Value-Directed Memory: Investigating Effects of List Length and Working Memory Capacity

by

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DEDICATION

To my family and my partner.

Thank you for your unwavering support, encouragement, and love.

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ABSTRACT

Human memory is limited, only retaining a small subset of information that is encountered on a daily basis. To compensate for this limitation, people can adopt a strategy to selectively promote memory of a subset of information based on its value. Prior research has established the utility of strategic value-directed memory processes using lists lengths that far exceed canonical working memory capacity. The goal of the present study was to investigate the continuity of value-directed memory control processes within the context of working memory and the role of working memory capacity on value-directed memory in order to further our understanding of strategic memory control and inform models of memory structure. To this end, participants studied and recalled lists of value-cued words that were within, near, or exceeded canonical working memory capacity limits. Findings revealed value-directed memory effects for all list lengths, even for the within-capacity list length of three words, suggesting a continuity of value-directed control processes across working memory and long-term. However, when participants were aware that list lengths were short, either due to explicit notification or changes in experimental parameters, value-directed memory effects were eliminated for the within-capacity list length of three words, suggesting that use of this strategic control process is contingent upon context, highlighting the important role of metamemory in value-directed memory control. Lower working memory capacity, due to individual differences or articulatory suppression, was associated with reduced overall recall of higher value items and reductions in selective promotion of memory for high-value items above low-value items for both sub- and supra-span list lengths. The presence of these deficits for list-lengths within canonical working

memory capacity suggests that reduced executive control associated with lower working memory capacity, rather than the reduced number of items one can hold in working memory, impair strategic value-directed memory emphasizing the importance of executive function in this strategic process. Taken together these findings reveal that, when employed, strategic value-directed control processes and associated limitations operate similarly across list lengths that fall within and exceed working memory capacity providing support for unitary store models of human memory.

CHAPTER 1

Introduction

Memory is like a purse –If it be over-full that it cannot shut, all will drop out of it. Take heed of a gluttonous curiosity to feed on many things, lest the greediness of the appetite of thy memory spoil the digestion thereof.

-Thomas Fuller

Memory is arguably one of the most important facets of human cognition. This system gives rise to and is responsible for constructing a narrative of past experiences that constitute our identities and, in one form or another, underlies the knowledge we accumulate over a lifetime. Despite these astounding achievements, human memory is not without its limitations. We will forget most of the abundant information we encounter daily. Though forgetting is adaptive, it can lead to anything from minor inconveniences to major errors (Schacter, 1999). One way to compensate for memory's limitations may be to remember strategically by prioritizing incoming information based on its importance or potential relevance to current or future goals. The present dissertation investigates when and how people strategically promote memory for valuable information and how the effects of value may vary depending on how much information is presented and individual differences in memory control.

Structure of Memory: Unitary Store and Multistore Models of Memory

As early as the 1800's Hermann Ebbinghaus and William James, the fathers of memory research and psychology respectively, discussed the subjective experience of two different memory states – one in which a small amount of information was held in a conscious but “fleeting” state, and another which was a limitless amount of information held dormant until called upon (Ebbinghaus, 1885/1919; James, 1890). Understanding what James referred to as “primary” and “secondary” memory, or what is now more commonly known as “short-term” and “long-term” memory (Cowan, 2008), has been the topic of thousands of research endeavors. Despite over a century of research following the initial observations of Ebbinghaus and James and numerous methodological advances, the structure of memory and the relationship between short-term and long-term memory are the subjects of continuing debate.

Regarding the structure of memory, the debate has largely fallen into two camps – those subscribing to multistore models and those subscribing to unitary store models (see Jonides et al., 2008 for review). According to multistore models of memory, memory is comprised of at least two separable systems, short-term and long-term memory, each with unique representations, neural correlates, and processes (Baddeley & Hitch, 1974; Izquierdo, Medina, Vianna, Izquierdo, & Barros, 1999; Norris, 2017; Waugh & Norman, 1965). Proposed by Baddeley and Hitch (1974), perhaps one of the most influential multistore models of memory dissociates long-term memory from ‘working memory’, a multi-component, capacity-limited system in which consciously available representations can be manipulated. Though sometimes used interchangeably, short-term memory is thought to be different from working memory, according to Baddeley and Hitch’s model, in that short-term memory refers to temporary storage whereas working memory refers to temporary storage and manipulation (Baddeley, 2012). Some of the most compelling evidence for Baddeley’s model and other multistore models comes from neuropsychological case studies. In one seminal case, patient K.F. suffered brain damage to his left parietal-occipital lobe that resulted in deficits in verbal short-term memory while his long-term memory function remained intact (Shallice & Warrington, 1970). Conversely, patient H.M.

had portions of his medial temporal lobe resected, ultimately resulting in dramatic deficits in long-term memory while short-term memory function remained normal (Scoville & Milner, 1957). The results from this pair of case studies, along with other behavioral and neuropsychological studies (see Baddeley, Allen, & Vargha-Khadem, 2010; Vallar & Papagno, 1995) are heralded as evidence for a double dissociation between short-term and long-term memory providing support of multistore models of memory.

In contrast with multistore models, unitary store models posit that short-term and long-term memory are not distinct systems, but rather components of a single memory system that rely on the same neural systems, representations, and processes. Evidence from modern neuroimaging studies has shown that activation in the medial temporal lobe, previously thought to be uniquely associated with long-term memory, is also present when completing short-term memory tasks, suggesting that short- and long-term memory may rely on overlapping neural mechanisms (Ranganath & Blumenfeld, 2005). Moreover, memory phenomena previously thought unique to long-term memory such as depth-of-processing effects (Flegal & Reuter-Lorenz, 2014; Rose & Craik, 2012), directed forgetting effects (Festini & Reuter-Lorenz, 2013; Oberauer, 2001), and false memories (Atkins & Reuter-Lorenz, 2008; Flegal, Atkins, & Reuter-Lorenz, 2010) has been observed using parameters consistent with working memory suggesting shared or identical processes operating on short-term and long-term memory. Together, this research provides converging support for unitary store models of memory.

One of the more influential unitary store models of memory is Cowan's embedded-processes model of working memory. This model relies on graded activation to explain differences in memory accessibility, where information in working memory is comprised of highly active long-term memory representations in the capacity-limited 'focus of attention', which is a subset of a larger set of relatively moderately active long-term memory representations (akin to 'short-term memory'), which is a subset of an even larger set of long-term memory representations, most of which are inactive at any given moment (Cowan, 1999). According to the embedded-processes model, the focus of attention is controlled, in part, by an executive control system. Results from neuroimaging research have suggested that frontal activations, previously thought to be home to a separable short-term memory store, actually reflect executive control processes used to support working memory (Alverez & Emory, 2006; Reuter-Lorenz & Jonides, 2007). Despite the considerable and mounting evidence supporting unitary store models of human memory, there is still some debate about whether or not working memory is a separable system from long-term memory. To the extent that working memory and long-term memory are components of the same store as posited by unitary store models, it would follow that the processes that give rise to value-directed effects observed for long lists that exceed working memory capacity would be available for use for lists that fall within working memory capacity. However, if memory is comprised of separable stores for working and long-term memory, with unique memory representations, processes, and phenomena, as is proposed by multistore models, then processes that result in value-directed memory effects present for lengthy lists would not be available for short lists that fall within working memory capacity. Research on value-directed memory may inform the unitary store versus multistore debate by elucidating the strategic processes brought to bear on lists that can be maintained actively in working memory and comparing them to the processes that yield value-directed memory effects for lengthy lists that far exceed working memory capacity.

Working Memory Capacity

Though unitary store and multistore models differ in their accounts of the storage and processes that operate on working memory representations, most concede that working memory is limited in capacity (see Jonides et al., 2008). The specific amount of information that can be held active in working memory still the subject of debate with a seminal work suggesting that people can actively maintain around seven items (Miller, 1956), a more modern account arguing that around four items can be held active (Cowan 2001, 2010), and still other research arguing for the severe limit of only one representation being able to be held active in the focus of attention (McElree, 2001). Though the debate is ongoing, for the purposes of this dissertation working memory capacity will be assumed to be between three and five items and the words 'capacity' and 'span' may be used interchangeably.

Neuropsychological measures of working memory capacity show that performance varies across individuals and over the course of the lifespan (Miyake & Shah, 1999; Park et al., 2002). These differences in capacity are strong predictors of a myriad of outcomes including reading comprehension (Daneman & Carpenter, 1980), writing skills (Swanson & Berninger, 1996), academic attainment (Alloway & Alloway, 2010), multitasking (Konig, Buhner, & Murling, 2005), reasoning and general intelligence (Conway, Kane, & Engle, 2003). Why is variation in working memory capacity a predictor of so many cognitive outcomes? Aside from working memory underlying many higher-level cognitive processes, standard working memory capacity measures are thought not only to measure the number of items that can be actively maintained, but also how effectively one can control the mind's active contents (Miyake & Shah, 1999). In this way, working memory capacity is more than simply a measure of the number of items held in a limited space but also a measure of executive control of these contents.

How and What is Remembered?

What is the name of the most recent person you met? What is your license plate number? There are a number of factors that influence what information is remembered and what information is lost. One such influence is the value associated with that information. To understand how valuable information is prioritized in memory, 'value' must first be conceptualized. Past centuries have brought different philosophical approaches to identifying and defining value (Chisholm, 1981; Frankena, 1967; Lewis, 1946; Plato, 428-347 B.C.E.; Zimmerman, 2002). For the purpose of this dissertation, 'value' is synonymous with 'importance'. Information is thought to have value if it is associated with goal-directed behavior and/or reward, with larger rewards or greater progress towards goals being associated with higher value. Value amount is either explicit, typically associated with a numeric quantity (e.g., points, money) or implicit, assigned based on task or personal relevance. Value can be granted by external actors, for example by the teacher or employer highlighting a piece of information as critical, and value can be granted internally, influenced by habit, emotion, salience, beliefs, or preferences. Once attributed, value can be used to influence limited attention and memory resources. There is a rich literature indicating that information associated with larger rewards is better remembered than information with low or no reward (see Miendlarzewska, Bravelier, & Schwarz, 2016 for review of reward and memory).

The subjective experience of memory is such that some information seems to be retained effortlessly while others information requires a conscious effort to be stored in memory. By one hypothesized mechanism, value paired with information can automatically stimulate a response in the reward-sensitive, midbrain dopaminergic system, which in turn projects to the hippocampus, increasing hippocampal plasticity in preparation for new learning (Adcock, Thangavel, Whitfield-Gabrieli, Knutson, & Gabrieli, 2006). Rodent models (Frey, Matthies, Reymann, & Matthies, 1991; O'Carroll, Martin, Sandin, Frenguelli, & Morris, 2006) and human studies (Bethus, Tse, & Morris, 2010; Murayama & Kitagami, 2014; Murayama & Kuhbandner, 2011; Rossato, Bevilaqua, Izquierdo, Medina, & Cammarota, 2009) have suggested that automatic, dopamine-driven memory enhancement tends to only emerge after a lengthy delay on the order of hours. It seems likely that another mechanism may be responsible for value-based memory enhancement over shorter timescales. Indeed, a number of behavioral studies have shown that words paired with high point values are more likely to be recalled than words paired with low point values in an immediate recall test (Castel, Balota, & McCabe, 2009; Castel, Benjamin, Craik, & Watkins, 2002; Castel, Farb, & Craik, 2007; Cohen, Rissman, Hovhannisyan, Castel, & Knowlton, 2017; Friedman & Castel, 2011; Hennessee, Castel, & Knowlton, 2017). This *value-directed memory* effect is thought to rely on voluntary and effortful processes.

Overview of the Present Dissertation

Unable to remember everything one encounters, people are able to compensate for cognitive limitations by voluntarily prioritizing information based on its value. The utility and consequences of such value-based control processes have been well-documented using lengthy lists of words that far exceed what can be maintained in an active state in working memory. The present dissertation builds on this extant knowledge by investigating the effects of value cues on memory for lists of items that are within, near, and exceed theoretical limits of working memory capacity and by examining the role of individual differences in working memory capacity on value effects for varying list lengths.

The first aim of this dissertation is to investigate the effect of value cues on memory of word lists of varying lengths including those considered to be within or near working memory capacity. According to unitary store models of human memory, the same control processes that result in value-directed memory effects for lengthy lists should be applicable to memory control for short lists within working memory capacity. This hypothesis is tested across two experiments in Chapter 2 in which participants study value-cued words for immediate recall from lists of 3- and 6-words, within and near span respectively, as well as 9-words, and 12-words, the typical list length used in previous value-directed memory research. In Experiment 1, list-lengths are presented in random order and are unbeknownst to participants. Experiment 2 investigated the effects of list-length foreknowledge on value-directed memory across sub-, near- and supra-span list lengths. Expanding upon the findings from Chapter 2, Chapter 3 evaluated the effects of value-cues on memory across multiple sub-span list lengths, including 2-, 3-, 4-, and 5- words, and two near-span list-lengths of 6- and 8-words. Additionally, Chapter 3 presents exploratory analyses of the effects of individual differences in working memory capacity and self-reported strategy use on value-directed memory of these short list lengths.

The second aim of this dissertation is to investigate the role of working memory capacity in value-directed memory of sub- and supra-span lists. If lower working memory capacity is associated with increased reliance on value-cues to guide memory, participants with lower working memory capacity should be more selective and show a larger difference between higher- and lower-value item recall than higher capacity participants, especially for shorter lists which presumably pose a reduced challenge for higher capacity individuals. This hypothesis is tested in a pair of experiments in Chapter 4. Informed by the exploratory analysis conducted in Chapter 3, Experiment 1 of Chapter 4 examines the relationship between individual differences in working memory capacity, as measured by three standard working memory tasks, and value-directed memory across lists of 3-, 6-, 9-, and 12-words. Experiment 2 extends these findings by investigating the effect of reducing working memory capacity with an experimental manipulation: articulatory suppression. The findings from all five experiments are summarized and their theoretical implications are discussed in Chapter 5.

This body of work will provide evidence to indicate that value can be used effectively regardless of list length, consistent with unitary store models of memory. Moreover, strategic factors and individual differences in working memory capacity have consequences for the implementation of value-directed remembering. All in all, this dissertation demonstrates that considerations of working memory have relevance for understanding how value can be used in the service of remembering.

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CHAPTER 2

Value-Directed Memory of Sub- and Supra-Span Lists

Introduction

Memory is a limited and imperfect system that typically maintains but a fraction of our day-to-day experiences. Prone to errors, lapses, and distortion, memory failures can result in slight annoyances, like forgetting where you placed your keys, to life-threatening blunders, like your surgeon forgetting where he placed his surgical sponge (Schacter, 1999). To compensate for memory's limitations, it is possible to remember strategically by prioritizing information based on its importance or potential relevance to current or future goals. One way to investigate the effects of "importance" in the laboratory is to assign varying levels of points to items and then test whether an item's subsequent memorability is influenced by its assigned value. Thus far, *value-directed memory* effects of this sort have been demonstrated for the recall of lists typically consisting of 12 or more words (Castel, Balota, & McCabe, 2009; Castel, Benjamin, Craik, & Watkins, 2002; Castel, Farb, & Craik, 2007; Cohen, Rissman, Hovhannisyan, Castel, & Knowlton, 2017; Friedman & Castel, 2011; Hennessee, Castel, & Knowlton, 2017).

The present investigation examines these effects with shorter lists including list lengths within the canonical parameters of verbal working memory capacity, typically considered to be less than six items (Cowan, 2001, 2010; Halford, Cowan, & Andrews, 2007). The goal of this project is to determine whether value-directed processing can be brought to bear on memory performance regardless of list length and putative memory store. More specifically, the current study examines the strategic use of value cues on immediate recall of lists of words that are within, near, or exceed working memory capacity and subsequent memory effects on delayed recall. By determining the continuity of value-directed control processes across sub- and supra-span list-lengths, the results of this work will contribute to the understanding of the structure of memory as a unitary or separable system.

Value Effects on Memory

Information has value if it is associated with goal-directed behavior and/or reward, with larger rewards or greater progress towards goals being associated with higher value. A large literature indicates that information associated with higher value (larger rewards/task-relevance) is better remembered than information with low or no value (low reward/task-irrelevant; see Miendlarzewska, Bravelier, & Schwarz, 2016 for review of reward and memory). One way value has been shown to promote memory is by increasing hippocampal plasticity via the midbrain dopaminergic-reward system (Adcock, Thangavel, Whitfield-Gabrieli, Knutson, & Gabrieli, 2006; Shohamy & Adcock, 2010). This process is thought to occur automatically, with little to no top-down control. However, dopaminergic-driven memory improvements are not typically evident immediately but may take from 12 to 24 hours to emerge (Bethus, Tse, Morris, 2010; Murayama & Kitagami, 2014; Murayama & Kuhbandner, 2011; Rossato et al., 2009), suggesting that this mechanism requires time-extended memorial processes such as consolidation to operate.

Value has also been shown to affect memory over shorter timescales. In an early demonstration of this, Castel, Benjamin, Craik, & Watkins (2002) had participants study lengthy lists of point-valued items and immediately recall as many words as possible from the recently studied list. After completing a few trials, participants were more likely to remember high-point items than low-point items. This so-called *value-directed recall* or *value-directed memory effect* provides evidence that value cues can be used to selectively promote a subset of information for immediate recall (Castel et al., 2002; 2007; 2009; Cohen et al., 2017; Friedman & Castel, 2011; Hennessee et al., 2017). The value-directed memory effect has been observed across a number of studies and is present across the lifespan to varying degrees (Castel, Humphreys, Lee, Galván, Balota, & McCabe, 2011).

Unlike value effects on recall after long delays of hours to days, which appear to benefit from automatic processing via the dopamine-reward system, value-directed immediate recall relies primarily on a voluntary but effortful memory control strategy. Indeed, deficits in value-directed immediate recall have been observed in clinical populations with marked decreases in cognitive control (Alzheimer's disease, Castel, Balota, & McCabe, 2009; ADHD, Castel, Lee, Humphreys, & Moore, 2011). Interestingly, people with ADHD have demonstrated deficits in value-directed recall in the absence of deficits in overall recall (Castel, Lee, Humphreys, & Moore, 2011), indicating that value-directed recall provides a metric of successful strategic memory control, separable from overall memory accuracy.

According to Castel's (2007) model of value-directed recall, participants engage in *evaluative processing* to determine the value of an item based on external factors, such as point-value, and internal factors, such as personal relevance (Hess, Rosenberg, & Waters, 2001). After value has been assigned, participants may selectively engage in deep, elaborative encoding of high-value words to promote these memory traces above competing traces (i.e., lower value words). In line with this interpretation, neuroimaging research has shown that regions commonly associated with semantic processing are more active when encoding high-value words, than low-value words (Cohen, Rissman, Suthana, Castel, & Knowlton, 2014). As a result, low-value words are allocated fewer attentional resources, their encoding is shallower, and in some cases, further processing of these items may be actively inhibited (Castel, 2007; but see Ariel & Castel, 2014). At the time of recall, participants recollect more high-value words than low-value words, likely due to encoding differences rather than differences in retrieval processing. Supporting this assertion, previous research has shown that value has little to no effect when presented at retrieval rather than at or near encoding (Loftus & Wickens, 1970; Naveh-Benjamin, Craik, Gavrilescu, & Anderson, 2000; Soderstrome & McCabe, 2011). Value-directed memory effects are robust; they are observed in recall immediately after study (Castel, et al., 2002, Experiments 1-3,), in recall after a brief delay with task-filled interval (Castel et al., 2002, Experiment 4; Hennessee, Castel, & Knowlton, 2017), and in an incidental recognition task given at the end of the study (Castel, Farb, & Craik, 2007), for list lengths ranging from 10 to 90 words.

