = -.01$, $p = .82$, which did not significantly differ for the other two conditions, $\beta_{31} = .01$ $p = .86$, and $\beta_{32} = .003$ $p = .92$. In sum, this analysis of output order indicated that participants in the No Judgment and Global Only conditions placed higher value items earlier on in the test phase, while the output order of participants in the Local Only condition did not vary as a function of item value.

Summary of Results

While overall memory performance did not differ as a function of judgment type, the condition where participants only provided global, trial-level judgments were equally as selective towards high-value items as participants in a comparison group who were not required to provide judgments. However, those who provided local, item-level confidence ratings were significantly impaired in their selectivity relative to the comparison group, displaying no prioritization of high-value items in their memory performance. Further, output order analyses indicated that participants who did not provide judgments, and those that only provided global judgments, retrieved the location of higher value items earlier on in the testing phase, while the output order of those who provided local judgments was not sensitive to item value.

Discussion

The goal of Experiment 8 was to determine which type of metacognitive judgment (local, global, or the combination) drives the shift in metacognitive resources from memory prioritization to metacognitive accuracy in the current study. The results definitively implicate the responsibility of local confidence ratings in causing this shift, as no memory selectivity was observed when these ratings were provided for each during encoding. In contrast, providing a single global judgment after retrieval did not influence memory selectivity relative to when no judgments were required, suggesting that these two processes can be completed without major disruption.

One potential reason these local confidence ratings may inhibit memory prioritization is the interference caused by not only retrieving the location of an item during test, but also the requirement to assess or monitor the quality of this memory. While selectivity in memory is primarily thought to be resultant of value-based *encoding* strategies (Castel, 2008), it is also the case that these strategies extend to the *retrieval* with participants generally recalling or relocating more important items earlier on in a free recall setting (Middlebrooks & Castel, 2018; Schwartz et al., 2020; Stefanidi et al., 2018). The analyses on output order suggest that when providing local judgments, participants' relocation order does not reflect the importance of items. As it stands, the current study cannot conclusively determine whether selectivity is impaired due to local judgment influences on value-based encoding by impairing strategic attentional allocation or if participants do indeed successfully encode information selectively, but that interference occurs during testing disrupting the strategic retrieval of information. In other words, is it the anticipation of providing local, item-level judgments that prevents participants from selectively encoding or that items are in fact items selectively encoded and some aspect of the retrieval process in combination with the provision of confidence judgments is disrupting participants' ability to output information as a function of its value?

This represents a potentially fruitful avenue for work to explore by varying the anticipation and presence of local judgments across trials and investigating memory selectivity. If value-based encoding is indeed negatively impacted by confidence judgments, just the belief that they will have to provide ratings on some trials should negatively impact selective output and memory overall. However, if value-based encoding remains intact and retrieval is being disrupted, then participants should still be selective on trials in which no confidence ratings are provided despite the anticipation that they may be. Results from the RAND condition in Experiment 7a, in which participants were given a randomized set of judgment and no judgment trials (although including both local and global judgments), indicated there was no selectivity even on judgment absent trials, providing some preliminary evidence that even the anticipation of providing local confidence ratings lowers selectivity, implicating the role of these judgments in value-based *encoding* impairments. However, in the same experiment, participants who made metacognitive judgments on the second, but not first set of trials were still selective when not providing judgments despite an awareness that they would later be required to, suggesting that these judgments may interfere with the *retrieval* of information based on its value. As such, this still remains an important open question to be directly tested in future work in order to shed further light on the exact causal relationships between these processes. In sum, the results from Experiment 8 add clarification to the process of providing a confidence rating after retrieving the location of each item appears to the driving factor behind this reduction in selectivity, further specifying the mechanism underlying this tradeoff in metacognitive resources observed in the previous experiments.

Chapter 4 Conclusion

The original goal of the Experiment 5 was to investigate how the metacognitive monitoring of visuospatial associative information may change as a result of differing levels of attentional load during encoding. Our initial hypotheses predicted higher monitoring accuracy in full relative to divided attention conditions and when the presentation format during encoding encouraged a particular processing orientation (i.e., higher global metacognitive accuracy for simultaneously presented information and higher local metacognitive accuracy for sequentially presented information). Our second, but not our first hypothesis was confirmed, as dividing attention during encoding did not reduce monitoring accuracy, while the type of presentation format did produce differential local and global accuracy.

We were also interested in how the value of information may influence metacognitive monitoring as increased attentional focus on high-value information during encoding may also have produced more accurate knowledge about memory strength for these items. We were surprised to find that, regardless of encoding condition, participants did not selectively remember information as a function of value, in contrast to a large body of prior work demonstrating maintained memory selectivity under a variety of different conditions (e.g., Castel et al., 2002, 2009, 2011; Cohen et al., 2014, 2016; DeLozier & Rhodes, 2015; Elliott & Brewer, 2019; Friedman et al., 2015; Gallo, Hargis, & Castel, 2019; Griffin et al., 2019; Hargis & Castel, 2017, 2018; Hayes et al., 2013; Hennessee et al., 2017, 2019; Middlebrooks & Castel, 2018; Middlebrooks et al., 2016, 2017; Robison & Unsworth, 2017; Schwartz et al., 2020; Siegel & Castel, 2018a, 2018b, 2019; Spaniol et al., 2013; Stefanidi et al., 2018; Wong et al., 2019).