Thus far, value-directed memory effects have been demonstrated using task parameters that exceed the canonical parameters of working memory (i.e., immediate recall of three to five items lists, Cowan, 2001), leaving the effect of value cues on memory representations in the context of working memory unknown. Can memory control processes give rise to value-directed immediate recall effects for lists within or near working memory capacity? According to embedded processes, or unitary store, models of memory, the answer to this question should be "yes." According to this view, human memory is comprised of a single, unitary system in which the contents of working memory entail the temporary activation of long-term representations (Cowan, 1999; Jonides et al., 2008; Nairne, 2002; Oberauer, 2002). Conceivably then, the processes that give rise to value-directed effects on immediate recall could also be applied to lists within the capacity of working memory. Indeed, memory phenomena previously thought unique to long-term memory, such as depth-of-processing effects (Flegal & Reuter-Lorenz, 2014; Rose & Craik, 2012), directed forgetting effects (Festini & Reuter-Lorenz, 2013; Oberauer, 2001), proactive interference (Keppel & Underwood, 1962), and false memories (Atkins & Reuter-Lorenz, 2008; Flegal, Atkins, & Reuter-Lorenz, 2010) have also been observed in canonical working memory tasks, suggesting that similar memory principles operate for sub- and supra-span lists and across short and long delays. Multistore models of memory, on the other hand, argue that working memory and long-term memory are separable systems, subject to different memory operations and processing constraints (Atkinson & Shiffrin, 1971; Baddeley & Hitch, 1974; Repovs & Baddeley, 2006; see Jonides et al. 2008 for a review of unitary store and multistore models of memory). As such, it is plausible that value-directed memory effects are unique to long-term memory stores and would not be evident for items stored in working memory.

Further, to the extent that memory control processes are engaged voluntarily, participants' strategies may influence whether or not phenomena that rely on control processes are evident. For example, in one study conducted by Rose and Craik (2012), level of processing effects typically observed in long-term memory were not observed in working memory unless participants were unaware they were going to be tested immediately. The authors interpreted this finding to indicate that participants can use different control processes based on their knowledge of testing conditions. Supporting these assertions, a recent study by Cohen and colleagues (2017) further suggests that value-directed control can be applied strategically for longer lists depending on feedback and testing conditions.

Here, we aim to determine whether there is continuity of value-directed memory effects on shorter lists of words and examine how knowledge of testing conditions affects the use of value. If memory is comprised of a single store, as proposed by an embedded processes or unitary store model of memory, control processes that result in value-directed memory effects in long-term memory should be available to lists within working memory and accordingly, value-directed memory effects would be present in immediate recall for list lengths that are within, near, or exceed working memory capacity. Conversely, finding that value-directed effects are limited to list lengths that exceeded working memory capacity would be consistent with multistore models of memory, which posits that memory is comprised of separable stores associated with unique memory phenomena, including deep, elaborative processing thought to give rise to better memory for higher value items. In either case, participants' strategic approach to the task may influence whether value-directed memory effects are evident at shorter list lengths. These possibilities are tested in the present pair of experiments. In Experiment 1, we examined the effect of value on recall accuracy for list lengths that are within, near, or exceed canonical working memory capacity. Value-directed memory effects were evident for all list lengths, ranging from 3 to 12 items, thereby demonstrating continuity of memory control processes across putative short-term and long-term stores.

We further hypothesized that value effects emerged even for shorter lists because list lengths were presented in a randomized order, which precluded accurate anticipation of the memory set size. In the absence of foreknowledge, participants were likely to adopt the same value-based control strategies for shorter and longer lists. However, if alternative less selective, and therefore less effortful, encoding strategies are available and can be uniquely applied to shorter lists, then value-directed memory effects could be reduced for shorter lists when list length is known in advance. This hypothesis was tested and supported by Experiment 2, in which participants were informed of the list length and list length was blocked. Both experiments also included a surprise recall task that followed the testing of all lists to measure longer-term memory of items whose value was cued in the context of short and long lists.

Experiment 1

Method

Participants. Participants were 46 young adults (18 – 22 years, *M* = 18.89; Males *n* = 32) who received course credit as compensation. To increase point value salience, participants were informed of their eligibility to receive a $5.00 performance-based bonus if they earned over 250 points over the course of the experiment. All participants were treated within the ethical guidelines of the American Psychological Association.

Materials. Using the MRC database (http://www.psy.uwa.edu.au/mrcdatabase/ uwa_ mrc.htm), 381 words were selected with the following characteristics: 3 to 8 letters in length, 1 to 3 syllables, familiarity of 400-640, concreteness rating of 300-600, and Kucera & Francis written frequency of 10-150. Stimuli were randomly sorted into 3 practice lists and 48 experimental lists of 3, 6, 9, or 12 words. There were 12 trials of each list length. Each word was assigned a value from 1 to 12. Across participants, word-point range pairings varied such that no word was consistently associated with a particular value.

Procedure. Each value-directed memory (VDM) trial began with the presentation of a fixation star in the center of the screen (500ms), followed by the simultaneous presentation of a word and its associated point value. As in Castel, Balota, and McCabe (2009) each word and associated point value appeared in the center of the screen for 2 seconds. Words-point pairs were presented sequentially with an inter-stimulus interval (ISI) of 500 milliseconds. The last word of each list was followed by a recall cue, three question marks “? ? ?”, which prompted

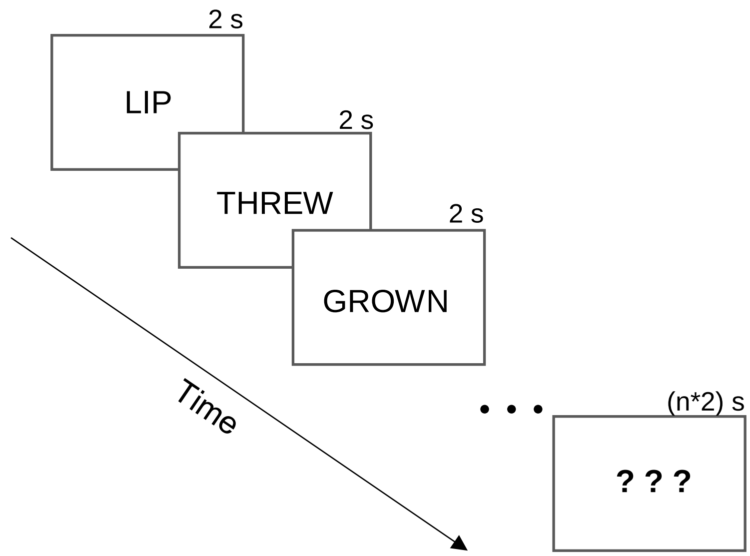

Figure 2.1 ***Diagram of the value-directed immediate recall task implemented in Experiment 1. Word-value pairs were presented sequentially until a recall cue "???" appeared.***

participants to say aloud all the words they could remember from the current trial (Figure 2.1). The recall cue duration varied based on list length with 2 seconds given for each word (ex. 6 seconds for a 3-word list).

Following Castel, Balota, & McCabe (2009), participants were instructed to try to maximize the number of points they earned, while also trying to recall as many words as possible from each list. Participants' correct verbal responses were recorded by a research assistant who was present in the room. Participants were informed of a potential $5.00 bonus for earning at least 250 points for correctly recalling words. At the end of the immediate recall task, participants were informed of their total points earned and were awarded their performance-based bonus.

Before beginning the VDM task, participants completed three practice trials comprised of 3-, 6-, and 12-word lists in a randomized order. The VDM task consisted of forty-eight VDM trials. There were 12 trials for each of the four list lengths, 3, 6, 9, and 12 words. List length varied pseudorandomly such that any particular list length did not appear more than twice in a row and list order was randomized. Participants did not know and could not anticipate how many words were in a given trial until the recall cue appeared. As in previous research (Castel et al., 2002, Castel et al., 2009), each word was randomly paired with a point value ranging from 1 to 12 and no point value was repeated within a trial. For lists had fewer than 12-words, not all point values could be represented. To maintain balance across list-lengths, point values were grouped into three levels: low (1-4 points), medium (5-8 points), and high (9-12 points). Point groups (high, medium, low) were equally represented both within each trial and across all 48 trials. All point values were equally represented across the 48 trials. The experiment was implemented using EPrime 2.0 software (Psychology Software Tools, Inc.) Following the immediate recall task, participants completed a two-minute unfilled break during which they received their performance-based bonus. After the break, participants completed a surprise, untimed delayed recall task where they recalled as many words as possible from the prior phase of the experiment. Lastly, participants completed the Digit Span Forwards/Backwards task, and a brief, open-ended exit survey to assess reports of strategy use.

Results

Results of non-parametric analyses are reported when parametric assumptions (i.e., normality) are violated. Greenhouse-Geisser corrections are applied when assumptions of sphericity are violated. *P*-value significance cutoffs are adjusted using the Holm-Bonferonni correction for familywise error rates (Holm, 1979). Participants earned an average of 1589 points (*range* = 1187 – 1853; *SD* = 141.63) points out of a possible 2340 points. All participants surpassed the 250-point goal and received the $5.00 performance bonus.

Effect of List length on Value-Directed Immediate Recall. The critical analyses focus on the value-directed memory effect, or increased likelihood of recalling higher-value compared to lower-value words, across the sub- and supra-span list lengths. A 3 x 4 repeated-measures analysis of variance (ANOVA) compared proportion of words recalled, where point category (low, medium, and high) and list length (3, 6, 9, and 12) were within-subject factors. The omnibus ANOVA revealed a main effect of point value, $F(1.15, 51.52) = 74.72$, $p < .001$, $\eta^2_p = .62$, a main effect of list length, $F(2.37, 107.60) = 807.43$, $p < .001$, $\eta^2_p = .95$, and a significant interaction between list length and point value on proportion of words recalled, $F(4.66, 209.58) = 26.10$, $p < .001$, $\eta^2_p = .37$ (Figure 2.2).

Planned contrasts investigating the main effect of value on recall revealed that participants recalled a larger proportion of high- than medium-value words, $t(45) = 8.21$, $p < .001$, $d = 1.21$, and a larger proportion of medium- than low-value words $t(45) = 7.90$, $p < .001$, $d = 1.18$. Unsurprisingly, planned contrasts revealed that participants recalled more words proportionally, as list length decreased, twelve words vs. nine words: $t(45) = 12.76$, $p < .001$, $d = 1.89$, nine words vs. six words: $t(45) = 21.98$, $p < .001$, $d = 3.26$, six words vs. three words: $t(45) = 17.43$, $p < .001$, $d = 2.55$ [$z(45) = 5.90$, $p < .001$].

These main effects are qualified by a point value by list length interaction. For lists of 12 words, the typical list length used in previous value-directed memory experiments, participants were more likely to recall high- than medium-value words, $t(45) = 6.67$, $p < .001$, $d = .87$, and medium- than low-value words, $t(45) = 8.95$, $p < .001$, $d = 1.20$, thus replicating the classic value-directed memory effect. Similar patterns emerged for list lengths of 9- and 6-words such hat participants recalled higher proportions of high- than medium-value words, 9-word: $t(45) =$

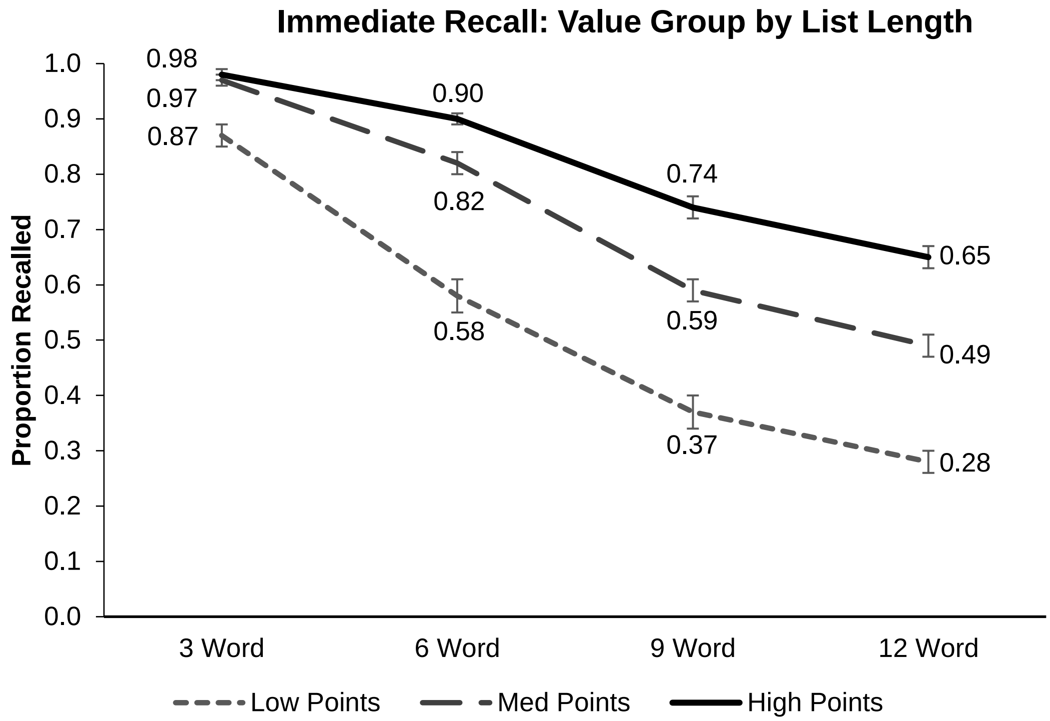

Figure 2.2 ***Experiment 1 average proportion of words correctly recalled (± standard error) across list lengths (3 Word = 3-word lists; 6 Word = 6-word lists; 9 Word = 9-word lists; 12 Word = 12-word lists) separated by point value group (Low Points = Low point value group, 1-4 points; Med Points = Medium point value group, 5-8 points; High Points = High point value group, 9-12 points).***

7.28, $p < .001$, $d = 1.09$; 6-word: $t(45) = 5.13$, $p < .001$, $d = .74$ [$z(45) = 4.28$, $p < .001$], and medium- than low-value words, 9-word: $t(45) = 6.74$, $p < .001$, $d = 1.02$; 6-word: $t(45) = 6.90$, $p < .001$, $d = 1.05$, demonstrating a value-directed memory effect a shorter supra-span lists. Critically, for lists of 3-words, which presumably does not exceed participants working memory capacity, participants recalled fewer low-value words than medium-value, $t(45) = 4.32$, $p < .001$, $d = .63$ [$z(45) = 3.96$, $p < .001$], or high-value words, $t(45) = 4.33$, $p < .001$, $d = .69$ [$z(45) = 3.85$, $p < .001$] , even at this very short list length. There was no difference in recall rates between medium and high-value words, $p = .74$ [$p = .79$], likely because performance was nearly at ceiling, 3-word medium value: $M = .97$, $SE = .008$, 3-word high value: $M = .98$, $SE = .007$.

Table 2.1 ***Summary statistics for Experiment 1 and 2 delayed recall. Average proportion of words correctly recalled for delayed recall task; SE reported in parentheses.***

	Experiment 1			**Experiment 2**		
	High	Medium	Low	High	Medium	Low
3 Word	.05 (.01)	.03 (.01)	.04 (.01)	.02 (.01)	.02 (.01)	.02 (.01)
6 Word	.04 (.01)	.04 (.01)	.03 (.00)	.05 (.01)	.03 (.01)	.04 (.01)
9 Word	.07 (.01)	.04 (.01)	.05 (.01)	.05 (.01)	.04 (.01)	.04 (.01)
12 Word	.11 (.01)	.07 (.01)	.05 (.01)	.08 (.01)	.06 (.01)	.05 (.01)
Average	**.08 (.01)**	**.05 (.01)**	**.04 (.00)**	**.06 (.01)**	**.04 (.01)**	**.04 (.00)**

Note. 3 Word = 3-word lists; 6 Word = 6-word lists; 9 Word = 9-word lists; 12 Word = 12-word lists; Average = proportion of recall collapsed across list-length; High = High point value group, 9-12 points; Medium = Medium point value group, 5-8 points; Low = Low point value group, 1-4 points.

Delayed Recall. To characterize the fate of value-cued words over time, we administered a surprise delayed recall test. Overall, participants accurately recalled an average of 21.22 words (*SD* = 11.13, range 6 - 54) during the delayed recall task. Summary statistics are reported in Table 2.1. To examine the effect of value and list length on delayed recall, we conducted a 3 x 4 ANOVA comparing proportion of words recalled in the delayed task, with immediate-recall list length (3, 6, 9, and 12) and point category (low, medium, and high) as within-subject factors. Not surprisingly, a main effect of list length $F(3, 135) = 17.30$, p <.001, $\eta^2_{\mathrm{p}} = .28$, indicated greater recall from longer lists which is expected given they constituted a larger pool from which to recall (3-word lists: 36 words max vs. 12-word lists: 144 words max). Importantly, there was a main effect of value, $F(2, 90) = 25.13$, $p < .001$, $\eta^2_p = .36$, and an interaction between list length and value, $F(4.62, 207.99) = 4.18$, $p = .002$, $\eta^2_p = .09$, on proportion of words recalled after a delay.

Planned pairwise comparisons revealed a persistent value-effect on delayed recall as indicated by greater proportion recalled of high- than medium-value words, $t(45) = 5.33$, $p < .001$, $d = .75$ [$z(45) = 4.41$, $p < .001$], or low-value words, $t(45) = 7.07$, $p < .001$, $d = 1.07$ [$z(45) = 5.04$, $p < .001$]. There was no significant difference between proportion of medium- and low-value words recalled, $p = .21$, $d = .24$ [$p = .11$]. For words derived from 12-word lists, participants recalled a higher proportion of high- than medium-value words, $t(45) = 5.00$, $p < .001$, $d = .76$ [$z(45) = 4.13$, $p < .001$], and a higher proportion medium- than low-value words, $t(45) = 3.35$, $p = .002$, $d = .49$ [$z(45) = 2.83$, $p = .005$]. Similar value-directed memory effects emerged for words originating from 9-word lists with participants recalling a higher proportion of high- than medium-value words, $t(45) = 3.33$, $p = .002$, $d = .57$ [$z(45) = 3.14$, $p = .002$], and a higher proportion of high- than low-value words, $t(45) = 3.87$, $p < .001$, $d = .45$ [$z(45) = 3.51$, $p < .001$], demonstrating a persistent value-directed memory effect for words from a shorter (< 12) supra-span list in delayed recall. For words originating from 6-word lists, participants recalled a higher proportion of high- than low-value memoranda, $t(45) = 2.39$, $p = .02$, $d = .19$ [$z(45) = 2.17$, $p = .03$]. However, this *p*-value is non-significant at the Holm-Bonferonni corrected threshold of $p = .007$. For 3-word lists, there were no difference between delayed recall of high-, medium-, and low-value words, *ps* > .20. In sum, value effects evident at immediate recall for longer lists of words have persisting effects on memory measurably after delays ranging from 2-30 minutes. Though these results suggest that value effects observed in immediate recall for 3- and 6-word lists may not persist into delayed recall, the ability to detect a value effect was likely limited by the small number of words participants recalled from 3- and 6-word lists in the delayed task (3-word: $M = 1.5$ words, $SE = .24$; 6-word: $M = 2.6$ words, $SE = .35$ versus 9-word: $M = 5.7$ words, $SE = .62$; 12-word: $M = 11.3$ words, $SE = .89$).

Discussion

The goal of Experiment 1 was to investigate whether value-directed memory effects would be evident for word-lists shorter than the 12-item lists that have been widely studied to date. Results indicate value-directed memory effects at all list lengths, including those near (6-words) or within (3-words) canonical working memory capacity. These findings suggest that processes giving rise to value-directed memory effects are not restricted to encoding of items from longer lists and can also be brought to bear on encoding items in shorter lists. Finally, we observed value-directed effects evident in immediate recall persist into delayed recall.

The results from Experiment 1 suggest a continuity of memory control processes across list lengths, an outcome that is consistent with a unitary store model of memory and challenging to the view that working memory and long-term memory are separable memory systems. However, an important feature of the design used in the first experiment was that participants were unaware of the number of words they would study in a given trial. This likely encouraged a uniform strategy of value-based encoding, resulting in value-directed effects for all list lengths, including those within and near canonical working memory capacity. To the extent that shorter, but not longer, lists can be successfully encoded and maintained with less effortful and less selective strategies, participants may opt to use such strategies rather than value-based encoding, if they could anticipate list length. To test this hypothesis, we conducted a second experiment in which participants were informed of the number of words that would occur in each list and list length was blocked. To the extent that value-directed encoding is more effortful than less selective strategies available for shorter lists, then value-directed memory effects should be reduced or eliminated for shorter lists relative to longer lists when list length is known prior to encoding.

Experiment 2

Method

Participants. Forty-four young adults participated (18 – 22 years, *M* = 18.86; Males *n* = 20), received course credit as compensation and were eligible to receive a $5.00 performance-based bonus at the end of the experiment. All participants were treated within the ethical guidelines of the American Psychological Association.

Procedure. The procedure was identical to Experiment 1 with two important modifications, (1) trials were blocked by list length and (2) participants were informed of the list lengths for the proceeding block of trials (Figure 2.3). There were 4 blocks containing 12 trials each. Blocks of trials varied pseudorandomly across participants and were never arranged in ascending or descending order by list length. As in Experiment 1, participants were instructed to

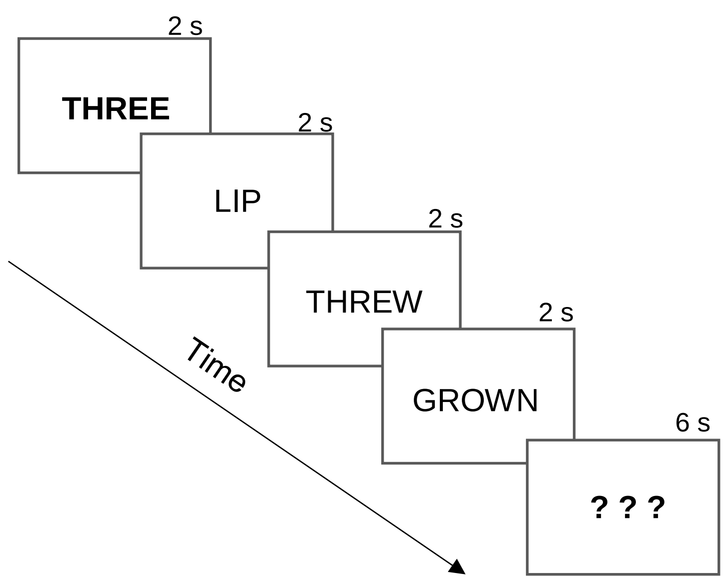

Figure 2.3 ***Diagram of the value-directed immediate recall task implemented in Experiment 2. Blocks of lists began with a notification as to how many words there were is each proceeding list. Word-value pairs were presented sequentially until a recall cue "???" appeared.***

recall as many words as possible while trying to maximize the number of points earned.

Results & Discussion

Participants earned an average of 1619 points (*range* = 1146 – 2046; *SD* = 205.14) out of a possible 2340 points. All participants surpassed the 250-point goal and received the $5.00 performance bonus.

Effect of List length on Value-Directed Immediate Recall. We examined the effect of point value on memory for the various list lengths by conducting a 3 x 4 repeated-measures ANOVA to compare proportion of words recalled, where point category (low, medium, and high) and list length (3, 6, 9, and 12) were within-subject factors. The ANOVA revealed a main effect of list length, $F(2.49, 107.22) = 545.65$, $p < .001$, $\eta^2_p = .93$, a main effect of point value, $F(1.12, 53.24) = 31.50$, $p < .001$, $\eta^2_p = .42$, and a significant interaction between load and point value on proportion of words recalled, $F(3.27, 140.79) = 18.71$, $p < .001$, $\eta^2_p = .30$ (Figure 2.4).

Once again, planned contrasts revealed that as list length decreased, participants recalled higher proportions of studied words, twelve words vs. nine words: $t(43) = 10.27$, $p < .001$, $d = 1.51$, nine words vs. six words: $t(43) = 19.83$, $p < .001$, $d = 2.89$ [$z(43) = 5.78$, $p < .001$], six words vs. three words: $t(43) = 9.94$, $p < .001$, $d = 1.66$ [$z(43) = 5.66$, $p < .001$]. As in Experiment 1, planned contrasts revealed a value-directed memory effect as indicated by greater proportional recall of high-value words than medium-value words, $t(43) = 4.71$, $p < .001$, $d = .64$, and likewise for medium-value words compared with low-value words, $t(43) = 5.22$, $p < .001$, $d = .81$.

These main effects for list length and point value are qualified by significant the list length by point value interaction. For the two longest list lengths, 12 and 9 words, value continued to affect recall with participants recalling more high-value than medium-value items, 12-word: $t(43) = 5.60$, $p < .001$, $d = .82$; 9-word: $t(43) = 2.89$, $p = .006$, $d = .44$, and more medium- than low-value items, 12-word: $t(43) = 5.58$, $p < .001$, $d = .86$; 9-word: $t(43) = 4.94$, $p < .001$, $d = .78$. For the 6-word list length, which approaches working memory capacity, there was no difference between recall of high- or medium-value words, $p = .23$. However, fewer low-value items were recalled than medium-, $t(43) = 2.69$, $p = .01$, $d = .41$, or high-value items, t(43) = 3.27, $p = .004$, $d = .45$. Importantly, unlike in Experiment 1 in which list length was unknown in advance, value has no effect on recall of three-word lists, as indicated by equivalent recall for words regardless of value group, *ps* > .20.

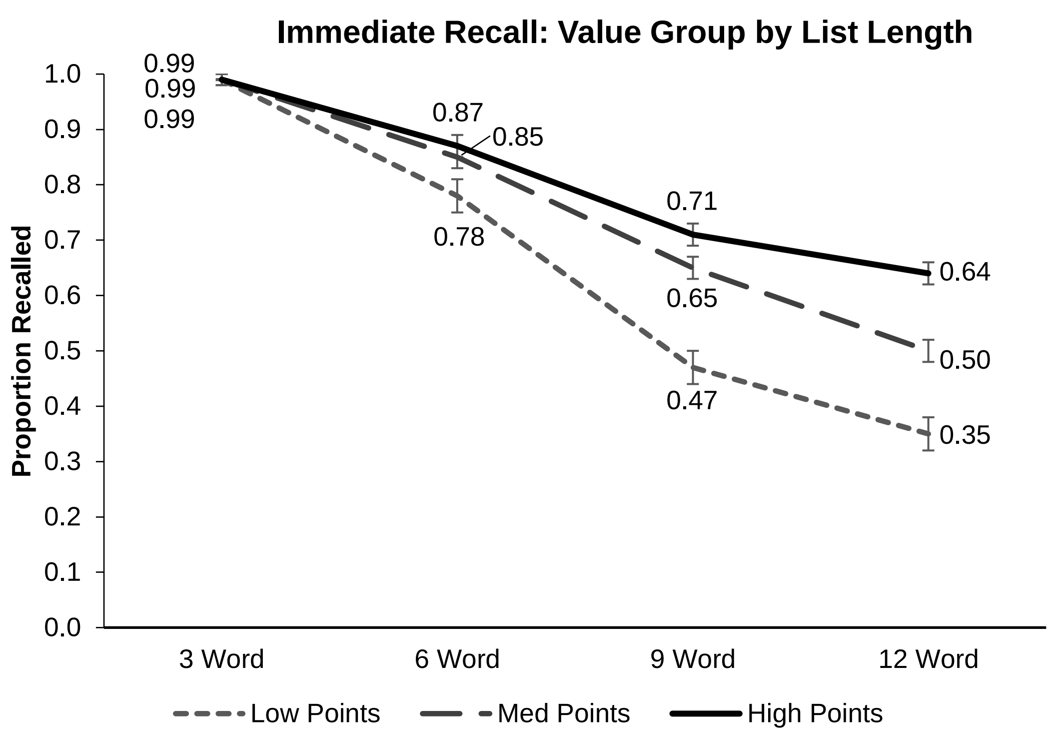

Figure 2.4 ***Experiment 2 average proportion of words correctly recalled (± standard error) across list lengths (3 Word = 3-word lists; 6 Word = 6-word lists; 9 Word = 9-word lists; 12 Word = 12-word lists) separated by point value group (Low Points = Low point value group, 1-4 points; Med Points = Medium point value group, 5-8 points; High Points = High point value group, 9-12 points).***

Delayed Recall. As in Experiment 1, we examined the effect of value on delayed recall. Participants accurately recalled an average of 17.18 words (*SD* = 9.90, range 3 - 43) during the delayed recall task. Summary statistics are reported in Table 2.1. A 3 x 4 repeated-measures ANOVA compared proportion of words recalled, with list length (3, 6, 9, and 12) and point category (low, medium, and high) as within-subject factors. Results indicated main effects of point value, $F(2, 86) = 9.06$, $p < .001$, $\eta^2_p = .17$, and list length, $F(2.42, 129) = 9.22$, $p < .001$, $\eta^2_p = .18$, on proportion of words recalled after a delayed. There was no interaction between list length and value on number of words recalled in the delayed task, $p = .12$. Planned pairwise comparisons revealed a persistent value effect in delayed recall such that participants recalled a higher proportion of high-value words than medium-value words, $t(43) = 4.24$, $p < .001$, $d = .72$ [$z(43) = 3.62$, $p < .001$], and low-value words, $t(43) = 4.49$, $p < .001$, $d = .73$ [$z(43) = 3.87$, $p < .001$]. There was no difference between medium and low-value delayed recall, $p = 1.00$ [$p = .91$].

Results of Experiment 2 indicate that, for a brief list that is well within canonical working memory capacity, immediate recall is virtually perfect regardless of associated point value, suggesting participants adopted a more effective strategy that ignored value, when they could anticipate the list length. Knowing the list length in advance, participants may have been less inclined to pay attention to the value of items in shorter lists, perhaps relying instead on a less selective, less effortful strategy. Conversely, value clearly influences immediate recall for supra-span lists, where strategies effective for shorter lists are no longer adequate for optimal performance. To test these effects statistically, Experiments 1 and 2 were compared directly to quantify the effects of foreknowledge of list length on basis of strategic value-directed memory where we expect the primary differences between groups to be evident in the sub- and near-span lists.

Effect of List length Knowledge on Value-directed Memory. We compared Experiments 1 and 2 directly to quantify the effects of foreknowledge of list length on basis of strategic value-directed memory. To test the effects of list length knowledge on immediate recall, we conducted a 2 x 3 x 4 mixed methods ANOVA comparing proportion of words recalled, where experiment was the between-subject factor (Experiment 1: Unknown List length vs. Experiment 2: Known List length) and value (low, medium, high) and list length (3, 6, 9, 12) were within-subject factors. The omnibus test revealed a main effect of experiment, $F(1, 88) = 11.11$, $p = .001$, $\eta^2_p = .11$, on immediate recall where participants that knew the upcoming list length recalled more words than those who did not, leading to significantly better memory performance overall in Experiment 2 than Experiment l. Importantly, experiment interacted with value to affect proportion of words recalled, $F(1.18, 104.03) = 9.35$, $p = .002$, $\eta^2_p = .10$. While experiment did not interact with list length, $p = .14$, there was a three-way interaction between experiment, value, and length on proportion of words recalled, $F(4.04, 355.29) = 4.29$, $p = .002$, $\eta^2_p = .05$.

Key planned comparisons revealed that foreknowledge of list length led to a higher proportion of low-value words recalled than when list length was unknown, $t(88) = 3.89$, $p < .001$, $d = .80$. Similarly, foreknowledge led to a higher proportion of medium-value words recalled, though this contrast was only marginally significant, $t(88) = 1.78$, $p = .08$, $d = .43$. Proportion of high-value words recalled was not influenced by list length knowledge, $p = .48$. Despite recalling more items overall, participants with foreknowledge earned a similar number of points compared to those without foreknowledge, $p = .42$.

The three-way interaction between experiment, value, and list length was driven largely by the difference in the treatment of low-value words in shorter lists across experiments.

Without foreknowledge, participants recalled a smaller proportion of low-value words in lists of 3-words, $t(53.92) = -4.79$, $p < .001$, $d = 1.06$ and 6-words, $t(88) = -4.77$, $p <.001$, $d = 1.00$, than participants with foreknowledge. Similarly, for 9- and 12-word lists, lack of foreknowledge was associated with smaller proportion of low- value words, 9-words, $t(88) = -2.17$, $p = .03$, $d = .48$; 12-words, $t(88) = -1.86$, $p = .07$, $d = .34$, however these contrasts were only marginally significant after correcting for multiple comparisons. For 12-word lists, the typical list length in studies of value-directed memory, foreknowledge had no effect on recall of high-, $p = .92$, or medium-value words, $p = .63$.

To test the effects of foreknowledge on delayed recall, we conducted a 2 x 3 x 4 mixed methods ANOVA on proportion of words recalled where experiment was the between-subject factor (Experiment 1: Unknown List length vs. Experiment 2: Known List length) and value (low, medium, high) and list length (3, 6, 9, 12) were within-subject factors. Though there was no main effect of experiment on delayed recall, $p = .08$, $\eta^2_p = .04$, there was a small interaction between experiment and value on proportion of words recalled in the delayed task, $F(2, 176) = 3.87$, $p =.02$, $\eta^2_p = .04$. Follow-up comparisons revealed that after a delay, participants with foreknowledge recalled a smaller proportion of high-value items, $t(88) = 2.41$, $p = .02$, $d = .50$ [$z(88) = 2.33$, $p = .02$], compared to participants without foreknowledge. There were no differences in medium-value, $p = .16$, $d = .33$ [$z(88) = 2.00$, $p = .05$, non-significant with Holm-Bonferonni correction], or low-value delayed recall across the two experiments, $p = .91$ [$p = .77$].

General Discussion

The goal of the present study was to investigate the use and effectiveness of value-directed memory strategies on shorter lists of words, namely those within and near canonical working memory capacity. To this end, we conducted two experiments in which word-value pairs were studied in lists of 3-, 6-, 9-, and 12-words. In Experiment 1, we tested the use of value-directed memory strategies when participants could not anticipate the length of the word list they were required to remember. Under these conditions, value-directed memory effects were evident for all list lengths such that priority was placed on the recall of higher value items relative to lower value items, even for lists of only 3 words. These results suggest that the same processes that yield value-directed effects in lengthy lists can be brought to bear on lists that fall within working memory capacity, as would be predicted by unitary store models of memory, and consistent with the embedded process model. Considering the possibility that alternative memory strategies, such as value-indiscriminate encoding and rehearsal, might be uniquely effective for shorter lists, Experiment 2 tested whether value-directed effects would be influenced by advance knowledge of list length, and especially for shorter lists. Foreknowledge of list length selectively mitigated value-directed effects for 3-item lists, for which all items were remembered equally well and the benefits of value eliminated. Together, the results of the two experiments indicate that value-directed memory involves deliberative and effortful processes that can be used to promote memory for high-value items regardless of list length, however these value-based effects are less likely to emerge for shorter, sub-working memory span lists if participants can rely instead on effective but less effortful, less selective strategies.

When and How is Value Used? Comparing Experiment 1 and 2

Directly comparing Experiment 1 and 2 provides valuable insights into how and when participants use value cues to guide memory. In Experiment 2, when foreknowledge of list length made value-directed encoding optional for shorter lists, participants recalled more words from these lists compared to Experiment 1 in which value-based encoding was likely uniformly applied across all lists lengths. In other words, for shorter lists, where alternative, effective memory strategies are available, value-directed encoding comes at the cost of overall memory performance. This finding aligns with the assumption that value-directed selectivity strategies are more effortful than simpler alternative strategies that do not rely on selective promotion.

Comparison of the two experiments also sheds light on the processes that yield value-directed memory effects. As previously discussed, strategic value-directed memory is thought to result from greater processing of higher value items, less processing of lower value items, or a combination of these two strategies. Previous research using eye-tracking and pupillary response has shown that participants fixate on high- and low-value words for similar durations, but their eyes dilate more when studying high-value words, suggesting that value-directed effects are not due to ignoring lower value items but enhanced processing of high-value words (Ariel & Castel, 2014). If this were indeed the case, greater value-directed memory effects would be driven by increased memory for high-value words, rather than decreased memory for low-value words. However, the present results suggest otherwise. Specifically, the greater value-directed memory effects evident in Experiment 1 compared to Experiment 2 can be attributed to poorer recall of low-value items, rather than better recall of high-value items—an effect evident across list lengths 3-9. Because participants could not anticipate list length for any given trial in Experiment 1, the unexpected instruction to "recall" could be conceptualized as an interruption of online value-directed encoding that is engaged in the service of retaining longer lists of items (12-words). Through this lens, it appears that participants prepare for the accrual of more words by disregarding the lower value words.

This is not to say that value-directed memory effects are driven by reduced processing of low-value items alone. It is possible that participants are both enhancing processing of high-value items and reducing processing of low-value items in both experiments, but foreknowledge of list length may only effect strategic processing of lower value words. Indeed, many participants reported both “ignoring” low-value words and “trying harder” on high-value words in an open-ended exit survey. Further, despite similar proportions of high-value immediate recall across the two experiments, in Experiment 1 where value-effects were observed at all list lengths, high-value words were more likely to be recalled during the delayed memory test than in Experiment 2. These results suggest that greater reliance on value-directed encoding contributes to the longer-term memorability of high-value words, perhaps highlighting an increased processing of high-value words not detected by immediate recall accuracy measures.

One limitation of the present research is that only one of the list lengths (3-words) falls definitively within canonical working memory capacity (< 6 verbal items; Cowan, 2001, 2010; Halford, Cowan, & Andrews, 2007), limiting our ability to generalize the present findings to other short list-lengths. Additionally, for the purposes of the present research we have relied on well-established canonical working memory capacity limits to make claims about which list lengths were within or exceeded working memory capacity. Future research could build on the present findings by measuring participants’ working memory capacity and relating those individual differences to value-directed memory of sub- and supra-span lists.

Another caveat arises from the design differences between Experiment 1 and 2. Unlike Experiment 1, in Experiment 2 participants were informed about the proceeding list lengths and list lengths were blocked rather than randomized. As such, foreknowledge of the list-length and the repeated presentation of a given list length could have contributed to participants’ abandonment of the value-directed strategy for the shorter lists. The blocked nature of the task could have allowed participants to hone their strategy with a given list-length, perhaps by allowing them to gain a better understanding of their recall capacity, resulting in increased low-value recall. However, for lists of 3- and 6- words, there was no effect of trial number (1-12) on low-value recall accuracy (3-words, p = .29; 6-words, p = .19), suggesting that foreknowledge rather than practice over the trial block that led to the observed reductions in value-directed recall.

Effects of Value-Directed Immediate Recall on Delayed Recall

Both experiments examined the long-term effects of value-directed immediate recall by testing value effects in a surprise delayed recall task. Across both experiments, participants recalled a higher proportion of high-value items than medium- or low-value items in the surprise delayed task, suggesting value-directed memory effects evident immediately after study persist after longer delays (2 to 30 minutes). In both experiments, theses value-directed delayed recall effects were largely due to the words recalled from the longest list length (12-words), a length which consistently yielded value-directed memory effects in immediate recall. In contrast, there were marginal to no effects of value on the long-term recall of words from 3- and 6-word lists in either experiment, despite the observed value-directed memory effects for these lists lengths in Experiment 1. However, our interpretation of the lack of a value-directed delayed recall effect for words derived from these shorter lists is challenging as few words from these lists were recalled. Future research that studies the fidelity of value-directed memory traces over time is needed to understand their relationship to other longer-term memory phenomena.

Conclusion

The current research provides evidence that value-directed control processes can be used to influence recall of items from short word lists, including lengths within and near working memory capacity, revealing that strategies known to benefit long-term retention of item information can operate effectively within the canonical parameters of working memory. However, we also provide evidence indicating that when people have advance knowledge of how many items they will have to retain, these value-directed control processes are largely abandoned for shorter lists to the overall benefit of memory for these lists. This suggests that value-directed control strategies are only used for shorter lists when alternative, less selective, and less effortful strategies are unavailable or potentially ineffective. Moreover, the results suggest that the use of value-based selective processing is costly for low-value items, which are less likely to be recalled when value-directed control strategies are employed for shorter lists. Furthermore, the results indicate that the promotion of memory for high-value value items persists for several minutes after immediate recall. Finally, the results provide support for unitary store models of memory by demonstrating that the same value-directed control processes can be used to guide memory of shorter lists capable of being maintained active in working memory and longer lists that exceed canonical capacity limits.