Given this unexpected finding, we sought to replicate it and shed further light on the underlying mechanism. In Experiment 6, we demonstrated that participants who experienced both presentation formats no longer exhibited differences in metacognitive accuracy according to the likely processing orientation. In fact, the results suggested that participants in this experiment took a more "middle of the road" processing orientation, as between-experiments comparisons indicated that those who experienced both conditions had higher accuracy on the "selected against" orientation (e.g., local accuracy in simultaneous trials) than those who only experienced one format, without suffering deficits in the other type of monitoring. These findings provide evidence that processing orientation during encoding can influence metacognitive monitoring accuracy and that monitoring accuracy can be improved by encountering information in different formats.

Again, results from Experiment 6 indicated no selectivity towards high-value information, replicating the unanticipated finding from Experiment 5. In Experiment 7, we sought to provide definitive evidence that these additional metacognitive monitoring tasks were leading to an impairment in selective encoding by presenting some trials with metacognitive judgments and some without. Participants who made judgments on their first block of trials were not selective on that block or even on the following block when no judgments were completed. On the other hand, participants who did not make judgments on the first block were selective as was expected; however, this selectivity disappeared on the second block when they were asked to provide local confidence ratings and global trial predictions. These results further support our hypothesis that the presence of these monitoring judgments led to an apparent shift in limited metacognitive resources from selective encoding to monitoring accuracy. Finally, in Experiment 8, we wanted to determine the main culprit of this shift of resources by requiring participants to complete only global or local judgments during testing. Relative to a control condition where no judgments were made, only the participants who made local confidence ratings during retrieval demonstrated no memory sensitivity to item value, while participants who made global trial predictions were equally as selective as participants in the control condition. Taken together, this set of experiments provides an important boundary condition on the ability to prioritize information, highlighting the limited ability to effectively divide resources between multiple metacognitively demanding processes.

This shift in metacognitive resources observed in the current study represents a novel form of JOL reactivity. While originally thought to not influence participants' actual memory performance, it is well established that making metacognitive assessments can actually cause changes in the amount and type of information remembered depending on the type of materials, which has been termed JOL reactivity (Double, Birney, & Walker, 2018; Janes, Rivers, & Dunlosky, 2018; Mitchum, Kelley, & Fox, 2016; Myers, Rhodes, & Hausman, 2020; Rhodes & Tauber, 2011; Soderstrom, Clark, Halamish, & Bjork, 2015; Tauber & Witherby, 2019). These experiments generally demonstrate that participants, either intentionally or unintentionally, alter their performance in response to being probed for perceived knowledge of their performance, usually in a positive manner by increasing recall or recognition accuracy (cf. Rhodes & Tauber, 2011; Tauber, Dunlosky, & Rawson, 2015 for data indicating that delayed JOLs do not improve memory performance in some contexts).

In the context of the current study, however, it appears as if metacognitive assessments (and particularly local item judgments) hindered, rather than improved selectivity, suggesting a shift in task prioritization from selectively encoding items based on their value to providing accurate metacognitive estimates during retrieval. It is important to note that providing these judgments did not change the amount of information remembered overall, consistent with prior work finding a lack of JOL reactivity on memory accuracy (Begg, Martin, & Needham, 1992;

Kelemen & Weaver, 1997; Tauber & Rhodes, 2012). The current results strongly indicate that the addition of metacognitive judgments may cause participants to shift prioritization from pursuing externally focused, task relevant goals to making internally focused, self-monitoring processes as accurate as possible when multiple tasks require our limited metacognitive monitoring and control abilities. As such, the current study provides evidence of a negative influence of metacognitive monitoring on memory prioritization where previous work has found neutral or positive effects on memory.

Aside from the follow-ups detailed in the individual experiment discussions, future work should be conducted to determine whether this shift in metacognitive resources occurs in other domains, such as with verbal memory, and with different types of secondary monitoring tasks like judgments of retention (i.e., predicting the amount of time for which an item can be accurately recalled as in Tauber & Rhodes, 2012) in order to provide converging evidence of this effect in different circumstances. More work also needs to be done to clarify the mechanism underlying this shift by examining whether this tradeoff occurs when metacognitive monitoring is done during encoding, as is typical in the JOL literature. What is known from the current study is that providing confidence ratings while retrieving information during the test phase renders participants' memory performance insensitive to value. If ratings were instead provided during study, it is possible that they would in fact reflect the differing value of information, which may in turn lead to typical selectivity findings. This however remains a question to be further explored. Finally, it would be useful to explore whether this shift in metacognitive resources occurs only under demanding associative memory conditions, and not when individual items are to-be-remembered. Associative binding in visuospatial memory is a cognitively demanding process which requires the explicit and effortful allocation of attention to different spatial locations (Treisman & Gelade, 1980; Treisman & Sato, 1990; Wheeler & Treisman, 2002). If these demands were eased by testing memory for visual or spatial features individually, it is possible that more resources would be available to devote to metacognitive monitoring and selective encoding, and consequently selectivity may be maintained. This remains unclear, however, and is a useful avenue of future research to pursue.