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CHAPTER 3

Investigating Strategic Value-Directed Working Memory

Introduction

Though we are incapable of remembering every piece of information we encounter, we can compensate for our memory limitations by strategically prioritizing information that will be of greatest value for achieving our future goals (Miendlarzewska, Bravelier, & Schwarz, 2016). Such *value-directed memory* has been studied in the laboratory by testing memory for information (i.e., words) paired with arbitrary extrinsic values (i.e., points or monetary rewards; Castel, Benjamin, Craik, & Watkins; 2002). The effects of value-directed memory are robust: Participants remember more higher- than lower-value items from lengthy lists of twelve or more value-cued words (Castel, Balota, & McCabe, 2009; Castel et al., 2002; Castel, Farb, & Craik, 2007; Cohen, Rissman, Hovhannisyan, Castel, & Knowlton, 2017; Friedman & Castel, 2011; Hennessee, Castel, & Knowlton, 2017). This pattern of value-directed memory is present to varying degrees across the lifespan (Castel, Humphreys, Lee, Galván, Balota, & McCabe, 2011) and is thought to be the result of strategic, voluntary control processes employed during encoding of valued items (Castel, 2007).

Multiple strategies have been proposed to underlie value-directed memory effects, including increases in semantic encoding of higher value items, increased rehearsal of higher value items, shallow or limited processing of lower value items, and/or ignoring lower value items (Castel, 2007). Because value-directed memory for immediate recall is thought to rely on voluntary, rather than automatic, processes, participants should have explicit knowledge of some of the processes used to selectively promote memory of high-value items. Self-report of strategy use can yield important and unique insights into value-directed memory mechanisms that might not be readily gleaned from recall accuracy alone. For example, in a previous study (Cohen, Rissman, Suathana, Castel, & Knowlton, 2014), though virtually all participants reported using a value-based strategy, the majority of respondents reported promoting memory of higher value words by engaging in some form of deep semantic encoding (e.g., focusing on word meaning, creating a story using words) and intentionally ignoring lower value items, while a minority reported engaging in more shallow forms of encoding (e.g., rote rehearsal, alphabetizing) and attempting to remember all items. Moreover, participants' self-reported strategy was related to value-directed memory performance and brain activity – reported use of deeper semantic encoding strategies was associated with more higher-, but not lower-, value items recalled and reported ignoring of low-value items was associated reduced activity in regions associated with semantic encoding when studying those words. These results highlight individual differences in strategic value use that are ultimately related to performance providing a potential avenue for value-directed memory intervention.

Memory strategies and evaluation are informed by metamemory processes, or thoughts about one's own memory abilities (Bjork, 1994; Dunlosky & Bjork, 2013; Flavell, 1979). It has been proposed that participants learn their approximate recall capacity in the context of the value-directed task and then use this assessment to optimize the range of values to which they will allocate the most resources (Castel, 2007; Middlebrooks, Murayama, & Castel, 2017). Indeed, it has been consistently observed that participants become increasingly effective at promoting memory of high-value items across the first few lists in value-directed memory tasks suggesting that participants learn to maximize performance as they become familiar with the task parameters and their own memory limitations (Castel et al., 2002; Castel et al., 2007; Castel et al., 2009; McGillivray & Castel, 2011). Moreover, participants recall fewer high-value items when they anticipate to be tested on item recognition rather than recall, providing further evidence for participants using knowledge of task parameters and judgements about their memory abilities to inform value-directed memory strategies (Middlebrooks et al., 2017).

The results of the experiments in the previous chapter highlight the importance of metamemory processes in value-directed memory control of sub- and near-span lists. In Chapter 2, two experiments sought to investigate the effects of value-directed strategic processes on immediate memory for shorter lists lengths that fell within or near canonical working memory capacity (3 – 5 items; Cowan, 2001). More specifically, Experiment 2.1, examined the effects of value cues on memory of shorter list lengths including a sub-working memory span list length of 3-words and a near-working memory span list length of 6-words. Based on unitary store models of human memory, which posit that memory is comprised of a single, unitary system (Cowan, 1999; Jonides et al., 2008; Nairne, 2002; Oberauer, 2002), it was hypothesized that value-directed memory effects typically observed for lengthy supra-capacity lists would also be evident for shorter sub- and near-capacity lists. Indeed, value-directed memory effects were documented for 3-word and 6-word lists providing support for unitary store models of memory, but value effects were eliminated and reduced, respectively, in Experiment 2.2 when participants were given foreknowledge of the short list lengths. These findings suggest that value-directed effects on sub-span lists are the product of voluntary strategic processes that can be abandoned or reduced for shorter lists when metamemory judgments conclude less effortful, nonselective strategies will suffice.

Experiment 2.1 was the first study to document the effects of value-directed memory strategies used on sub- and near-span list lengths, though it is not without limitations. Only one sub-span (3-words) list length was used, raising the question of generalizability to other sub-span list lengths. Moreover, it remains unclear what explicit strategies underlie value-directed effects observed for sub- and near-span lists and whether or not they are the same processes that yield strategic value effects at longer list lengths. Important insights into strategic value-directed processes for sub-span and near-span lists could be gained by evaluating participants' self-reported strategy and experience when studying shorter value-cued lists. In order to fully understand value-directed strategic processing in working memory, a more detailed of examination of value-directed effects for shorter lists lengths the effect of value cues should be observed at multiple sub-working memory span list lengths accompanied by an analysis of self-reported strategy use.

The goal of the present investigation is to more completely characterize the effect of value cues on working memory by investigating the effect of value cues on recall of multiple sub-working memory span lists lengths. Informed by the findings from Experiment 2.1 in which participants were unaware of list-length, it was hypothesized that value-directed effects would be observed at sub-span list lengths thereby providing additional support for unitary store models of memory. However, as indicated by the results of Experiment 2.2, value-directed effects for sub-span list lengths are context-dependent with value-effects absent for sub-span lists when participants were granted foreknowledge of list length. As such, it was hypothesized that the reduced number of supra-span lists in the present experiment may result in a reduced use of value-directed strategic control as participants learn that most lists may be effectively remembered using less effortful, nonselective strategies. In addition to measuring value-directed memory, participant self-reported strategy use was collected to address underlying assumptions and gain further insight into the strategic processes used to recall shorter value cued lists. If the hypotheses presented here are confirmed, we will determine the effect of value cues on sub-span lists, ultimately contributing to our understanding of strategic value processes.

Method

Participants

Participants were 44 young adults (18 – 24, *M* = 18.71; Males *n* = 17) from the University of Michigan subject pool who received course credit as compensation. To increase point value salience, participants were informed that they were eligible to receive a $5.00 performance-based bonus at the end of the experiment if they earned over 250 points over the course of the experiment. All participants were treated within the ethical guidelines of the American Psychological Association.

Materials

Two hundred thirty nine words were selected from the MRC database (http://www.psy.uwa.edu.au/mrcdatabase/ uwa_ mrc.htm). Words were 3 to 8 letters in length, 1 to 3 syllables, had a concreteness rating of 300-600, had a Kucera & Francis written frequency of 10-150, and had a familiarity of 400-640. Stimuli were randomly sorted into 3 practice lists and 48 experimental lists of 2, 3, 4, 5, 6, or 8 words. Each word was paired with a point value from 1 to 12 and no point value was repeated within a trial. Across participants, word-point range pairings varied such that no word was consistently associated with a particular value. Low (1 – 4) and high (9 – 12) point values were equally represented across the 48 trials with each value being presented a total of 22 times. High- and low-value points were represented equally across positions in lists. Because several critical analyses compare recall of high- versus low-value items, medium point values (5 – 8) served as filler to ensure an adequate and equal number of high- and low-value items for analysis and were presented 12 times each. Medium values were used only for lists-lengths of 3, 5, 6, and 8, to produce equivalent number of observations of high- and low-values within a list (ex. 5 words: 2 low, 2 high, 1 medium) and to maintain parallel construction of list lengths of 3 and 6 in previous experiments.

Procedure

The experiment was implemented using EPrime 2.0 software (Psychology Software Tools, Inc.). Each value-directed memory (VDM) trial began with the presentation of a fixation star in the center of the screen (500ms), followed by the simultaneous presentation of a word and its associated point value. As in Castel, Balota, and McCabe (2009) and previous research conducted in our laboratory (Chapter 2) each word and associated point value appeared in the center of the screen for two seconds. Words-point pairs were presented sequentially with an inter-stimulus interval (ISI) of 500 milliseconds. The last word of each list was followed by a recall cue, three question marks "? ? ?", which indicated that participants were to say aloud all the words that they could remember from the current trial. The recall cue duration was varied based on list length with two seconds given for each word (ex. 6 seconds for a 3-word list). Participants' correct and incorrect verbal responses were recorded by a research assistant who was present in the room.

As in previous experiments, participants were instructed to try to maximize the number of points they earned. Because every word is paired with a positive point value participants were informed they should also try to recall as many words as possible from each list. Participants were told that they would be awarded a $5.00 bonus if they were able to earn at least 250 points for correctly recalling words. Before beginning the VDM task, participants completed three practice trials comprised of 2-, 5-, and 8-word lists. The VDM task consisted of 48 VDM trials. There were eight trials for each of the six list lengths: 2, 3, 4, 5, 6, and 8 words. List length varied pseudorandomly such that any one list length did not appear more than twice in a row and list order was randomized across participants. Participants did not know how many words were in a given trial until the recall cue appeared.

After completion of the computerized value-directed memory task, participants were given a two-minute break during which they were awarded their performance-based bonus. After the break, participants completed a surprise, untimed delayed recall task in which they were asked to recall as many words as from the prior phase of the experiment. Participants then completed a brief, computerized exit survey to assess reports of strategy use. To access verbal working memory capacity, experimenters then administered the Digit Span Forwards/Backwards task (Wechsler, 1997). For the Digit Span task, the experimenter reads a list of numbers aloud at a pace of one digit per second. The participant then repeats the list of digits in the order in which they were read (forward) in the first portion and then in reverse order (backward) in the second portion of the task. The list length begins small (two digits) and then increases in length (up to nine digits forward, eight digits backward) if the participant continues to respond correctly by repeating all numbers in their appropriate order. The experimenter continues to read progressively longer lists until the participant makes an error on two lists of the same length or the maximum list length is reached. The Digit Span task was scored using the instructions from the WAIS III manual in which participants receive one point for each correct list they recall, with a maximum possible score of 34 points.

Results

Results of non-parametric analyses are reported when parametric assumptions (i.e., normality) are violated. Greenhouse-Geisser corrections are applied when assumptions of sphericity are violated. *P*-value significance cutoffs are adjusted using the Holm-Bonferonni correction for familywise error rates (Holm, 1979). Participants earned an average of 1209 points (*range* = 1022 – 1349; *SD* = 74.28) out of a possible 1454 points. All participants surpassed the 250-point goal and received the $5.00 performance bonus.

Effect of List Length on Value-Directed Immediate Recall

The critical analyses focus on the effect of value on memory across the different sub- and near-span list lengths. A 2 x 6 repeated-measures analysis of variance (ANOVA) compared proportion of words recalled, where point category (low and high)[1] and list length (2, 3, 4, 5, 6, and 8) were within-subject factors. The omnibus ANOVA revealed a main effect of point value, $F(1, 43) = 20.44$, $p <.001$, $\eta^2_p = .32$, a main effect of list length, $F(2.78, 119.39) = 232.91$, $p <.001$, $\eta^2_p = .84$, and a significant interaction between list length and point value, $F(3.21, 138.10) = 9.55$, $p < .001$, $\eta^2_p = .18$, on proportion of words recalled (Figure 3.1).

Planned contrasts investigating the main effect of value on recall revealed that participants recalled a larger proportion of high- than low-value words, $t(43) = 4.52$, $p < .001$, $d = .68$. Unsurprisingly, planned contrasts revealed that participants recalled a larger proportion of words as list length decreased, 8- vs. 6-word lists: $t(43) = -15.26$, $p < .001$, $d = 2.39$, 6- vs. 5-

[1] Medium values (5 – 8 points) were excluded from the analysis because they were used as filler, were not represented on all trials, and were not represented at all list lengths which may have affected their effect on recall. Exploratory analysis showed that medium-value words were recalled at similar rates as low-value words, 3-words: *M* = .99, *SE* = .00; 5-words: *M* = .84, *SE* = .02; 6-words: *M* = .76, *SE* = .02; 8-words: *M* = .54, *SE* = .02.

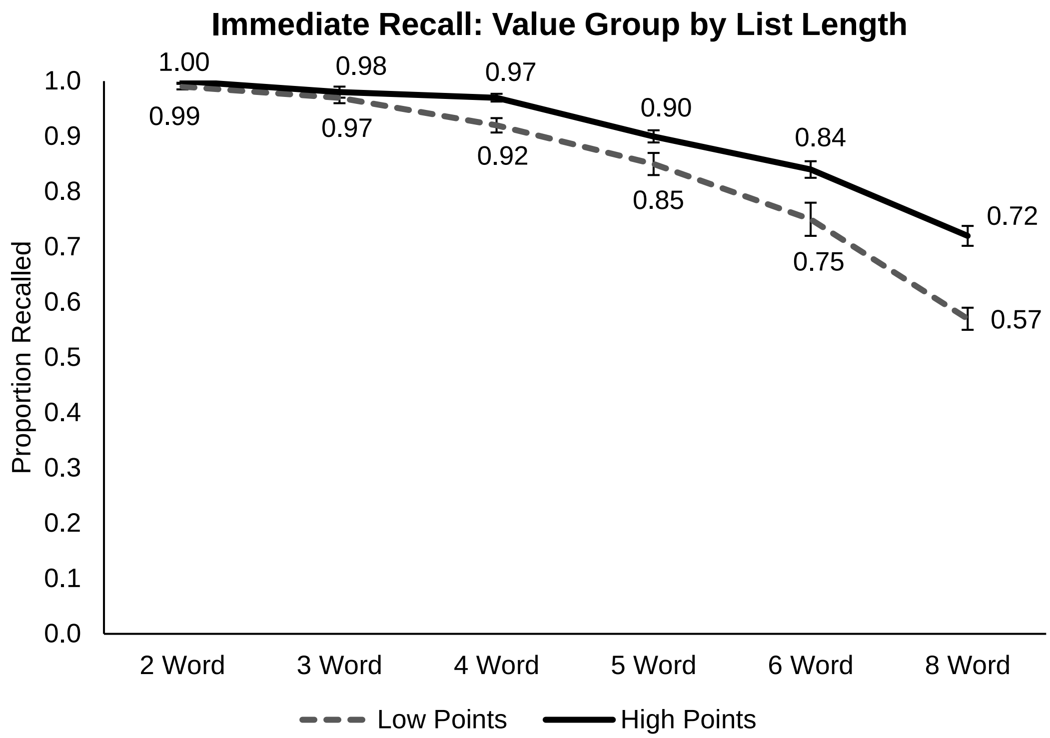

Figure 3.1 ***Average proportion of words correctly recalled (± standard error) across list lengths (2 Word = 2-word lists; 3 Word = 3-word lists; 4 Word = 4-word lists; 5 Word = 5-word lists; 6 Word = 6-word lists; 8 Word = 8-word lists) separated by point value group (Low Points = Low point value group, 1-4 points; High Points = High point value group, 9-12 points).***

word lists: $t(43) = -8.06$, $p < .001$, $d = 1.41$, 5- vs. 4-word lists: $t(43) = -7.75$, $p < .001$, $d = 1.13$ [$z(43) = -5.22$, $p < .001$], and 4- vs. 3-word lists: $t(43) = -5.52$, $p < .001$, $d = .98$ [$z(43) = -4.41$, $p < .001$], and 3- .vs 2-word lists, $t(43) = -2.22$, $p = .03$, $d = 1.13$ [$z(43) = -2.12$, $p = .03$].

These main effects are qualified by a point value by list length interaction. For supra-span lists lengths of 8- and 6-words, participants were more likely to recall high- than low-value words, 8-words: $t(43) = 4.76$, $p < .001$, $d = .71$; 6-words: $t(43) = 3.41$, $p = .001$, $d = .48$, thus demonstrating a value-directed memory effect for near- but supra-span lists. Similar patterns emerged for lists lengths 5 and 4, which approximate memory span; participants recalled higher proportions of high- than low-value words, 5-words: $t(43) = 2.60$, $p = .01$, $d = .40$, 4-words: $t(43) = 3.63$, $p = .001$, $d = .59$ ($z(43) = 3.24$, $p = .001$), demonstrating value-directed memory effects for list lengths within canonical working memory capacity limits. For the shorter sub-span lists of 3- and 2-words, performance was at or near ceiling, 3-words: high-value $M = .98$, $SE = .01$ vs. low-value $M = .97$, $SE = .01$; 2-words: high-value $M = 1.00$, $SE = .003$ vs. low-value $M = .99$, $SE = .005$, which may have limited the ability to detect value effects. Indeed, recall of high- and low-value words did not differ significantly, 3-words: $p = .32$ ($p = .25$); 2-words: $p = .18$ ($p = .18$), despite participants recalling more high- than low-value items.

Effect of Value on Perseverations and Delayed Recall

Next, analysis was conducted to examine the effect of value on immediate recall perseverative errors, or repeating words from previously studied lists despite their absence on the current trial, and on delayed recall. Perseverative errors and delayed recall accuracy may be additional measures, in addition to immediate recall accuracy, with which to measure depth of processing or selective promotion as a function of item value. If participants are encoding high-value words more deeply than low-value words, it would follow that there would be more high-value than low-value items perseverated and recalled after a delay. This measure of delayed repetition may be particularly useful in cases when immediate recall accuracy is at ceiling and does not dissociate between conditions, as in the case of 2- and 3-word lists.

The total number of perseverative errors was low, with participants repeating an average of 1.82 words from previously studied lists ($SD = 1.40$; Range: 0 – 5). Using a negative binomial distribution due to the rare occurrence of intrusions, a 2 x 6 general linear mixed model was conducted where value (high, low) and list length of origin (2, 3, 4, 5, 6, and 8) were within-subject predictors of number of perseverative errors. The omnibus test revealed no main effect of value, $p = .50$, list length of origin, $p = .50$, or interaction between value and list length on perseverative errors, $p = .51$.

Finally, I examined the effects of value on delayed recall. On average participants recalled 9.82 words from the immediate recall task in a surprise delayed recall task (*SD* = 5.53; Range: 2 – 30). To examine the effect of value on delayed recall, a 2 x 6 repeated measures ANOVA was conducted where value (high, low) and list length (2, 3, 4, 5, 6, and 8) were predictors of the proportion of words recalled after a delay. The omnibus test revealed a main effect of list-length of origin, $F(5, 210) = 5.12$, $p < .001$, $\eta^2_p = .11$, a trending effect of value, $F(1, 42) = 3.09$, $p = .09$, $\eta^2_p = .07$, and no interaction between list-length and value, $p = .61$, on delayed recall. Follow-up analysis showed that participants recalled a slightly larger proportion of higher- (*M* = .06, *SE* = .005) than lower- (*M* = .05, *SE* = .005) value items in the delayed recall task. Similar to what was observed in Experiments 2.1 and 2.2, this result indicates that value effects first observed in immediate recall persist to some extent in a delayed recall task. There were, however, no effects of value on delayed recall of words from 2-word lists, $p = .68$, and 3-word lists, $p = 1.00$. This could suggesting that strategic value-directed control may not have been used to guide memory for these two short list lengths, however the interpretation may be limited by the small number of words recalled from these short lists after a delay (2-word: *M* = 0.5 word, *SE* = .12; 3-word: *M* = 0.9 word, *SE* = .12 versus 6-word: *M* = 2.1 words, *SE* = .23; 8-word: *M* = 3.4 words, *SE* = .38).

Self-Report Strategy and Value-Directed Immediate Recall

After participants completed the value-directed memory task, they were given a computerized, exit survey with open-ended and Likert scale questions to assess strategy use. Exit survey responses were analyzed to gain insight into participant strategy use, how reported strategy may be related to performance, and how strategy may vary as a function of working memory capacity. Computer errors resulted in the loss of exit survey data for two participants. A complete list of survey questions is provided in Appendix A.

The majority of participants (71%) reported using multiple strategies over the course of the value task. As such, participants' open-ended responses to the question "which strategy did you use MOST" were coded to reflect either a rote rehearsal based strategy, or a semantic-based strategy (e.g., made a story with the words). Fifty-nine percent of participants reported using a semantic-based strategy most often to improve memory. Regarding selective encoding, nearly all participants (93%) endorsed "paying special attention or trying harder on the highest value items" at least some of the time, and most participants (56%) reported doing this always or almost always. On the other hand, only 34% of participants reported "ignor[ing] low-value items" some of the time and just 7% reported doing this always or almost always. Regarding free recall, 76% of participants reported recalling the words "in whatever order [they] could remember them" always or almost always whereas only 30% of participants reported trying to "recall the highest value words first".

Bivariate Spearman's Rho correlations were conducted to assess the relationships between participants' value-directed memory task performance and reported frequency of

Table 3.1 Self-reported strategy use. Percentage of participants that endorsed frequency of particular on the strategy exit survey; Spearman Rho correlations with high- and low-value accuracy; Significant correlations in BOLD

Strategy	Never	Almost Never	Sometimes	Almost Always	Always	High Value	Low Value
Tried harder on high-value items	5 %	2 %	37 %	39 %	17 %	.07	-.15
Ignored low-value items	34 %	32 %	27 %	7 %	0 %	**-.31**	**-.51**
Recalled highest value words first	13 %	25 %	32 %	22 %	8 %	-.01	-.30
Recalled words in whatever order	0 %	2 %	22 %	32 %	44 %	-.09	**.34**

strategy use, ranked ordinally from “never used” to “always used”. Endorsement of “paying special attention or trying harder on the highest value items” was not related to proportion of high-, p = .65, or low-value items recalled, p = .37, or overall accuracy, p = .80. Higher frequency of “ignoring low-value items”, was associated with lower overall accuracy, $r_s(39) = -.57$, $p < .001$ and total points earned, $r_s(39) = -.47$, $p = .002$. This relationship was driven by fewer low-value items recalled, $r_s(39) = -.51$, $p = .001$, as would be expected, but also fewer high-value items recalled, $r_s(39) = -.31$, $p = .05$. Regarding strategies used at recall, higher frequency of recalling items “in whatever order [they] could remember them” was associated with a larger proportion of low-value items recalled, $r_s(39) = .34$, $p = .03$, whereas recalling “the highest value words first” was marginally associated a smaller proportion of low-value items recalled, $r_s(39) = -.30$, $p = .06$.

Working Memory Capacity and Value-Directed Immediate Recall

Beyond the effects of list length and strategy on value-memory, an exploratory analysis was conducted to investigate the effects of individual differences in working memory capacity on value-directed memory of sub- and near-working memory span lists. Working memory capacity was measured using the WAIS III digit span forward/backward test with higher composite scores associated with higher working memory capacity (Wechsler, 1997). On average, participants’ total digit span score was 19.07 (*SE* = .52, range: 12 – 27). A median split was conducted to divide participants into a ‘high capacity’ group (n = 23, M = 21.43) and ‘low capacity’ group (n = 21, M = 16.48).

Independent samples *t*-tests were conducted to compare high and low working memory capacity groups on total points earned, proportion of words accurately recalled, proportion of high-value words recalled, and proportion of low-value words recalled. There was a significant effect of working memory capacity on points earned and overall accuracy with high capacity participants earning more points, $t(42) = 3.40$, $p = .001$, $d = 1.05$, and recalling a higher proportion of words overall, $t(42) = 3.11$, $p = .003$, $d = .96$, than lower capacity participants. There was a significant effect of working memory capacity on high-value recall and a marginally significant effect on low-value recall where high capacity participants recalled a larger proportion of high-value items, $t(42) = 2.84$, $p = .007$, $d = .87$, and low-value items, $t(42) = 1.92$, $p = .06$, $d = .59$, than lower capacity participants (Figure 3.2). There was no effect of working memory capacity on high- or low-value delayed recall, $ps > .65$.

Finally, the relationship between individual differences in working memory capacity and strategy use were analyzed. Spearman's Rho correlations were conducted with digit span score

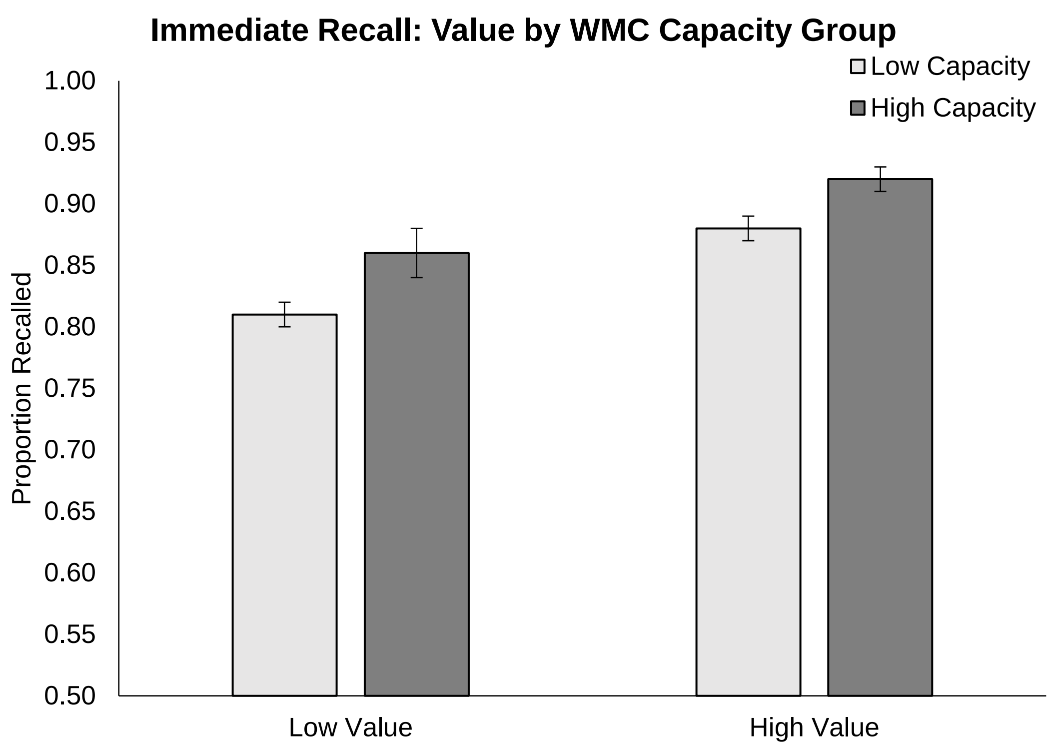

Figure 3.2 ***Average proportion of words correctly recalled (± standard error) across working memory capacity groups separated by point value group (Low Points = Low point value group, 1-4 points; High Points = High point value group, 9-12 points).***

as a continuous variable and strategy use frequency ranked ordinally from “never used” to “always used”. Interestingly, working memory capacity was negatively related to the reported frequency of “ignoring low-value items”, $r_s(39) = -.36$, $p = .02$, highlighting a potential strategy difference associated with capacity limits. Individual differences in working memory capacity were not related to other self-reported strategies, *ps* > .38.

General Discussion

Building on the finding that value effects were present for a single sub-span list length of 3-words, the goal of this study was to further characterize the impact of value cues on working memory by examining value-directed memory using a range of shorter lists lengths. To this end, participants recalled value-cued words from lists of 2-, 3-, 4-, and 5-words, all within canonical capacity, as well as lists of 6- and 8-words. In line with the findings presented in the previous chapter, the present results indicate the presence of strategic value effects for lists that are within canonical working memory capacity. This finding provides additional evidence that the same strategic processes can be brought to bear on multiple sub- and supra-capacity list lengths providing further support for a unitary store model of human memory.

More specifically, evidence of value-directed memory effects was observed for lists of 4-words with value-directed memory effects increasing as list length increased. Participants performed at ceiling for 2- and 3-word lists which limited the detection of value-directed memory effects. Two other exploratory measures of value effects, perseverative errors and delayed recall accuracy, were also examined as potential indices value-directed effects that may have been masked in immediate recall. Despite significant value-directed on immediate recall for 4-words or more, perseveration errors showed no effect of value suggesting this measure maybe insensitive to value-directed memory, at least in healthy young adults. Value-directed memory effects did, however, persist in a surprise delayed recall task such that participants recalled a slightly larger proportion of higher- than lower-value items, though this effect was only marginal. However, the lack of value-directed effects in delayed recall for words from 2- and 3-word lists potentially suggests that value-directed control strategies may not have been employed for these list lengths in this experiment.

Unlike in Experiment 2.1, there were no significant value-directed memory effects for 3-word lists in the present investigation. This difference could be due to the differences in the design of the two experiments. Across both experiments, participants were unaware of exactly how many words they would be studying in a given list until that list had concluded. In the first experiment, however, only 1/4 of the lists studied were lengths that fell within canonical working memory capacity. In this experiment, on the other hand, 2/3 of the lists studied were lengths that fell within canonical working memory capacity. As established in Experiment 2.2, use of value-directed memory control strategies for sub-span lists can depend upon experimental context and participants' knowledge of experimental demands. It is possible that participants, faced with multiple short lists, opted for a strategy that relied less on value cues as they became familiar with the parameters of the current experiment. In support of this hypothesis, a direct comparison of value-directed memory effects for 6-word lists across the two experiments revealed that participants in the current investigation, which required study of fewer supra-capacity lists, showed a reduced value-directed memory effect as indicated by a significantly lower proportion of high-value items recalled, $t(88) = -2.99$, $p = .004$, $d = .63$, but a significantly higher proportion of low-value items recalled, $t(88) = 3.99$, $p < .001$, $d = .85$, compared to participants from Experiment 2.1. These results suggest that participants relied less on value cues to guide memory strategies in the current study compared to a previous study with more challenging task parameters highlighting the importance of experimental context on value-directed memory strategy use for sub-span lists.

In order to gain further understanding of when and how value-cues are used to guide memory, participants were asked to complete an open-ended/Likert survey on strategy use and task experience. Most, but not all, participants reported using value cues to guide memory strategies. Further, while most participants reported regularly paying special attention to the higher value items, less than half of the participants reported regularly ignoring lower value items. The current results are in contrast with previous findings in which virtually all participants report using value cues to guide memory of longer lists and the majority of participants reported ignoring lower value items (Cohen et al., 2014). It is likely that the differences in reported strategies in the present investigation compared to previous research is due to differences in experimental parameters, namely the present use of sub-capacity list lengths. The decreases in self-reported value use in the present experiment compared to previous reports support the assumption that, as participants learn that they are able to recall all or most of the items, they are more likely to abandon value-directed memory strategies in favor of other less-effortful nonselective strategies. Further, higher reported frequency of attention to low-value items in the present experiment compared to previous reports hints at a potential step-wise strategy use based on task demands such that participants may first avoid using value in favor of less effortful, value-indiscriminate strategies, then as task demand increases (e.g., longer lists) participants use value-directed strategies but continue to encode lower value items, and as task demand consistently exceeds working memory capacity, participants continue to use value-directed strategies including intentionally ignoring lower value items in service of high-value item memory. This interpretation is supported by the result indicating lower working memory capacity participants reported ignoring lower value items more frequently than higher capacity participants. Interestingly, individual differences in working memory capacity were not related to the method used to memorize the words (rote rehearsal vs. semantic processing) suggesting that capacity differences in value-directed memory are driven by differences in selecting what to memorize rather than the method of memorization.

An exploratory analysis was conducted to examine the relationship between individual differences in working memory capacity, as measured by Digit Span Forward/Backward performance, and value-directed memory of these short lists. The results indicated that higher capacity participants recalled a larger proportion of both higher and lower value items. Similar to the findings presented here, Robinson and Unsworth (2017) found that working memory capacity was positively correlated with both lower and higher value item recall of long lists (30 words), suggesting that the relationship between working memory capacity and value-directed memory is similar for sub- and supra-span lists. One potential explanation is that higher capacity individuals are more effective at selectively promoting high-value items, but as high-value accuracy approaches ceiling, these individuals are able to allocate remaining resources to low-value item memory. Alternatively, working memory capacity, while related to overall accuracy, may be unrelated to strategic value-directed control processes. In order to gain further understanding of the relationship between working memory capacity and value-directed memory, future research will need to focus on disentangling the overall high recall performance of high capacity individuals from greater efficacy in value-directed selective processing perhaps by experimentally manipulating working memory capacity. Moreover, the present investigation is limited because working memory capacity is measured using a single task. Future research should use multiple measures of working memory function in order to increase validity and ensure that the relationship between working memory capacity and value-directed memory is not limited to one specific measure.

The present research is not without limitations. Because immediate recall accuracy for 2- and 3-word lists was at ceiling with limited variability, it is unclear whether value cues were used to guide memory for these short list lengths. It could be the case that value was used to guide memory, with higher value items being repeated more frequently or undergoing deeper encoding, but the short list lengths allowed for perfect recall of all encoded items regardless of resource allocation. Future research could aim to detect value-effects at these short list lengths using measures other than immediate recall accuracy which might be better suited to detect subtle differences, such as response times for correct recognition or rejection of semantically related probes. Moreover, in the self-report strategy survey, the majority of participants reported switching strategies over the course of the experiment. Because the survey was administered at the end of the computerized task, it is unclear which lists are impacted by which strategy, and how effective a particular strategy is at promoting recall. Future research can provide further insight into the use and efficacy of different strategies by probing for strategy use multiple times over the course of the experiment or by instructing participants to use a particular strategy on all trials.

Conclusion

The goal of the present investigation was to further characterize value-directed memory effects in working and short-term memory by investigating the effect of value cues on recall of multiple sub-working memory span lists. Building on the findings from the previous chapter, the current research provides evidence of value-directed effects for multiple sub- and near span list lengths within seconds of study demonstrating that use of value-based strategies are not limited to supra-span lists or a single sub-span list length. However, unlike a previous experiment in which sub-span lists lengths were relatively rare, there were no value effects for 3-word lists in the present investigation, suggesting that value-directed control processes for very short lists are context-dependent and are only evident when alternative, less selective strategies may not be effective. In support of this interpretation, results from the self-reported strategy survey indicate that relatively few participants engaged in the most selective strategy of "ignoring low-value items" with most participants opting to study all items but "pay special attention to higher-value items". Finally, results of an exploratory analysis provided evidence that higher working memory capacity individuals recalled more items regardless of value, though it remains unclear whether this if there are capacity-related differences in effective value-directed control. Future research is required to understand the potential importance of working memory capacity in value-directed memory of shorter lists. Together, the findings from this study provide further support for the unitary store model of human memory and provide insight into the strategies underlying this voluntary control process.

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CHAPTER 4

The Role of Working Memory Capacity in Value-Directed Memory

Introduction

Selective promotion of high-value information is an effective way to compensate for the limitations of our attention and memory systems. Previous research has found value-directed memory effects, recalling more high- than low-value items, for lengthy lists of words that far exceed working memory span ([typically 4-5 items, Cowan, 2001] Castel, Balota, & McCabe, 2009; Castel, Benjamin, Craik, & Watkins, 2002; Castel, Farb, & Craik, 2007; Cohen, Rissman, Hovhannisyan, Castel, & Knowlton, 2017; Friedman & Castel, 2011; Hennessee, Castel, & Knowlton, 2017). Building on this research, Chapters 2 and 3 aimed to investigate and characterize value-directed memory effects for sub-span lists. Results from two experiments demonstrate value-directed effects for lists ranging from 3-6 items, indicating that the control processes that underlie value-directed memory effects can be brought to bear successfully on information currently active in working memory. However, when participants can anticipate that they will be receiving shorter lists (via task instructions or list context), value-directed effects are minimized or even eliminated for shorter sub-span lists, highlighting the importance of strategic factors in value-directed memory effects.

Multiple component processes have been proposed to underlie value-directed memory of word lists. According to Castel's model (Castel, 2007) an evaluative process determines the extent to which resources will be allocated to studying (i.e., encoding) a piece of information.

The information's extrinsic value (e.g., associated with task, points, monetary reward, explicit instruction), intrinsic value (e.g., associated with personal beliefs, significance; Hess, Rosenberg, & Waters, 2001), and meta-memory judgments about one's own capacity limitations are thought to contribute to this evaluation (Castel, 2007). As a consequence of this evaluation, higher value items are selectively promoted through increased rehearsal and/or deep, semantic processing (e.g., thinking of the meaning of the word, using it in a sentence/song; Castel, 2007; Cohen, Rissman, Suthana, Castel, & Knowlton, 2014). Further encoding and rehearsal of lower value items are curtailed, or even actively inhibited (Castel, 2007; but see Ariel & Castel, 2014). At recall, people get feedback as to how many words they were able to remember, and in some cases how many points they earned. This information can inform metamemory judgments made during the evaluative process.

Value-Directed Memory, Selectivity, and Working Memory Capacity

Several of the processes proposed to mediate value-directed memory, namely evaluative processing, item selection, increased rehearsal, deep semantic processing, and inhibition, operate on representations held actively in working memory. That is, working memory and the executive functions it entails, are needed to implement item maintenance, prioritization, selection, and inhibition within this mental workspace (Baddeley & Hitch, 1974; Cowan, 2001; Halford, Cowan, & Andrews, 2007). Though capacity and control functions are potentially separable features of working memory, the two are intimately linked and are often measured using tests of working memory capacity or span (Engle, Kane, & Tuholski, 1999; McCabe, Roediger, McDaniel, Balota, & Hambrick, 2010). To the extent that the component processes underlying value-directed memory rely on working memory, individual differences indicated by standard measures of working memory capacity should be related to differences in value-directed memory.

To date, the effects of working memory capacity on value-directed memory (Castel, 2007; Castel et al., 2002, 2007, 2009; Castel, Humphreys, Lee, Galván, Balota, & McCabe, 2011; Castel, Murayama, Friedman, McGillivray, & Link, 2013) have been studied primarily by comparing healthy younger and older adults. Compared with younger adults, older adults tend to have lower working memory capacity and/or deficits in working memory control (Borella, Carretti, De Beni, 2008; Hasher & Zacks, 1988; Reuter-Lorenz & Sylvester, 2005). Interestingly, older adults recall a similar number of high-value items as younger adults, despite recalling fewer items overall (Castel et al., 2002, 2007, 2009, 2011). In addition to comparing high- and low-value recall accuracy, Castel and colleagues have used the *selectivity index* as a metric to assess proximity to optimal performance. Selectivity is an additional measure of value-directed control processes that can be easily compared across conditions and groups. Selectivity is calculated for each list as the total number of points earned at recall divided by the maximum number of points possible given the number of words recalled (with 1.00 being optimal performance). Based on this index of value-directed memory, older adults are as selective as or more selective than younger adults (Castel et al., 2002, 2007, 2009, 2011, 2013). Taken together, despite having lower working memory capacity and recalling fewer items, older adults can use value cues to guide memory as well as or better than younger adults, suggesting they may use value to compensate for memory limitations.

The finding that older adults are at least as selective as their younger counterparts may seem at odds with extant research on aging and working memory control. Both aging and lower working memory capacity have been associated with deficits in selective attention (McDowd &

Birren, 1990), inhibition of irrelevant stimuli (Hasher & Zacks, 1988), meta-memory assessments (Isingrini, Perrotin, & Souchay, 2008) and deficits in spontaneous adoption of optimal cognitive strategies (Mata, von Helversen, & Rieskamp, 2010; Lemaire, 2010). Why then are healthy older adults excelling at value-directed memory control? It could be that the typical value-directed memory task is not sufficiently challenging to detect control deficits in healthy older adults. Indeed, older adults with very mild and mild Alzheimer's disease, a disease associated with reduced memory function and control (Perry & Hodges, 1999), recalled fewer high-value items are were less selective than healthy older adults (Castel, Balota, & McCabe, 2009). Moreover, when additional demands are added to the classic value-directed memory task in the form of to-be-forgotten memoranda (forget words associated with negative point values), healthy older adults are less selective than their higher working memory capacity young adult counterparts (Hayes, Kelly, & Smith, 2012). Thus, memory control deficits associated with lower working memory capacity may reduce value-directed memory effects and selectivity, but only when the task is sufficiently challenging.