In sum, Chapter 4 provides evidence of a new form of JOL reactivity in which the addition of metacognitive monitoring tasks disrupts the ability to prioritize information in memory. Despite previous work indicating that memory selectivity is a robust phenomenon invariant to changes in attentional load during encoding (Middlebrooks et al., 2017; Schwartz et al., 2020; Siegel & Castel, 2018b; cf. Experiments 2a and 2b in Chapter 2), persistent in old age (Castel et al., 2002; Siegel & Castel, 2018a), and present in those with lower working memory capacity (Hayes et al., 2013; Robison & Unsworth, 2017), our findings indicate that the addition of a simple local item monitoring task during retrieval draws resources away from the prioritization of high-value information and towards accurate monitoring performance. That is, resources that would otherwise be used for the selective encoding and retrieval of information as a function of its importance are diverted towards accurately monitoring item-level memory. This indicates that (i) these processes likely rely on the same form of cognitive resources and (ii) the division of these resources between these different task demands proves difficult resulting in a tradeoff. As such, whereas previous work has demonstrated that prioritization in memory may withstand fluctuations in attentional resources during encoding, the current study provides novel evidence that drawing upon metacognitive resources may force participants to abandon their value-based study strategies, wiping out the previously ubiquitous effects of information importance on memory.

Table 4.1 (Experiment 5)

Two-Level Hierarchical Linear Model of Relocation Accuracy

Fixed Effects	**Coefficients**
Intercept (β_{00})	1.17***
Predictors of intercept	
Comparison 1: Sim-FA v. Sim-DA (β_{01})	–1.39***
Comparison 2: Sim-FA v. Seq-FA (β_{02})	–1.11**
Comparison 3: Sim-FA v. Seq-DA (β_{03})	–1.95***
Value (β_{10})	0.01
Predictors of Value	
Comp1: Sim-FA v. Sim-DA (β_{11})	–0.01
Comp2: Sim-FA v. Seq-FA (β_{12})	0.05+
Comp3: Sim-FA v. Seq-DA (β_{13})	0.004
Trial (β_{20})	0.06*
Predictors of Trial	
Comp1: Sim-FA v. Sim-DA (β_{21})	0.12*
Comp2: Sim-FA v. Seq-FA (β_{22})	–0.02
Comp3: Sim-FA v. Seq-DA (β_{23})	0.03
Value × Trial (β_{30})	0.01
Predictors of Value × Trial	
Comp1: Sim-FA v. Sim-DA (β_{31})	–0.0001
Comp2: Sim-FA v. Seq-FA (β_{32})	–0.0004
Comp3: Sim-FA v. Seq-DA (β_{33})	0.004
Random Effects	**Variance Components**
Intercept (person-level) (r_0)	0.59***
Value (r_1)	0.02***
Trial (r_2)	0.001
Value × Trial (r_3)	0.0001

Note. In these analyses, relocation accuracy was coded as 0 (*not correctly placed*) or 1 (*correctly placed*). Levels 1 models were of the form $\eta_{ij} = \pi_{0j} + \pi_{1j}$ (Value) + π_{2j} (Trial) + π_{3j} (Value × Trial). Level 2 models were of the form $\pi_{0j} = \beta_{00} + \beta_{01}$ (Comp1) + β_{02} (Comp2) + β_{03} (Comp3) + r_{0j}, $\pi_{1j} = \beta_{10} + \beta_{11}$ (Comp1) + β_{12} (Comp2) + β_{13} (Comp3) + r_{1j}, $\pi_{2j} = \beta_{20} + \beta_{21}$ (Comp1) + β_{22} (Comp2) + β_{23} (Comp3) + r_{2j}, $\pi_{3j} = \beta_{30} + \beta_{31}$ (Comp1) + β_{32} (Comp2) + β_{33} (Comp3) + r_{3j}.

$^{+}p < .10$ $^{*}p < .05$ $^{**}p < .01$ $^{***}p < .001$.

Table 4.2 (Experiment 6a)

Linear Regression Models of Relocation Accuracy and Confidence Ratings

Fixed Effects	**Relocation Accuracy Coefficients**	**Confidence Rating Coefficients**
Intercept (b_0)	1.04***	7.64***
Trial (b_1)	0.05	0.15^{+}
Value (b_2)	0.01	0.02
Format (b_3)	–0.73***	–1.64***
Trial × Value (b_4)	0.01	0.01
Trial × Format (b_5)	–0.002	0.03
Value × Format (b_6)	0.03	–0.05
Trial × Value × Format (b_7)	0.02	0.05

Note. In these analyses, the relocation accuracy outcome variable was coded either 0 (*incorrectly placed*) or 1 (*correctly placed*) and the confidence rating outcome variable was on a scale from 1 (*not at all confident*) to 10 (*extremely confident*). In both models, the categorical presentation format variable was included as the dummy coded variable "Format" with values of 0 (*simultaneous*) or 1 (*sequential*). The continuous predictor variables Trial and Value were group-mean centered when entered into the model. Models were of the following form: Relocation Accuracy/Confidence Ratings = $b_0 + b_1$ (Trial) + b_2 (Value) + b_3 (Format) + b_4 (Trial × Value) + b_5 (Trial × Format) + b_6 (Value × Format) + b_7 (Trial × Value × Format).

$^{+}p < .10$ $^{*}p < .05$ $^{**}p < .01$ $^{***}p < .001$.