For healthy young adults, the effects of individual differences in working memory capacity on value-directed memory have been mixed. Using the standard value-directed memory task (12-word lists followed by immediate recall), two studies of young adults found that working memory capacity was not related to selectivity (Castel, Balota, & McCabe, 2009; Cohen, Rissman, Suthana, Castel, & Knowlton, 2014) but was positively related to overall recall (Cohen et al., 2014). In another study, when task demand was increased by increasing list length and adding a value-directed forgetting component, working memory capacity was positively related to selectivity suggesting that, like in healthy older adults, perhaps increasing task demand and taxing inhibitory processes may be necessary to detect capacity-related differences in value-directed memory (Hayes, Kelly, & Smith, 2012). However, Middlebrooks and colleagues (2017) found no relationship between value-directed memory performance across working memory capacities despite taxing inhibitory processes by playing distracting noises and music during the study of value-cued words. Together, the extant research on the role of working memory capacity in value-directed memory in healthy young adults is unclear and may depend on the task demands.

In Chapter 3, an exploratory analysis was conducted to investigate the effect of individual differences in working memory capacity, as measured by the Digit Span Forward/Backward task, on value-directed memory of sub- and near-span lists in healthy young adults. Similar to the observations of Cohen and colleagues (2014), the results indicated that lower capacity young adults recalled fewer higher *and* lower value items—an outcome that suggests lower capacity participants are not promoting higher value items to compensate for capacity limitations. Rather this pattern of results may suggest that individuals with higher working memory capacity are more effective at selectively promoting high-value items but are also able to recall more low-value items because of their larger capacity. Alternatively, higher capacity individuals, while able to recall more words overall, may be equally as effective as lower capacity individuals at promoting memory of high-value items over low-value items. Discriminating between these two possibilities in healthy young adults may require increased task demand and larger value-directed effects than were observed in Experiment 3.1. To examine the role of working memory capacity in value-directed memory, we made the following design decisions. First, the same task parameters used in 2.1 were used here to increase the likelihood of value-effects for list lengths at the lower-bound of canonical working memory capacity (3-words). Further, in the previous chapter working memory capacity was measured using a single measure of working memory function –the Digit Span Forward/Backward (Wechsler, Coalson, & Raiford, 1997). To the extent that different working memory measures may rely more or less on particular component processes of working memory, any single measure may be an insufficient characterization of that variable. As such, multiple validated working memory measures were used to create a more complete characterization of working memory function and, in turn, a more complete understanding of the effects of individual differences in working memory on value-directed memory of sub- and supra-span lists.

The goal of the present study is to investigate the role of working memory capacity in value-directed recall of sub- and supra-span lists. Accordingly, a compensatory account would predict that individuals with lower working memory capacity would rely more on value cues in order to compensate for capacity limitations ultimately resulting in similar proportion of high-value items recalled at the cost of low-value item recall and greater selectivity compared to individuals with higher capacity. Conversely, if lower working memory capacity is associated with a deficit in memory control, value cues would be used less effectively, resulting in a lower-proportion of high-value items recalled and/or a higher proportion of low-value items recalled and reduced selectivity compared to individuals with high working memory capacity. Moreover, working memory capacity differences in value-directed memory control may vary dependent upon whether or not the current list-length exceeds working memory capacity such that there may be no differences for lists that are within all participants' capacity (3-words) but differences for lists that only exceed low capacity participants memory limitations (6-words). These possibilities are tested in the present pair of experiments.

In Experiment 1, the effects of individual differences in working memory capacity on value-directed recall were tested for list lengths that are within, near, or exceed canonical working memory capacity.   Similar to findings from Experiment 3.1, lower working memory capacity was associated with fewer higher and lower value items recalled, challenging the idea that lower working memory capacity individuals may increase reliance on value cues to compensate for poorer memory. It was hypothesized that lower working memory capacity is causally related to reductions in value-directed recall and selectivity. If so, I expected that an experimental manipulation intended to reduce capacity and attentional resources would reduce value-directed memory effects and selectivity for sub- and supra-span lists. This hypothesis was tested and supported by Experiment 2, in which participants engaged in articulatory suppression while studying value-cued words.

Experiment 1

Method

Participants. Participants were 46 young adults (18 – 29 years, $M = 20.48$; Males $n = 9$) recruited from the University of Michigan campus and surrounding areas in Ann Arbor, MI and Ypsilanti, MI. Participants were compensated $15 for their participation in the experiment. To increase point value salience, participants were informed that they were eligible to receive a $5.00 performance-based bonus if they earned over 250 points over the course of the experiment. All participants were treated within the ethical guidelines of the American Psychological Association.

Materials. Materials were identical to those used in Experiments 2.1. Using the MRC database (http://www.psy.uwa.edu.au/mrcdatabase/ uwa_ mrc.htm), I selected 381 words that were 3 to 8 letters in length, 1 to 3 syllables, had a familiarity of 400-640, had a concreteness rating of 300-600, and had a Kucera & Francis written frequency of 10-150. Stimuli were randomly sorted into 3 practice lists and 48 experimental lists of 3, 6, 9, or 12 words. There were 12 trials of each list length. Each word was randomly assigned a value from 1 to 12. All computerized tasks were implemented using EPrime 2.0 software (Psychology Software Tools, Inc.)

Procedure. ***Value-directed Memory Task.*** The value-directed memory task procedure is identical to the task procedure used in Experiment 2.1. Each value-directed memory (VDM) trial began with the presentation of a fixation star in the center of the screen (500ms), followed by the simultaneous presentation of a word and its associated point value. Each word, and its associated point value presented to the right of the word, appeared in the center of the screen for 2 seconds. Words-point pairs were presented sequentially with an inter-stimulus interval (ISI) of 500 milliseconds. The last word of each list was followed by a recall cue, three question marks "? ? ?", which indicated that participants were to say aloud all the words that they could remember from the current trial. The recall cue duration was varied based on list length with 2 seconds given for each word (ex. 6 seconds for a 3-word list). Participants were instructed to try to maximize the number of points they earned. As every word is paired with a positive point value participants were informed they should also try to recall as many words as possible from each list. Participants were told that they would be awarded a $5.00 bonus if they were able to earn at least 250 points for correctly recalling words. Participants' verbal responses were recorded by a research assistant who was present in the room and participants were awarded their performance-based bonus after completing the computerized task.

Before beginning the VDM task, participants completed three practice trials comprised of 3-, 6-, and 12-word lists. The VDM task consisted of forty-eight VDM trials. There were 12 trials for each of the four list lengths, 3, 6, 9, and 12 words. List length varied pseudorandomly such that any given list length did not appear more than twice in a row and list order was randomized. Participants did not know how many words were in a given trial until the recall cue appeared. Each word was randomly paired with a point value ranging from 1 to 12. No point value was repeated within a trial and all point values were equally represented across the 48 trials. Point values were divided into three groups: low (1-4 points), medium (5-8 points), and high (9-12 points). Point groups (high, medium, low) were equally represented both within each trial and across all 48 trials. Following the value-directed recall task, participants completed a brief, open-ended exit survey to assess reports of strategy use.

Working Memory Capacity Measures. Following the exit survey, participants completed four working memory capacity measures: The Digit Span Forward/Backward tasks (Digit Span; Wechsler, Coalson, & Raiford, 1997), the Reading Span task (Daneman & Carpenter, 1980), and the Operation Span task (Unsworth, Heitz, Schrock, & Engle, 2005). For the Digit Span Forward/Backward tasks, the experimenter read a list of numbers aloud at a pace of one digit per second. The participant was instructed to repeat the list of digits in the order in which they were read (forward) in the first task or in reverse order in which they were read (backward) in the second task. The list lengths begin small (2 digits) and then increase (up to 9 digits forward, 8 digits backward) if the participant continues to respond correctly by repeating all numbers in their appropriate order. Once the participant makes two consecutive errors on two lists of the same length or the maximum list length is reached the task is complete. For the computerized Reading Span task (Daneman & Carpenter, 1980; Friedman & Miyake, 2004), participants were instructed to read aloud a series of sentences, remembering the last word of each sentence to recall at the end of the trial. The task consists of 12 trials, 3 of each sentence set-size, beginning with 2 sentences and increasing to 5 sentences. Participants were instructed to press the spacebar to advance to the next sentence or cue immediately after reading each sentence. At the end of the series of sentences, a recall cue (‘? ? ?’) appeared indicating that participants should recall aloud as many of the to-be-remembered words as possible. An experimenter was present in the room to ensure that participants complied with instructions and to record participants’ verbal responses. Finally, for the automated Operation Span task, participants completed a series of simple math equations (e.g., 9/9 + 1 = ?) each followed by a single to-be-remembered letter. At the end of each trial, participants were instructed to identify all of the to-be-remembered letters from the completed series in the correct order. Participants complete 15 trials, 3 of each set-size, ranging from 3 to 7 letters.

Results

Results of non-parametric analyses are reported when parametric assumptions (i.e., normality) are violated. Greenhouse-Geisser corrections are applied when assumptions of sphericity are violated. *P*-value significance cutoffs are adjusted using the Holm-Bonferroni correction for familywise error rates (Holm, 1979). Participants earned an average of 1529 points (*range* = 1035 – 1855; *SD* = 196.45) points out of a possible 2340 points. All participants surpassed the 250-point goal and received the $5.00 performance bonus.

Effect of List Length on Value-Directed Immediate Recall. First, to examine the effect of value on recall across the sub- and supra-span list lengths, 3 x 4 repeated-measures ANOVA compared proportion of words recalled, where point category (low, medium, and high) and list length (3, 6, 9, and 12) were within-group factors. The omnibus ANOVA revealed a main effect of point value, $F(1.16, 52.29) = 65.83$, $p < .001$, $\eta^2_p = .59$, a main effect of list length, $F(2.34, 105.48) = 842.86$, $p < .001$, $\eta^2_p = .95$, and a significant interaction between list length and point value on proportion of words recalled, $F(4.40, 197.88) = 23.19$, $p < .001$, $\eta^2_p = .34$.

Planned contrasts investigating the main effect of value on recall revealed that participants recalled a larger proportion of high- than medium-value words, $t(45) = 8.83$, $p < .001$, $d = 1.28$ [$z(45) = 5.45$, $p < .001$], and a larger proportion of medium- than low-value words $t(45) = 6.86$, $p < .001$, $d = 1.08$. As in previous experiments, planned contrasts revealed that participants recalled more words proportionally, as list length decreased, twelve words vs. nine words: $t(45) = -14.33$, $p < .001$, $d = 2.28$, nine words vs. six words: $t(45) = -18.98$, $p < .001$, $d = 2.90$, six words vs. three words: $t(45) = -16.74$, $p < .001$, $d = 2.66$ [$z(45) = -5.91$, $p < .001$].

These main effects are qualified by a value by list length interaction. For lists of 12-, 9-, and 6-words, participants were more likely to recall high- than medium-value words, 12-word:

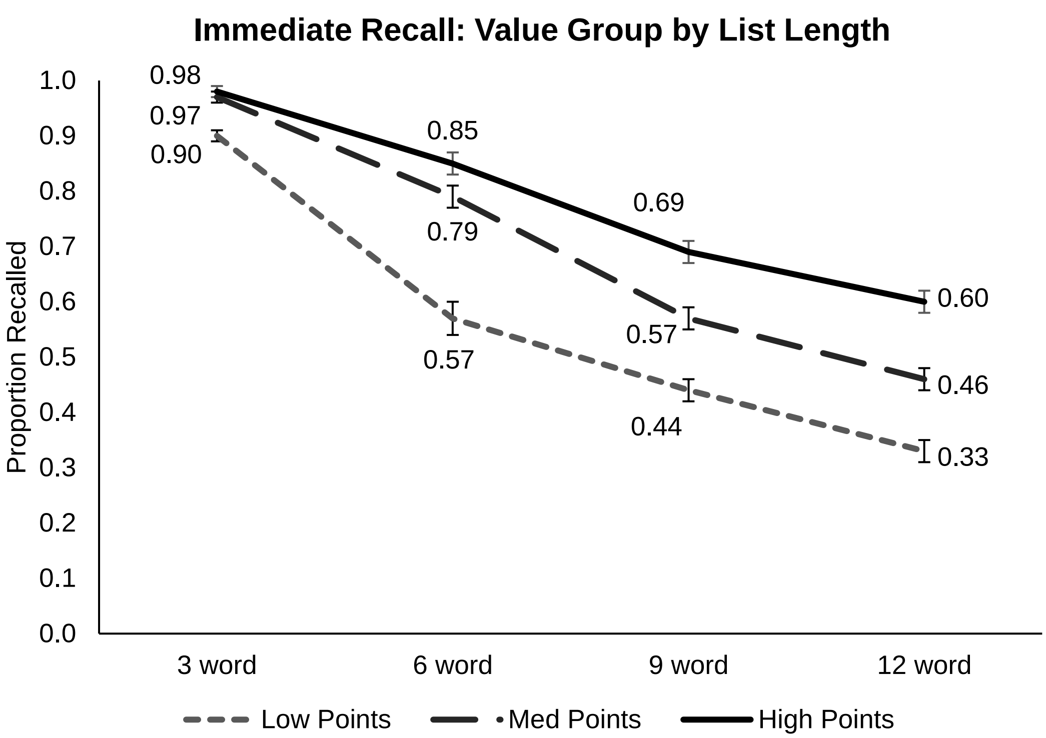

Figure 4.1. ***Experiment 1 average proportion of words correctly recalled (± standard error) across list lengths (3-word = 3-word lists; 6-word = 6-word lists; 9-word = 9-word lists; 12-word = 12-word lists) separated by point value group (Low point value group, 1-4 points; Medium point value group, 5-8 points; High point value group, 9-12 points).***

$t(45) = 8.09$, $p < .001$, $d = 1.19$; 9-word: $t(45) = 6.48$, $p < .001$, $d = .94$; 6-word: $t(45) = 4.88$, $p < .001$, $d = .63$, and medium- than low-value words, 12-words: $t(45) = 5.75$, $p < .001$, $d = .83$; 9-word: $t(45) = 5.20$, $p < .001$, $d = .76$; 6-word: $t(45) = 6.85$, $p < .001$, $d = 1.04$, thus replicating the classic value-directed memory effect across multiple list lengths and the pattern of results observed from Experiment 2.1. For lists of 3-words, which presumably does not exceed participants working memory capacity, participants recalled fewer low-value words than medium-value, $t(45) = -5.00$, $p < .001$, $d = .82$, or high-value words, $t(45) = -5.20$, $p < .001$, $d = .83$, even at this very short list length, again replicating the findings from Experiment 2.1. As in the previous experiment, there was no difference in recall rates between medium- and high-value words, $p = .28$, likely because performance was at ceiling, 3-word medium-value: $M = .97$, $SE = .008$, 3-word high-value: $M = .98$, $SE = .006$.

Effect of List Length on Selectivity. In addition to accuracy, the effect of value and list length on selectivity, or proximity to optimal performance, was examined using a modification of Castel's selectivity index (Castel, 2002). In previous research, the selectivity index is calculated by dividing the number of points a participant earned in a given trial by the maximum number of points the participant could have earned given the number of words they recalled on that trial. For example, a participant who recalled 3 words valued at 7, 8, and 12 points (total = 27 points) from a 12-word list where the three highest point values were 10, 11, and 12 (total = 33 points) would have a selectivity index of .82 (= 27 points /33 points) for that trial. A participant can performs optimally, or receives a 1.00 on the selectivity index, if they (a) forsake the lower value words, recalling only the higher value words or (b) recall all of the words on a list. However, the variable list lengths in the present paradigm do not allow for every point value to be represented in every trial as in previous research. To account for the trial-to-trial variability in maximum points that can be earned, point values were standardized across trials by recoding all low-value items (1-4 points) as 1, medium-value items (5-8 points) as 2, and all high-value items (9-12 points) as 3 before calculating selectivity. This standardization restricts the range of the selectivity index, potentially limiting our ability to detect differences in selectivity across list lengths, but ultimately generates a more conservative estimate of selectivity given the variability between lists.

To investigate the effect of list length on optimal performance, a repeated-measures ANOVA was conducted comparing selectivity across the four list lengths (3, 6, 9, and 12). The results indicated an effect of list length on selectivity, $F(2.51, 112.76) = 222.55$, $p < .001$, $\eta^2_p = .83$. Planned contrasts revealed that participants were less selective as list lengths increased: 3- vs. 6-words lists, $t(45) = 8.99$, $p < .001$, $d = 1.50$ [$z(45) = 5.82$, $p < .001$], 6- and 9-word lists, $t(45) = 12.45$, $p < .001$, $d = 1.93$ [$z(45) = 5.84$, $p < .001$], and 9- and 12-word lists, $t(45) = 4.51$, $p < .001$, $d = .48$, indicating that as demands on memory increase, value-based strategy use decreases or becomes less effective.

Working Memory Capacity Measures. The critical analyses focus the effects of individual differences in working memory capacity (WMC) on value-directed memory of sub- and near-working memory span lists. To this end, *z*-scores were calculated for each of the working memory tasks – the digit span forward task, the digit span backward task, the reading span task, and the operation span task – and then added together to create a WMC composite score for each participant ($M = 0.0$, $SD = 3.1$). A median split was conducted to divide participants into a 'high capacity' group ($n = 23$, $M = 2.41$, $SD = 2.36$) and 'low capacity' group ($n = 23$, $M = -2.41$, $SD = 1.41$).

To investigate the relationship between WMC and value-directed recall, a 2 x 3 x 4 repeated-measures ANOVA was conducted comparing proportion of words recalled, where point category (high, medium, and low) and list length (3-, 6-, 9-, and 12-words) were within-group factors and working memory capacity groups (high vs. low) was a between-subject factor. There was a main-effect of WMC on recall, $F(1, 44) = 20.48$, $p < .001$, $\eta^2_p = .32$, and an interaction between WMC and list length on recall, $F(2.41, 105.91) = 2.88$, $p = .05$, $\eta^2_p = .06$. There was, however, no interaction between WMC and value on recall, $p = .34$, and no three-way interaction between WMC, list length, and value, $p = .44$. Follow-up planned comparisons revealed that high WMC participants recalled more words overall compared to low WMC participants, $t(44) = 4.57$, $p < .001$, $d = 1.32$. High WMC participants recalled more words at all list lengths, 3-words: $t(36.33) = 3.90$, $p < .001$, $d = 1.67$ [$z(44) = 3.51$, $p < .001$]; 6-words: $t(44) = 3.92$, $p < .001$, $d = 1.10$; 9-words: $t(44) = 4.08$, $p < .001$, $d = 1.17$; and 12-words: $t(44) = 3.28$, $p = .002$, $d = 1.06$.

Because accuracy and selectivity are partially separable measures, it is possible that high WMC participants are equally as selective as their low capacity counterparts, though high WMC participants recalled more items of every value. To test the relationship between working memory capacity and selectivity, a 2 x 4 repeated-measures ANOVA was conducted that compared selectivity where list-length (3, 6, 9, 12) was a within-subject variable and working memory capacity groups (high vs. low) was a between-subject factor. Though high WMC participants ($M = .90$, $SD = .03$) were more selective than low WMC participants ($M = .88$, $SD = .05$), there was no effect of working memory capacity group on selectivity, $p = .11$, $\eta^2_p = .06$, and no interaction between working memory capacity group and list length on selectivity, $p = .39$, $\eta^2_p = .02$. However, categorizing capacity as either high or low, though it may aid in interpretation, reduces variability and detail in the data. Considering that the variability in the selectivity index is already restricted as presently calculated, additional restrictions to variability

a) b)

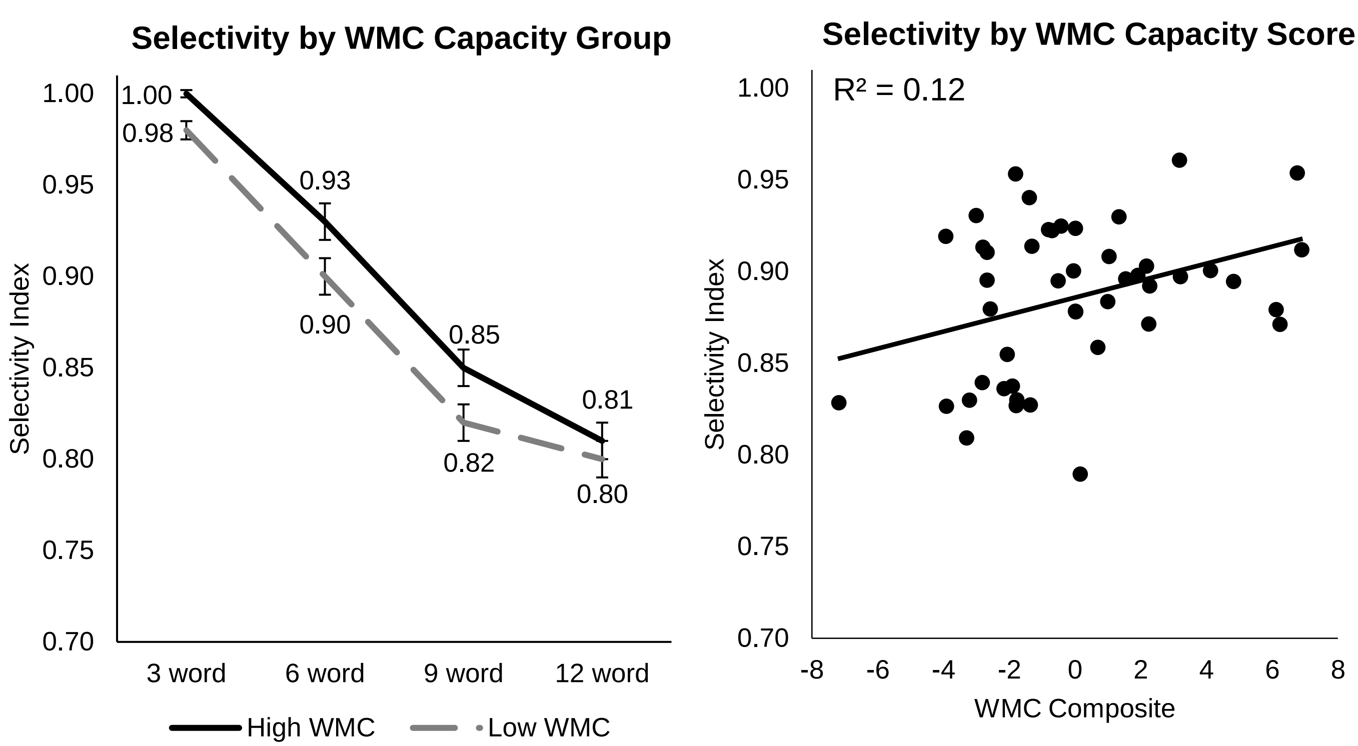

Figure 4.2 ***Experiment 1 a) Average selectivity index score across list length separated by working memory capacity group (High WMC = high working memory capacity group; Low WMC = low working memory capacity group) and b) the correlation between average selectivity score and working memory composite scores.***

may reduce the ability to detect the effect of working memory capacity on selectivity. As such an additional correlational analysis was conducted where both working memory capacity and selectivity were continuous measures. Results revealed a moderate positive relationship between WMC and overall selectivity, $r(45) = .35$, $p = .02$. Taken together with the trending difference in average selectivity from the ANOVA, the results suggest that higher capacity participants recalled more items overall and did so while remaining more selective than their lower capacity counterparts.

Self-Report Strategy and Value-Directed Immediate Recall. After participants completed the value-directed memory task, they were given a computerized, exit survey identical to what was used in Experiment 3.1 with open-ended and Likert scale questions to assess strategy use. An analysis of the exit survey responses was conducted potentially to gain insight into strategy use, how reported strategy may be related to performance, and how strategy may vary as a function of working memory capacity. A complete list of survey questions is provided in Appendix A.

Participants responded to strategy questions by endorsing the frequency with which they used those strategies ranging from "never" used to "always" used. The majority of participants (82%) reported using multiple strategies over the course of the value task. As such the response options were not mutually exclusive. Regarding encoding, 67% of participants endorsed "paying special attention or trying harder on the highest value items" and 53% of participants reported "ignor[ing] low-value items" at least some of the time. Regarding free recall, 69% of participants reported recalling the words "in whatever order [they] could remember them" always or almost always whereas 43% of participants reported trying to "recall the highest value words first".

Spearman's Rho correlations were conducted to assess the relationships between reported frequency of self-reported strategy use, ranked ordinally from "never" used to "always" used,

Table 4.1 Self-reported strategy use. Percentage of participants that endorsed frequency of particular on the strategy exit survey; Spearman Rho correlations with high- and low-value accuracy; Significant correlations in BOLD

Strategy	Never	Almost Never	Some-times	Almost Always	Always	High Value	Med Value	Low Value
Tried harder on high-value items	11 %	22 %	26 %	28 %	13 %	- .12	- .02	.16
Ignored low-value items	26 %	22 %	24 %	20 %	9 %	**.39**	.02	**- .76**
Recalled highest value words first	15 %	17 %	24 %	28 %	15 %	.17	- .03	**- .33**
Recalled words in whatever order	2 %	4 %	24 %	26 %	43 %	- .06	- .10	.07

and overall recall, proportion of low-value items recalled, proportion of medium-value items recalled, and proportion of high-value items recalled. Unsurprisingly, more frequent use the "ignoring low-value items" strategy was negatively correlated with low-value recall, $r_s(45) = -.76$, $p < .001$, but positively correlated with high-value recall, $r_s(45) = .39$, $p = .008$, suggesting that ignoring low-value items allowed for resources to be allocated to remembering higher value items. There was no relationship with reported frequency of ignoring low-value items and medium-value recall accuracy, $p = .90$. Greater frequency of "ignoring low-value items", was associated with a marginally significant lower overall accuracy, $r_s(45) = -.27$, $p = .07$, but not in total points earned $p = .41$. Higher frequency of "ignoring low-value items" was also associated with greater selectivity, $r_s(45) = .49$, $p = .001$. Recalling "the highest value words first" was associated with a decreased proportion of low-value items recalled, $r_s(45) = -.33$, $p = .03$. Endorsement of "paying special attention or trying harder on the highest value items" or recalling items "in whatever order [they] could remember them" was not related to any accuracy outcome, *p*s = .30. Though lower WMC participants reported a higher frequency of "ignoring low-value items" (*M* = 1.91 [sometimes], *Mode* = 1.00 [almost never]) compared to high WMC participants (*M* = 1.31 [almost never], *Mode* = 0.00 [never]), working memory capacity was not significantly related to frequency of "ignoring low-value items", $p > .14$ or any other reported strategy, *ps* > .73.

Discussion

The goal of Experiment 1 was to investigate how individual differences in working memory capacity are related to value-directed memory of sub- and supra- working memory span lists. Replicating the findings from Experiment 2.1, results indicate value-directed memory effects at all lists lengths, even at the short sub-capacity list length of 3-words. There was a main effect of working memory capacity on recall such that higher capacity individuals recalled more high-, medium-, and low-value items. Despite recalling more low-value items, selectivity indices indicated higher capacity participants were more selective than their lower capacity counterparts. These results run contrary to the hypothesis that lower capacity participants would use value cues to compensate for capacity or functional limitations, instead suggesting that lower capacity participants may exhibit a memory control deficit compared to higher capacity participants.

The results of Experiment 1 suggest that working memory serves to support value-directed memory processes, in that individuals with greater working memory capacity demonstrate greater selectivity, indicative of more optimal use of value cues. If this interpretation is correct, then interfering with working memory function should experimentally reduce the efficacy of value-directed memory processes. To this end, a second experiment was conducted in which participants' working memory function was experimentally reduced by requiring them to engage in articulatory suppression (Murray, 1968) while studying value-cued words. To the extent that working memory supports value-directed processes, as suggested by the results from Experiment 1, then the recall of high-value items and selectivity should be reduced by this experimental manipulation.

Experiment 2

Method

Participants. Participants were 50 young adults (18 – 27 years, M = 18.96; Males n = 19) recruited from the University of Michigan campus subject pool. Participants received course credit for their participation in the experiment. As in previous experiments, participants were informed that they were eligible to receive a $5.00 performance-based bonus at the end of the experiment. In previous experiments, all participants surpassed the 250-point goal by over 750 points, potentially raising the concern that the point goal was not sufficiently challenging and thereby undermining the intent to increase point value salience. To ensure that the goal for this experiment was sufficiently challenging, participants were informed that they were eligible to receive a performance-based bonus if they earned over 1000 points over the course of the experiment. All participants were treated within the ethical guidelines of the American Psychological Association.

Materials & Procedure. Materials and procedure were identical to Experiment 1 with a few notable exceptions. Namely, participants were instructed to begin repeating the word "the" aloud at a steady pace when cued (Murray, 1968) and continue saying "the" until the cue to recall the list of words appeared (i.e. ? ? ?). The cue to begin the articulatory suppression (AS) was a green cross that appeared center screen (1s) before the first word of every list. Following the immediate recall task, the receipt of the performance-based bonus, and completion of a brief, open-ended exit survey, participants completed the Digit Span Forward/Backward task. In order to limit the session to 60 minutes, as required by the subject pool guidelines, no other working memory capacity tasks were administered.

Results & Discussion

Participants earned an average of 1319 points (*range* = 975 – 1862; *SD* = 227.72) out of a possible 2340 points. Two participants (4%) failed to meet the 1000-point goal (975 and 987 points) and did not receive the $5.00 performance bonus.

Articulatory Suppression on Value-Directed Recall across List Lengths. The critical analyses focus on the value-directed memory effect across the sub- and supra-span list lengths while engaging in articulatory suppression. A 3 x 4 repeated-measures ANOVA compared proportion of words recalled, where point category (low, medium, and high) and list length (3, 6, 9, and 12) were within-group factors. Summary statistics are reported in Table 1. The omnibus ANOVA revealed a main effect of point value, $F(1.48, 72.28) = 67.44$, $p < .001$, $\eta^2_p = .58$, a main effect of list length, $F(2.38, 116.96) = 695.43$, $p < .001$, $\eta^2_p = .93$, and a significant interaction between list length and point value on proportion of words recalled, $F(4.24, 207.72) = 4.03$, $p = .003$, $\eta^2_p = .08$ (See Fig. 3).

Planned contrasts revealed the persistence of a value effect despite articulatory suppression such that participants recalled a larger proportion of high- than medium-value words, $t(49) = 7.79$, $p < .001$, $d = 1.14$, and a larger proportion of medium- than low-value words

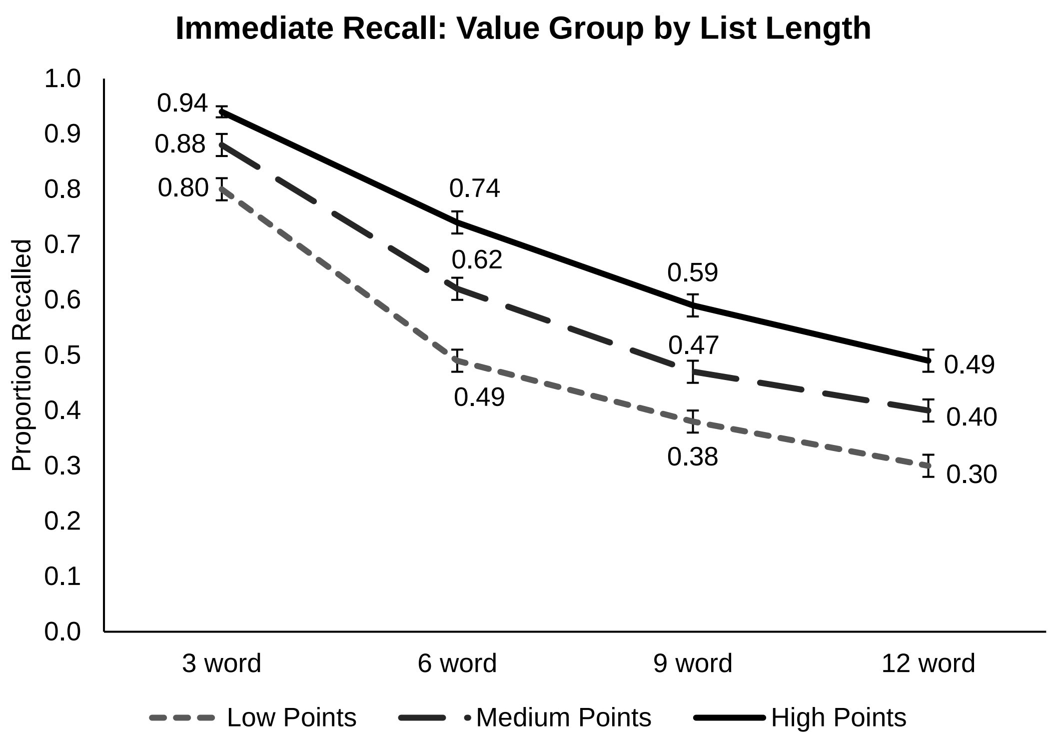

Figure 4.3 ***Experiment 2 average proportion of words correctly recalled (± standard error) across list lengths (3-word = 3-word lists; 6-word = 6-word lists; 9-word = 9-word lists; 12-word = 12-word lists) separated by point value group (Low point value group, 1-4 points; Medium point value group, 5-8 points; High point value group, 9-12 points).***

$t(49) = 6.20$, $p < .001$, $d = .93$. As in previous studies, planned contrasts revealed that participants recalled more words proportionally, as list length decreased, twelve words vs. nine words: $t(49) = -10.12$, $p < .001$, $d = 1.49$ [$z(49) = -5.74$, $p < .001$], nine words vs. six words: $t(49) = -14.95$, $p < .001$, $d = 2.28$ [$z(49) = -6.15$, $p < .001$], six words vs. three words: $t(49) = -18.29$, $p < .001$, $d = -2.69$.

These main effects are qualified by a point value by list length interaction. For lists of 12-, 9-, and 6-words, participants were more likely to recall high- than medium-value words, 12-word: $t(49) = 5.39$, $p < .001$, $d = .75$; 9-word: $t(49) = 6.87$, $p < .001$, $d = .96$; 6-word: $t(49) = 5.84$, $p < .001$, $d = .84$, and medium- than low-value words, 12-word: $t(45) = 5.50$, $p < .001$, $d = .79$; 9-word: $t(49) = 3.48$, $p = .001$, $d = .55$; 6-word: $t(49) = 4.94$, $p < .001$, $d = .70$ [$z(49) = 4.36$, $p < .001$], demonstrating the persistence of a value-directed memory effect across multiple list lengths while engaging in articulatory suppression. For lists of 3-words, participants recalled more high-, $t(49) = 6.43$, $p < .001$, $d = .90$ [$z(49) = 4.65$, $p < .001$], and medium-value words, $t(49) = 4.66$, $p < .001$, $d = .68$ [$z(49) = 3.77$, $p < .001$], than low-value words as in Experiment 1 without AS. In contrast to Experiment 1 in which high- and medium-value recall were equivalent, participants suppressing articulation recalled more high- than medium-value items for lists of just 3 words, $t(49) = 4.20$, $p < .001$, $d = .55$ [$z(49) = 3.59$, $p < .001$]. In sum, participants suppressing articulation exhibited the value-directed memory effect at all list lengths.

How does Articulatory Suppression affect VDM? Comparing Experiment 1 and 2. To further understand the effect of articulatory suppression (AS) on performance, I compared performance from the current experiment to performance in Experiment 1, in which participants did not suppress articulation. I compared recall accuracy by conducting a 2 x 3 x 4 mixed-measures ANOVA in which Experiment (E1[No-AS] vs. E2 [AS]) was a between subjects factor and value and list length were within subjects factors. There was a significant main-effect of experiment, $F(1, 94) = 27.02$, $p < .001$, $\eta^2_p = .22$, and an interaction between experiment and list length on recall, $F(2.41, 226.60) = 5.23$, $p = .004$, $\eta^2_p = .05$. Experiment did not interact with value to affect recall, $p = .31$. However, there was a three-way interaction between experiment, length, and value, $F(4.50, 422.95) = 5.31$, $p < .001$, $\eta^2_p = .05$.

Planned follow-up contrasts revealed lower recall with than without AS, $t(94) = -5.21$, $p < .001$, $d = 1.07$. This was true at all list lengths: 3-words, $t(81.73) = -5.59$, $p < .001$, $d = 1.19$, 6-words: $t(94) = -5.05$, $p < .001$, $d = 1.03$, 9-word: $t(94) = -4.51$, $p < .001$, $d = .94$, 12-word: $t(94) = -3.37$, $p = .001$, $d = .70$. For 3-word lists, AS led to lower recall of high-, $t(81.64) = -3.32$, $p = .001$, $d = .69$, medium-, $t(72.34) = -5.34$, $p < .001$, $d = .78$, and low-value items, $t(87.91) = -4.09$, $p < .001$, $d = .82$ than No-AS (E1). For 6-word and 9-word lists, compared to No-AS, AS led to lower recall of high-value, 6-words: $t(94) = -4.02$, $p < .001$, $d = .78$, 9-word: $t(94) = -3.88$, $p < .001$, $d = .74$, and medium-value items, 6-words: $t(94) = -5.28$, $p < .001$, $d = 1.12$, 9-word: $t(94) = -3.97$, $p < .001$, $d = .76$. However, there were no significant differences in recall of low-value items across the experiments after applying Holm-Bonferroni correction for multiple comparisons, 6-words: $p = .04$, 9-words: $p = .06$. Finally, for lists of 12-words, AS led to lower recall of high-value items, $t(94) = -4.08$, $p < .001$, $d = .88$, but recall of medium-value items, $p = .02$, or low-value items, $p = .39$, did not differ across the experiments after applying Holm-Bonferroni correction for multiple comparisons. In sum, articulatory suppression resulted in fewer high-value items recalled at both sub- and supra span lengths but only fewer low-value items recalled for sub-span lists, indicating a reduction in the value-directed effect for near- and supra-span lists.

Articulatory Suppression on Recall Selectivity across List Lengths. Next, the effect of list length on selectivity while engaging in articulatory suppression was examined using a modified variant of Castel's selectivity index (Castel et al., 2002) described above. To investigate the effect of articulatory suppression on selectivity, a 2 x 4 mixed-measures ANOVA was conducted where experiment (E1 [No-AS] vs. E2 [AS]) was the between subject factor and list length was the within subject factor (Fig. 4). There was a main effect of experiment on selectivity, $F(1, 94) = 18.36$, $p < .001$, $\eta^2_p = .16$, and a marginally significant interaction between experiment and list length on selectivity, $F(2.56, 240.75) = 2.70$, $p = .06$, $\eta^2_p = .03$. Planned follow-up contrasts revealed lower selectivity with AS than without AS, $t(94) = -4.28$, $p < .001$, $d = .88$, across all list lengths, 3-word: $t(77.00) = -4.53$, $p < .001$, $d = .94$; 6-word: $t(94) =$

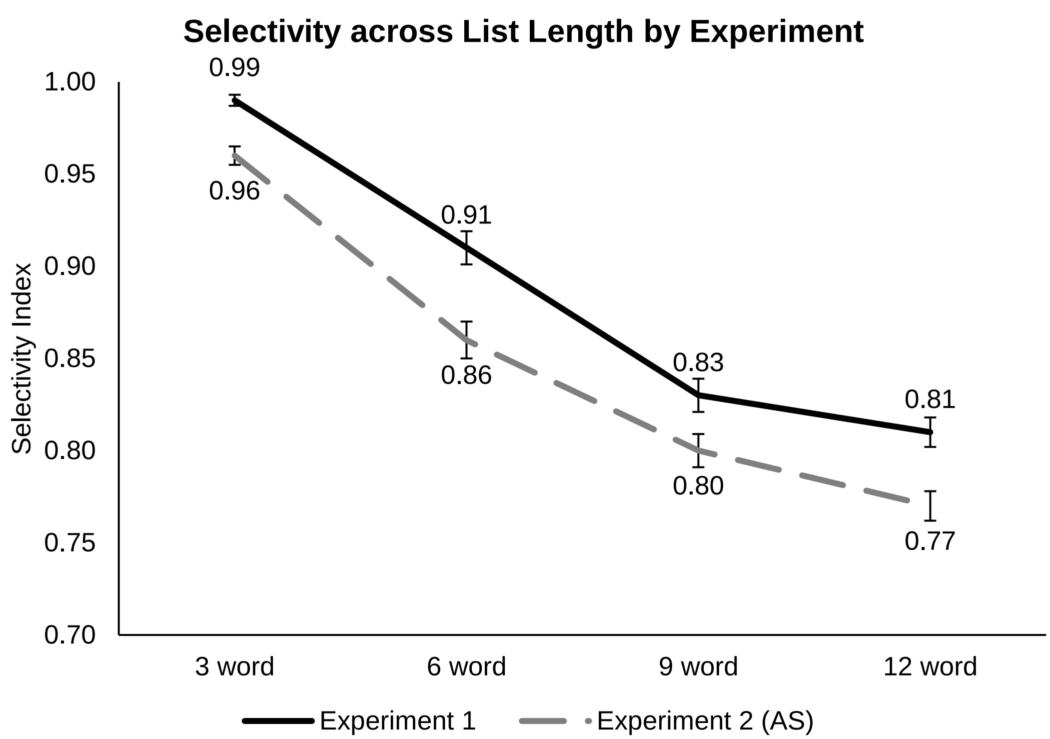

Figure 4.4 ***Average selectivity index (± standard error) across list lengths (3 Word = 3-word lists; 6 Word = 6-word lists; 9-word = 9-word lists; 12-word = 12-word lists) separated by experiment (Experiment 1= No articulatory suppression; Experiment 2 (AS) = Articulatory Suppression)***

-4.21, $p < .001$, $d = .76$; 9-word: $t(94) = -2.97$, $p = .004$, $d = .50$; 12-word: $t(94) = -3.00$, $p = .003$, $d = .67$, confirming the detrimental effect of articulatory suppression on the selective promotion of higher value items across all list lengths. These comparative analyses and their implications are discussed in greater detail below.