CHAPTER 5: CONCLUSION

Overview of Findings

Visuospatial memory is an important cognitive ability that allows us to remember the identity and location of various objects and places in our environment. Given the need to associate particular items with particular spatial locations, visuospatial memory represents a cognitively demanding form of associative memory which can be challenging for both younger and older adults alike (Chalfonte & Johnson, 1996; Thomas et al., 2012). In particular, visuospatial binding may require the effortful and deliberate allocation of attention to different spatial locations in order to bind features present in that location (Treisman & Gelade, 1980; Treisman & Sato, 1990; Wheeler & Treisman, 2002), implicating the critical role of attention in this memory domain. Visual attention is guided by both automatic processes that capture attention in a bottom-up fashion and controlled processes that are goal-directed and strategically allocated in a top-down manner (Posner, 1980; Theeuwes, Atchley, & Kramer, 1998). Information importance has been shown to involve both bottom-up and top-down attentional processes resulting in privileged status in memory for more important information (Castel et al., 2002; Castel, 2008). Crucially, metacognitive monitoring and control play an important role in influencing top-down, goal-directed memory, especially when the amount of information encountered exceeds memory capacity (Castel, 2008). The goal of the current Dissertation was to explore the various attentional, memorial, and metacognitive processes at play in visuospatial memory and further clarify how information importance influences these processes. Potential age-related changes are also explored as older adults have been shown to produce differential patterns of memory with regard to information importance given more constrained memory capacity (Baltes & Baltes, 1990).

The research described in Chapters 2-4 investigated how younger and older adults remember information of differing value when attentional resources are strained to different extents during encoding and when different types of metacognitive monitoring processes are required during retrieval. We began by examining how visuospatial strategic memory prioritization and the ability to selectively attend to information may be reduced in different manners. Next, we compared how older adults' pattern of memory may differ from their younger adult counterparts in both their strategy implementation and their attentional biases. Finally, we investigated the metacognitive processes associated with younger and older adults' visuospatial memory prioritization and why this additional demand on metacognitive resources may have influenced subsequent memory performance.

The Critical Role of Attention in Visuospatial Binding

In Chapter 2, participants studied different types of stimuli (i.e., household neutral items and numbers of differing magnitude) within a spatial grid array and were asked to remember as much information as they could. The encoding conditions differed for participants as some were required to study simultaneously presented items allowing for more top-down control of attention and others to study sequentially presented items which allows for relatively less control. In some experiments, participants also completed a secondary concurrent task while encoding items intended to distract them from their study strategies. Memory performance was examined as a function of the item characteristics to determine whether task goals were effectively pursued.

In Experiment 1, participants studied everyday household items randomly paired with point values within the grid and were asked to maximize their point score (a summation of the points associated with correctly relocated items). This visuospatial VDR task (also used in the following chapters) was conducted in either a sequential or simultaneous presentation format and in the presence or absence of a secondary tone discrimination task. While participants in the divided attention conditions recalled fewer item-location associations overall, participants in all encoding conditions prioritized high-value information in memory, providing further evidence that selectivity can be maintained even when attentional resources are taxed. However, differences between presentation formats emerged when conducting spatial resolution analyses examining errors. Errors in the simultaneous conditions were only influenced by item value when attention was full during encoding, while errors in the sequential conditions were not influenced by item value, regardless of available attentional resources. The results suggested that participants can strategically allocate attention during encoding even under cognitively demanding conditions and that gist-based visuospatial memory may only be influenced by information importance when adequate attentional resources are available.

In Experiment 2, we sought to provide evidence of impaired selectivity by varying the type of resources used in the secondary encoding tasks. While the divided attention tasks in Experiment 1 recruited only auditory processing resources, in Experiment 2 we incorporated tasks dependent on audio-nonspatial and audio-spatial resources (Experiment 2a) and tasks dependent on visual-nonspatial and visual-spatial resources (Experiment 2b). As such, we examined whether tasks requiring overlapping processing resources may impair the ability to selectively encode information in dual-task conditions. Participants in the divided attention conditions of Experiment 2a completed auditory tone distractor tasks that required them to discriminate between tones of different pitches (audio-nonspatial) or auditory channels (audio-spatial), while studying items in different locations in a grid (visual-spatial) differing in reward value. Results indicated that, while reducing overall memory accuracy, neither cross-modal auditory distractor task influenced participants' ability to selectively encode high-value items relative to a full attention condition, suggesting maintained cognitive control. Participants in Experiment 2b studied the same important visual-spatial information while completing demanding color (visual-nonspatial) or pattern (visual-spatial) discrimination tasks during study. While the cross-modal visual-nonspatial task did not influence memory selectivity, the intra-modal visual-spatial secondary task eliminated participants' sensitivity to item value. These results added novel evidence of conditions of impaired cognitive control, suggesting that the effectiveness of top-down, selective encoding processes is attenuated when concurrent tasks rely on overlapping processing resources. Taken together, results from Experiments 1 and 2 suggest that while memory prioritization is relatively robust to distraction, that if the same processing resources are used in concurrent tasks, the ability to selectively remember information may therefore suffer.

Overall, Chapter 2 demonstrates that, for the most part, younger adults are effective in utilizing strategies to maximize visuospatial memory performance relative to task goals. However, there are some circumstances in which strategy use fails. When task goals call for the prioritization of high-value information, if overlapping processing resources are devoted to another task while information is being studied, participants lost track of their study agenda and selectivity was impaired.

Memory for Risks and Rewards in Younger and Older Adults

While Chapter 2 was primarily interested in the attentional mechanisms underlying our ability to remember visuospatial information differing in importance, Chapter 3 focused on potential age-related differences in memory and strategy execution. In Experiments 3a and 3b, younger and older adults completed the visuospatial VDR task under different presentation formats in order to examine associative memory selectivity as a function of age. In Experiments 4a and 4b, younger adults studied both positively and negatively valued items in the different presentation formats to determine how strategy implementation may change with the potential to lose as well as gain points.

In Experiment 3, we examined whether age-related impairment in visuospatial binding could be alleviated by strategic focus on important information and whether varying study time and presentation formats would affect such selectivity. We also used spatial resolution error analyses to examine participants' gist-based visuospatial memory with respect to information importance. Younger and older adults were presented with items worth different point values in a visuospatial display. When items were presented sequentially (Experiment 3a), participants became more selective with task experience, but when items were presented simultaneously (Experiment 3b), selectivity was maintained throughout the task. These patterns were also observed when encoding time was reduced for younger adults. Although older adults successfully engaged in value-based memory strategies, age-related visuospatial memory deficits were still present, even for high-value information, consistent with the associative deficit hypothesis. However, under some conditions, older adults showed reduced spatial relocation errors for high-value item-location associations. The results suggest that strategic control can be used when binding information in visuospatial memory, and that both younger and older adults can benefit by focusing on high-value items and their locations, despite associative memory deficits present in old age.

Experiment 4 examined how participants top-down strategies may change in the presence of positively and negatively valued information providing insight into potential reward maximization or loss minimization approaches. Participants studied number-items ranging from -

25 to +25 indicating point values in a grid display and were instructed to maximize their score (a summation of correctly remembered positive and negative information; incorrectly placed negative items resulted in a subtraction from the overall score). Items were presented in a sequential, simultaneous (Experiment 4a), or self-regulated format (Experiment 4b) where participants controlled which items to study and the length of study time per item. In Experiment 4a, participants selectively recalled high-magnitude over low-magnitude items, but also displayed a positivity preference in memory. In Experiment 4b, we were able to determine whether this positivity preference was a result of bottom-up, automatic, or top-down strategic processes. Results indicated that participants explicitly chose to study positive items more frequently and for more total time relative to negative items, suggesting a deliberate strategy to focus on positive information. This bias for highly positive information suggests an overt points-gained approach, as opposed to a loss aversion approach, to remembering value in the visuospatial domain.

In sum, Chapter 3 demonstrates older adults' ability to engage in effective value-directed encoding strategies despite cognitively demanding binding conditions. However, some age-related deficits were also revealed as memory for high-value information was still impaired relative to younger adults. Younger adult participants displayed a bias towards positive high-value information over negative high-value information equal in magnitude, especially in demanding conditions, representing an inefficiency in strategy execution given the task goals. As a whole, the results of Chapter 3 reveal both age-related similarities and differences in goal-directed memory ability.

Metacognitive Monitoring of Important Visuospatial Information in Visuospatial Memory

While Chapters 2 and 3 focused on attention and memory in the visuospatial domain, Chapter 4 sought to examine how accurately participants monitor their memory and whether this monitoring ability differs as a function of information importance. Experiment 5 analyzed global and local metacognitive monitoring accuracy under differing levels of attentional load during encoding. Experiment 6a was conducted to determine whether the differences observed in local and global accuracy in Experiment 5 would be maintained in a within-subjects design. Experiment 6b evaluated older adults' global and local metacognitive accuracy as a function of presentation format. Experiments 7a and 7b clarified unexpected findings from Experiments 5 and 6 with regards to null effects of value on memory. Finally, Experiment 8 explored the mechanisms underlying the evident shift in metacognitive resources from the previous experiments by varying the type of monitoring judgments made by participants.

In Experiment 5, participants completed the visuospatial VDR task under the same encoding conditions used in Experiment 1 (sequential/simultaneous format and full/divided attention. During the test phase, participants provided metacognitive monitoring judgments in both local (i.e., item-level confidence ratings) and global (i.e., trial-level overall accuracy predictions) forms. Surprisingly, there was no effect of item value on memory, as participants displayed no selectivity. In terms of metacognitive measures, participants provided higher estimates of the number of items they thought they correctly recalled (i.e., global predictions) and higher average item confidence ratings (i.e., local confidence) in the simultaneous and full relative to sequential and divided attention conditions. These metacognitive assessments were only correct for the global predictions where participants in the simultaneous conditions were more accurate than those of the sequential condition in their predictions. On the other hand, for local confidence ratings, participants in the sequential conditions were more accurate than those in the simultaneous conditions. Whether attention was full or divided during encoding did not seem to affect either types of metacognitive accuracy.

Experiment 6a was conducted to examine whether the experience of both presentation formats may eliminate differences in monitoring accuracy afforded by either format and to replicate the unexpected finding of impaired selectivity. Participants completed half of trials with sequentially presented items and half with simultaneously presented items in counterbalanced orders. Memory performance and magnitude of estimates largely mirrored the results from Experiment 5 with higher memory accuracy, global predictions, and local confidence ratings on simultaneous relative to sequential trials. The unexpected null effect of value on relocation accuracy in Experiment 5 was also replicated, with participants again demonstrating no selectivity towards high-value information in either encoding condition. Critically, in contrast to Experiment 5, there was no difference in the accuracy of the local or global estimates of performance between presentation formats. Importantly, participants who experienced the sequential format prior to the simultaneous format had higher local metacognitive accuracy on simultaneous trials as compared to those who only experienced the simultaneous format. On the other hand, participants who experienced the simultaneous format prior to the sequential format had higher global metacognitive accuracy than those who only experienced the sequential format. These respective increases in metacognitive accuracy in Experiment 6a did not come at the cost of the other type of metacognitive accuracy; that is, global metacognitive accuracy did not suffer when local metacognitive accuracy was increased on simultaneous trials and local metacognitive accuracy did not suffer when global metacognitive accuracy was increased on sequential trials.

Similar to younger adults in Experiment 6a, older adults in Experiment 6b had higher memory accuracy, global predictions, and local confidence ratings on simultaneous relative to sequential trials. Older adults also displayed no selectivity towards high-value information in either encoding condition and there was no difference in the accuracy of the local or global estimates of performance between presentation formats. Between-experiment age comparisons indicated that older adults were less accurate in their memory for items in the simultaneous format, but equally as accurate under sequential format conditions. Older adults also predicted they would remember less information overall relative to younger adults resulting in equivalent global metacognitive accuracy. However, despite providing lower local confidence ratings overall, older adults were less locally metacognitively accurate than younger adults, as indicated by smaller average correlations between confidence ratings and relocation accuracy.

In Experiment 7a, we wanted to more directly isolate the role of this metacognitive monitoring task in causing the lack of selectivity observed in Experiments 5 and 6. Participants completed half of trials with monitoring judgments and half without monitoring judgments in a blocked and counterbalanced order. Participants in a third condition were unaware of which trials would have monitoring judgments to limit the effects of anticipation on encoding strategy. Overall memory performance did not depend on the type of trial or the order of these trials, as participants' overall relocation accuracy was equivalent between judgment present and judgment absent trials and equivalent between the different block orders. Crucially, the degree of memory selectivity depended on the trial type and order of trials. When participants completed a block of trials with metacognitive judgments first, they displayed no selectivity on that block *and* the following block without metacognitive judgments. In the inverse of that condition, participants were selective on the first block of judgment absent trials, but this selectivity disappeared on the second block of trials when judgments were added. In the randomized order of conditions in which participants were unaware of whether or not a trial would include judgments during retrieval, participants were not selective on judgment present or judgment absent trials. Finally, block order did not influence the accuracy of either global or local judgments.

Older adults in Experiment 7b completed the same task as younger adults in Experiment 7a. Memory performance did not vary as a function of block order, trial type, or item value. Similarly, the magnitude of global predictions and local confidence ratings did not depend on these factors. Interestingly, completing metacognitive judgments in the first block impaired older adults' global metacognitive accuracy relative to those that completed them in the second block. There was no effect, however, of block order on local metacognitive accuracy. Finally, between-experiment comparisons indicated that older adults, while recalling less information overall, were equally as accurate in their global and local metacognitive judgments, adjusting them to account for their poorer memory ability relative to younger adults.

Finally, in Experiment 8, we clarified which judgment type was leading to this shift in metacognitive resources. Participants completed only local or global judgments across a series of visuospatial VDR trials. While overall memory performance did not differ as a function of judgment type, the condition where participants only provided global, trial-level judgments were equally as selective towards high-value items as participants in a comparison group who were not required to provide judgments. However, those who provided local, item-level confidence ratings were significantly impaired in their selectivity relative to the comparison group, displaying no prioritization of high-value items in their memory performance. Further, output order analyses indicated that participants who did not provide judgments, and those that only provided global judgments, retrieved the location of higher value items earlier on in the testing phase, while the output order of those who provided local judgments was not sensitive to item value.

Interpreted as a whole, Chapter 4 provides evidence of a novel form of JOL reactivity in which, instead of improving memory performance, the monitoring of memory by providing confidence ratings served to detract from participants' ability to selectively prioritize information in memory. That is, metacognitive assessments (and particularly local item judgments) hindered, rather than improved selectivity, suggesting a shift in task prioritization from selectively encoding items based on their value to providing accurate metacognitive estimates during retrieval. The current results strongly indicate that the addition of metacognitive judgments may cause participants to shift prioritization from pursuing externally focused, task relevant goals to making internally focused, self-monitoring processes as accurate as possible when multiple tasks require our limited metacognitive monitoring and control abilities.

A Conceptual Model of Factors Influencing Memory Capacity and Prioritization

The research discussed in the previous chapters provides evidence of how two important cognitive processes, the ability to remember information and the ability to prioritize information in memory, are differentially affected by various factors. Memory capacity and selectivity represent two relatively functionally independent processes, as evidenced by dissociations in which one process is impaired and the other remains intact (e.g., in aging, reduced memory capacity, but unaffected selectivity; Castel et al., 2002; Siegel & Castel, 2018a). Despite this functional independence, many cognitive tasks require the usage of both of these processes, particularly when we encounter more information than we can remember. In real-world situations, for example when studying for a comprehensive exam or remembering the contents of a long grocery list forgotten at home, we want to be able to remember as much information as possible, but also to discriminate between information of differing value to prioritize particularly important information (i.e., a significant theorem that will undoubtedly appear on the exam or a crucial ingredient for tonight's recipe).

In a lab setting, this is demonstrated in both the verbal (Castel et al., 2002; Middlebrooks et al., 2017) and visuospatial (Schwartz et al., 2020; Siegel & Castel, 2018a, 2018b) value-directed remembering (VDR) paradigms in which participants are presented with words or objects paired with point values indicating their importance with the goal of maximizing their later point score, a summation of the points associated with correctly remembered information. Maximizing this point score requires participants to both correctly remember as much of the information as possible and to selectively focus on high-value information given that the amount of presented information exceeds memory capacity. As such, successful performance on this task requires maximization of memory capacity (i.e., to correctly output as much information as possible) and of memory selectivity (i.e., to optimize output relative to the value of information).

The conceptual model shown in Figure 5.1 illustrates how various factors have been shown to influence these two cognitive processes resulting in different patterns of performance on VDR tasks. On the right side of the model, the two cognitive processes involved in successful VDR task performance are shown: memory capacity (as measured by overall correct memory output) and memory prioritization (as measured by selectivity towards item value). The various factors that influence these two cognitive processes are shown on the left side of the model. Arrows of different colors connect these factors to the processes with green arrows indicating a mostly positive (solid line) or sometimes positive (dashed line) effect of the factor, red arrows indicating a mostly negative (solid line) or sometimes negative (dashed line) effect, and gray arrows indicating no effect. This model incorporates both the previous work on memory capacity

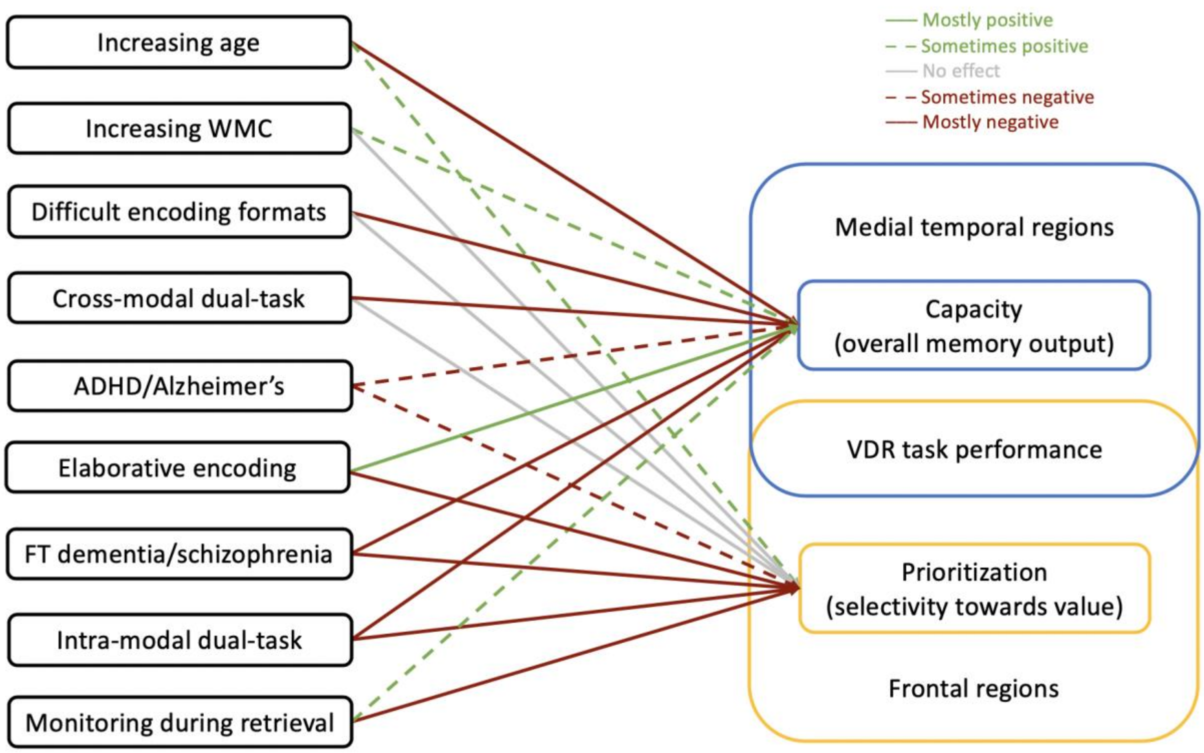

Figure 5.1. A conceptual model integrating results of various factors on memory capacity and prioritization ability. Green arrows indicate a positive effect of the factor on the cognitive process, red arrows indicate a negative effect, and gray arrows indicate no effect.

Note: WMC: working memory capacity, ADHD: attention-deficit/hyperactivity disorder, FT: frontotemporal, VDR: value-directed remembering.

and selectivity that, for the most part, finds few effects on prioritization ability and the experiments in the current Dissertation that did succeed in impairing selectivity in cognitively healthy younger adults.

Firstly, advancing age consistently results in lower memory capacity overall, but does not affect or sometimes even improves the ability to selectively prioritize information (Castel et al., 2002, 2013; Siegel & Castel, 2018a, 2018b, 2019; Dissertation Exps. 3a & 3b). On the other hand, people with higher working memory capacity (WMC) have sometimes been shown to exhibit higher memory performance on VDR tasks, but generally do not exhibit differences in selectivity relative to lower WMC individuals (Hayes et al., 2013; Middlebrooks et al., 2017; Robison & Unsworth, 2017; Siegel & Castel, 2018a; Dissertation Exp. 1). Further, there are typically capacity decrements, but intact selectivity in the presence of difficult encoding formats like sequentially presented information and when attention is divided in cross-modal dual-task conditions (Middlebrooks et al., 2017; Middlebrooks & Castel, 2018; Siegel & Castel 2018a; Dissertation Exps. 1 and 2a). In disorders with attentional impairments like attention-deficit/hyperactivity disorder (ADHD) and Alzheimer's disease (Castel et al., 2009, 2011a, 2011b; Wong et al., 2019), selectivity is reduced relatively to healthy controls, but not entirely eliminated as participants still display sensitivity to value in their memory performance. One circumstance in which memory capacity is improved is when elaborative encoding strategies are used (e.g., relational processing, mental imagery); however, no changes in prioritization ability are observed (Hennessee et al., 2019). The complete elimination of selectivity is finally observed in certain neurocognitive disorders like frontotemporal dementia and schizophrenia, accompanied by capacity deficits (Patterson et al., in preparation; Wong et al., 2019). Lastly, results from the current Dissertation suggest that in cognitively healthy younger adults, selectivity impairments are present in intra-modal dual-task paradigms and when metacognitive resources are diverted to other task demands (Dissertation Exps. 2b & Exps. 5-8). In sum, this conceptual model provides a current picture of the various factors influencing memory capacity and selectivity and highlight how the findings from the current Dissertation add to our knowledge of these cognitive processes.

In general, findings from these VDR studies are consistent with the neurocognitive "working-with-memory" framework posited in Moscovitch and Winocur (2002). In this framework, the medial temporal lobes including the hippocampus are responsible for explicit memory processes, encoding and retrieving information. On the other hand, the frontal cortex typically associated with executive functioning is responsible for strategic functions like enacting encoding and retrieval strategies relevant to task goals by influencing input to or output from medial temporal regions, monitoring the strength of memory, and associating relevant temporal-spatial contexts. This framework which distinguishes the medial temporal and frontal contributions to memory performance maps nicely onto the VDR findings described in this model. While medial temporal regions like the hippocampus may be responsible for encoding and retrieving information relatively automatically and without regard to item characteristics like value, frontal regions may be responsible for the strategic components of encoding and retrieval by distinguishing between items of differing value to prioritize them in memory and monitoring memory performance to ensure fit with task goals.

Importantly, the only conditions in which selectivity impairments are observed in VDR tasks appear to be when these frontal region resources are diminished, as observed in frontotemporal dementia (Wong et al., 2019) and schizophrenia (Patterson et al., in preparation) patients, in intra-modal divided attention tasks (Dissertation Exp. 2b), and in conditions of high metacognitive load (Dissertation Exps. 5-8). Frontotemporal dementia and schizophrenia patients typically exhibit executive functioning deficits related to frontal cortex dysfunction (Heinrichs & Zakzanis, 1998; Johns et al., 2009; Minzenberg et al., 2009; Piguet et al., 2011; Saykin et al., 1991) and neuropsychological and neuroimaging studies of metacognition have shown that engagement in metacognitive processes requires effective executive functioning and relies primarily on frontal regions (Eslinger et al., 2005; Fleming et al., 2014; Fleming & Dolan, 2012; Roebers & Feurer, 2016; Shimamura, 2008). When tasks require the same form of processing resources, it is also likely that frontal regions are required to make decisions about the allocation of these limited resources (McCabe et al., 2010; Meyer & Kieras, 1997). On the other hand, when medial temporal region resources are diminished via task demands (e.g., cross-modal divided attention, difficult encoding formats) or participant characteristics (e.g., lower WMC, ADHD, Alzheimer's disease), this results in capacity deficits, but has relatively little effect on the ability to prioritize information (e.g., Castel et al., 2002, 2009, 2011a, 2011b; Middlebrooks et al., 2017; Middlebrooks & Castel, 2018; Schwartz et al., 2020; Siegel & Castel, 2018a, 2018b, 2019).

Taken together and interpreted in the context of the "working-with-memory" framework (Moscovitch & Winocur, 2002), previous work and the results described in the current Dissertation provide consistent evidence of maintained prioritization when medial temporal functioning is compromised, but marked impairment in prioritization when frontal functioning is reduced. Future work should directly examine predictions made by this model by examining memory capacity and selectivity under other conditions when the ability to utilize frontal resources is attenuated, with the current model predicting deficits in memory selectivity consistent with the previously discussed work.

Conclusions

The goal of the current Dissertation was to shed further light upon the different attention, memory, and metacognitive mechanism present in remembering information in the visuospatial domain. In particular, we sought to elucidate the interplay between bottom-up, stimulus-driven factors and top-down, participant-driven factors involved in attending to, remembering, and monitoring important information and how the relative influence of these factors may change with age. Chapter 2 demonstrated that, while robust in many circumstances, memory prioritization is liable to impairment when attention must be divided between tasks requiring similar processing resources. Chapter 3 investigated age-related differences in memory for important demonstrating a preserved ability to prioritize high-value information representing efficient memory strategy and intact prioritization ability. Finally, Chapter 4 investigated how metacognitive monitoring, both local and global, may vary as a function of information importance and encoding difficulty. Differences in processing orientation afforded by presentation formats led to superior local metacognitive monitoring accuracy for sequentially presented information and superior global metacognitive monitoring accuracy for simultaneously presented information. An unexpected tradeoff was also found in that the addition of these metacognitive monitoring tasks resulted in a lack of selectivity towards high-value information. As clarified by the subsequent experiments in Chapter 4, this represented a shift in the allocation of limited metacognitive resources from memory prioritization to monitoring accuracy primarily driven by local confidence ratings during encoding. As such, the current Dissertation provided further insight into the complex relationship between attention, memory, and metacognition and how various bottom-up and top-down factors may influence these processes in younger and older adults.

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