General Discussion

Though many important value-directed memory processes rely on operations that take place in working memory, previous studies investigating the relationship between working memory capacity in value-directed memory of supra-span lists have yielded mixed results leaving the role of working memory capacity in this control process unclear. Some studies have shown that lower capacity participants, namely healthy older adults, compensate for their capacity limitations by selectively promoting high-value item memory at the cost of low-value item recall (Castel et al., 2002, 2007, 2009, 2011, 2013), while other studies have shown that lower working memory capacity participants exhibit executive control deficits resulting in reduced selective promotion of high-value items (Castel, Balota, & McCabe, 2009; Hayes, Kelly, & Smith, 2012), while still other have found no relationship between capacity and value-directed memory (Castel, Balota, & McCabe, 2009; Cohen, Rissman, Suthana, Castel, & Knowlton, 2014; Middlebrooks et al., 2017). The goal of this study was to elucidate the role of working memory capacity in value-directed memory. To this end, two experiments were conducted that built on previous investigations by examining the role of working memory capacity in value-directed memory of both sub- and supra-span lists (Experiment 1) and the effects of reducing working memory capacity with an experimental manipulation: articulatory suppression (Experiment 2).

In Experiment 1, participants completed three working memory span measures, the Digit Span Forward/Backward, Operation Span, and Reading Span, which were used to determine working memory capacity. As in previous investigations (Cohen et al., 2014; Chapter 3), results from the present study indicated that individuals with lower working memory capacity recalled fewer words regardless of value. Compared to high working memory capacity participants, lower working memory capacity participants reported a marginally higher frequency of using the strategy of "ignoring low value items", so it would follow that they would recall fewer low-value items. However, adoption of this strategy did not necessarily result in promotion of high-value items. Instead, working memory capacity was positively related to selectivity indicating that, in addition to recalling fewer words overall, lower capacity participants were less selective about the items they recalled compared to higher capacity participants. Moreover, low capacity-related reductions in selectivity were present for list lengths that were both within and exceeded canonical working memory capacity. Together, these results provide support for the control deficit hypothesis suggesting that lower capacity young adults are less able to control the contents of working memory ultimately resulting in reduced value-directed memory control.

Interestingly, there were no capacity group differences in selectivity for 12-word lists, the list length typically used in value-directed memory studies. This result may suggest that once the list length has sufficiently surpassed all participants' capacities, control differences across working memory capacity groups are minimized. Though potentially due to the restricted range of the modified selectivity index used in this study, this finding may help explain the lack of relationship between working memory capacity and value-directed memory in previous research using 12-word+ lists (Castel, Balota, & McCabe, 2009; Cohen, Rissman, Suthana, Castel, & Knowlton, 2014).

Based on the results of Experiment 1, it was predicted that limiting working memory function with articulatory suppression would reduce value-directed effects, as indicated by a smaller difference between high- and low-value recall, and selectivity. This hypothesis was tested in Experiment 2. Results indicated that value-directed effects persisted across sub- and supra-span list lengths, despite articulatory suppression, however the comparative analysis with Experiment 1 indicates decreased value-directed memory effect, as hypothesized, for near- and supra-span list lengths stemming largely from reductions in high-value recall. This suggests that articulatory suppression, an attentionally-demanding and capacity limiting manipulation, interferes with the mechanism(s) that contribute to the promotion of high-value items, perhaps by disrupting increased rehearsal and/or deep encoding of higher value words. Interestingly, for the sub-span list length of 3-words, articulatory suppression resulted in an increased value-directed memory effect compared to participants that did not suppress articulation (E1). This could indicate that taxing working memory may have differential outcomes for sub- vs supra-span lists. For example, participants may attempt to rely more on value cues when faced with a working memory-demanding dual task. This strategy may be somewhat effective for sub-span lists but, as list length increases, the ability to selectively promote higher value items is compromised. Alternatively, the increased value-directed memory effect for 3-word lists could be the result of recall of higher value items no longer being at ceiling. This hypothesis is supported by the patterns of selectivity across experiments. If articulatory suppressing participants did indeed rely more on value cues for the sub-span list, selectivity should have been maintained or increased. Instead, articulatory suppression resulted in significant decrease in selectivity at all list lengths, even the 3-word list length, compared to no suppression. Together, these results indicate that articulatory suppression, an attentionally-demanding and capacity-limiting dual task, reduced value-directed effects and selectivity suggesting that lower working memory capacity is associated with declines in value-directed memory control processes.

One limitation of the current work is that many of the critical analyses from this chapter rely on across experiment comparisons, making the current findings vulnerable to cohort effects. Because the results from Experiment 4.1 so closely replicate those from Experiment 2.1, it seems unlikely that that the presence of value-directed effects at both sub- and supra-span list lengths are linked to specific cohorts. Regardless, future research should examine value-directed-memory effects with and without articulatory suppression using a within-subject design. Further, articulatory suppression, while effective at modulating value-directed memory, is a blunt tool potentially disrupting multiple processes limiting the ability to make claims about specific mechanisms underlying value-directed memory. Future research could build on the findings presented here by testing the contribution of specific component processes of attention and working memory to value-directed memory of sub- and supra-capacity lists. Finally, different exit surveys were used across Experiments 1 and 2, stifling the ability to determine the effects of articulatory suppression on self-reported strategy. Future research should include self-report strategy questions that are administered across conditions and potentially over the course of the experiment, rather than the end, to gain a more accurate understanding of how strategy may be influenced by individual differences in working memory capacity or working memory capacity manipulations.

Conclusions

The present investigation examined the role of working memory capacity in value-directed recall of sub- and supra-span lists. Across two experiments, lower working memory capacity was associated with reduced recall of high-value items and reduced selectivity in healthy young adults. The current research provides evidence that lower working memory is associated with a control deficit that is ultimately detrimental to value-directed memory. Moreover, the effects of working memory capacity are relatively consistent across sub-, near-, and supra-span list lengths, suggesting that the same control processes, and their associated deficits, are brought to bear on these different list-lengths, providing further evidence for unitary store model of human memory.

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CHAPTER 5

Conclusions

Human memory, though capable of astonishing feats, is limited. Unable to remember the incredible amount of information we encounter on a daily basis, humans can use value cues to strategically promote a subset of information for later recall. A number of studies (Castel, 2007; Castel et al., 2002, 2007, 2009, 2011, 2013; Cohen et al., 2014, 2017; Robinson & Unsworth, 2017) have demonstrated that value cues can be used to voluntarily guide memory of lengthy lists of words that exceed working memory capacity (3-5 items; Cowan, 2001). The aims of this dissertation were twofold: 1) to investigate the effects of value cues on memory for lists of words that were within or near working memory capacity and 2) to examine the role of working memory capacity on value-directed memory of sub-, near-, and supra-span lists. Results indicated that 1) value-directed memory effects are evident for sub- and near-span lists; 2) these effects can be eliminated or reduced for shorter list lengths when participants are informed of list lengths or the proportion of short lists is high, and 3) lower working memory capacity, due to individual differences or articulatory suppression, was associated with reduced value-directed memory control for both sub- and supra-span lists. The experimental evidence is summarized, and the implications are discussed in greater detail below.

Summary of Findings

The first aim of this dissertation was to determine whether value cues would influence the recall of items from list lengths below or approaching working memory span. In Chapter 2, this was accomplished by including value-cued words in lists lengths of 3-, 6-, and 9-words in addition to the typical 12-word lists. Results from Experiment 2.1 indicated that value-directed memory effects were evident for all list lengths, even short, sub-span lists of 3 words. However, when participants were informed of the proceeding list length, as in Experiment 2.2, value-directed memory effects were eliminated for the sub-span list length of 3-words and reduced for the near-span list length of 6-words. Together, the results of these two experiments suggest that while value-directed control processes can be used to control memory for list lengths that are within working memory capacity, use of this control strategy may be abandoned or reduced if participants can anticipate that they may be able to remember all of the items without it, presumably relying on a less selective memory strategy instead.

The experiments in Chapter 2 included only one condition that could be characterized as sub-span, (i.e., 3-word lists) and one condition that was near-span (i.e., 6-words). The goal of Chapter 3 was to build upon the findings from Chapter 2 by including multiple sub-span and near-span list lengths. In experiment 3.1, participants studied value-cued words in 2-, 3-, 4-, 5-, 6-, and 8- word lists. Value-directed memory effects were evident for lists of 4, 5, 6, and 8 words. For lists of 2 and 3 words, however, participants performed at ceiling thereby precluding the possibility to observe value effects. Although participants were not given explicit foreknowledge of the list lengths, most lengths were within working memory capacity, which presumably mitigated the use of value-directed strategies, similar to the effects observed in Experiment 2.2. Nevertheless, the results from Chapter 3 replicate and basic effects established in Chapter 2, providing further evidence of value-directed effects for sub- and near-working memory span lists, while highlighting the optional use of this strategy when list length can be anticipated, along with the potential importance of metamemory judgements for determining when value-directed memory control strategies will be applied.

The second aim of this dissertation was to gain an understanding of the mechanisms contributing to value-directed memory. In Chapter 4, two experiments investigated the role of working memory capacity in value-directed memory of sub- and supra-span lists. Results from Experiment 4.1 indicated that healthy young adults with lower working memory capacity, compared to high capacity participants, recalled fewer words across all value groups and were less effective at selectively promoting higher value items. Converging evidence for the importance of working memory capacity in value-directed memory was sought in Experiment 4.2 which used articulatory suppression to reduce working memory capacity, experimentally. Like lower capacity young adults in Experiment 1, participants engaged in articulatory suppression recalled fewer words across all value groups and were less effective at selectively promoting higher value items for all list lengths compared to participants that were not engaged in articulatory suppression. The results of this pair of experiments suggest that working memory capacity contributes to the efficacy of value-directed control processes and highlights the continuity of this relationship across sub- and supra-span lists.

While overall the results suggest continuity across list lengths, consistent with a unitary memory store framework, an alternative set of set of explanations could potentially account for these effects. If value effects occurred at a perceptual level that was early in the processing stream, prior to or coincident with conscious processing, these could presumably influence all subsequent memory processes. The fact that value-directed effects can be modulated voluntarily, however, argues against a purely low-level mechanism account of value-directed memory. Nevertheless, given evidence that top-down processes can influence bottom-up processing

(McMains & Kastner, 2011; Ruthruff, Remington, & Johnston, 2001), this account cannot be completely ruled out.

In addition to these primary effects, a number of exploratory analyses revealed suggestive results that warrant follow-up. In Chapters 2 and 3, participants completed a surprise, delayed free-recall task at the end of the experiment to explore the endurance of value-effects over time. As in immediate recall, participants recalled more higher- than lower-value items indicating that value-directed memory effects first observed in immediate recall persist after a lengthy delay (2-20 minutes). In addition to delayed recall, perseverative errors, or recalling items from previously studied lists, were examined in Chapter 3 to investigate a potential role of value on these intrusions. The results indicated no effect of value on perseverative errors. However, the number of perseverative errors was very low (M = 1.82 words), potentially limiting the ability to detect a value effect. This measure, while not particularly informative in healthy young adults, may be more useful in studies of populations that are more prone to perseverative errors (e.g., prefrontal patients, Milner, 1963; Parkinson's disease patients, Lees & Smith, 1983).

Across all chapters, participants self-reported strategy use was collected in an open-ended exit survey administered at the end of the experiment. A more thorough examination of strategy use was conducted in Experiment 3.1 and on 4.1 using an expanded exit survey that inquired about specific strategies. Participants reported similar rates of both rote rehearsal and deep, semantic encoding to support memory of words. Unlike previous research in which virtually all participants reported using value cues to guide memory (Cohen et al., 2014), results from the present studies indicated that most, but not all, participants reported using the value cues to guide memory strategy at least some of the time. In yet another departure from previous research with longer lists in which most participants reported "ignoring low-value items" (Cohen et al., 2014), less than half of the participants in the present study endorsed regularly “ignoring lower-value items”. The differences between the findings from the present research and previous research are likely due to differences in experimental design, namely the present use of sub-span lists. As speculated in Chapter 3, strategic selectivity may be implemented in a step-wise manner dependent upon memory demand such that when demand is low, participants are more likely to use less effortful, nonselective strategies for memory, but as demand increases participants use value-cues to guide memory first by attending to all value-cued items, then as demand consistently exceeds capacity, by ignoring low-value items.

In support of this hypothesis, the “ignoring low value-items” strategy was endorsed by a smaller proportion of participants in Experiment 3.1, in which most list lengths were within canonical working memory capacity compared to Experiment 4.1 in which most list lengths exceeded canonical working memory capacity (Chp. 3: 36% vs. Chp. 4: 53% ignored low-valued items at least sometimes). Moreover, in Experiment 3.1 and Experiment 4.1, greater endorsement of “ignoring lower-value items” was associated with lower working memory capacity, though this correlation was only marginal in Experiment 4.1. Interestingly, individual differences in working memory capacity were not related to the method used to memorize the words (rote rehearsal vs. semantic processing) suggesting that capacity differences in value-directed memory strategy are due to differences in selecting what to remember rather than the method of memorization. Future research may aim to elucidate the role of strategy in value-directed memory and how list length may affect this relationship, perhaps by probing strategy use more frequently or instructing participants to use a particular strategy, in order to further our understanding of value-directed memory control and potentially inform value-directed memory interventions.

Theoretical and Practical Implications

Beyond our understanding of value-directed control processes, the findings presented in this dissertation have implications for the structure of human memory. As previously discussed, unitary store models of memory, embedded processes models in particular, posit that human memory consists of single, unitary system in which the contents of working memory are comprised of highly activated long-term memory representations (Cowan, 1999; Jonides et al., 2008; Nairne, 2002; Oberauer, 2002). In contrast, multistore models of human memory argue that human memory consists of separate systems for short-term storage (i.e., working memory) and long-term memory storage (Atkinson & Shiffrin, 1971; Baddeley & Hitch, 1974; Repovs & Baddeley, 2006). Both models agree that working memory is limited in capacity; however unitary store models propose that working memory is limited by attentional control mechanisms which are responsible for increasing accessibility of long-term memory representations, whereas multistore models argue that working memory is a separable, capacity-limited storage space that feeds information into and retrieves information from long-term memory stores (See Jonides et al., 2008 for review).

It would follow that to the extent that working memory and long-term memory are components of separable systems, they would rely on different processes that would presumably contribute to unique memory phenomena associated with each system. Indeed, one of the main findings from the current investigation is that value-directed memory effects, previously only documented for lists exceeding the capacity limitations of working memory, are evident for short lists that can be entirely maintained in working memory. Moreover, control deficits associated with lower working memory capacity negatively impact value-directed memory of both sub- and supra-span lists. These results suggest that the same control processes, and their associated deficits, can operate on lists that are capable of being held in their entirety in a highly activated state (working memory; Cowan, 1999), and lists that exceed the boundaries of working memory capacity and are therefore less activated. However, as observed in Experiment 2.2, when participants are aware of memory demands value-directed memory strategies are abandoned in favor of less effortful, nonselective strategies for lists that can be effectively maintained in a highly active state, underscoring the importance of metamemory judgments in value-directed strategy use. These findings contribute to a growing body of research documenting that phenomena previously thought unique to long-term memory are evident in working memory (Atkins & Reuter-Lorenz, 2008; Festini & Reuter-Lorenz, 2013; Flegal, Atkins, & Reuter-Lorenz, 2010; Flegal & Reuter-Lorenz, 2014; Oberauer, 2001; Rose & Craik, 2012). While the current results do not speak to memory storage directly, if identical processes are indeed operating for sub- and supra-span lists, this provide evidence for unitary store models of human memory. Though we observed value-directed memory effects in both working memory and long-term memory contexts, the possibility remains that processes unique to separate memory stores operated to result in similar patterns across memory systems. While less parsimonious, further research, potentially using neuroimaging methods, may shed light on the precise processes that give rise to value-directed memory effects for sub-span lists and ultimately inform our understanding of the structure of human memory.

The research presented here also has implications for our understanding of working memory capacity. Individual differences in performance on working memory capacity measures have been shown to predict higher-order cognitive ability, including language comprehension, reasoning, problem-solving ability, scholastic achievement, and general intelligence (Daneman & Merikle, 1996; Engle & Kane, 2004). Given its importance to high-level cognitive functioning, a considerable body of research has aimed to understand the origin of individual differences in working memory capacity. In addition to differences in span (number of items that can be held active), some theories of individuals differences in working memory capacity argue that they arise from differences in executive or attentional control (Barrett, Tugade, & Engle, 2006; Cowan et al., 2008; Engle & Kane, 2004). The results of the present research indicate that lower working memory capacity, as measured in part by complex span tasks, is associated with decreases in selective promotion of high-value items for both sub- and supra-span lists suggesting differences in executive control, rather than span per se, contribute to differences in value-directed recall across working memory capacities. This finding supports previous research positing that differences in working memory capacity are due predominantly to differences in executive or attentional control (Barrett, Tugade, & Engle, 2006; Cowan et al., 2008; Engle & Kane, 2004).

In addition to the theoretical implications of this work, the findings presented here may contribute to applied research aimed to improve memory control in real-world settings such as educational or work environments. As previously mentioned, individual differences in working memory capacity are strong predictors of educational and learning outcomes (Daneman & Merikle, 1996; Engle & Kane, 2004). According to Cognitive Load Theory, working memory capacity may be occupied by intrinsic cognitive load, or the nature of the relevant material and the learner), extrinsic cognitive load, or information not directly necessary for learning relevant information, or germane cognitive load, or the resources needed to create new learning schemas (Paas, Renkl, & Sweller, 2003; Sweller, 1994;). Extraneous information can occupy limited working memory resources that should be allocated to learning relevant information, which can be particularly burdensome to individuals with reduced working memory capacity or cognitive control (Paas, Renkl, & Sweller, 2003). To minimize the burden of extraneous information, instructional design in the classroom can be used to decrease extraneous cognitive load allowing for more cognitive resources to be allocated to learning (Sweller, 1994; Van Merrienboer & Sweller, 2005). To this end, explicit value cues paired with information may be a useful tool to focus cognitive resources on higher value information and reduce the allocation of cognitive resources to the extraneous intrinsic evaluative processes and lower value information. Individuals with lower working memory capacity and/or less effective at memory control may particularly benefit from explicit value cues to guide memory. Further, considering that participants adjust their memory strategy dependent upon foreknowledge of cognitive demands, as observed in Chapter 2, it may also be beneficial to examine the effects of informing people of the number of relevant points they should plan to encounter when consuming information in real-world settings so that they might proactively select an appropriate memory strategy. Further research is warranted to determine if the value-directed memory control processes observed in laboratory settings are similarly applied in real-world settings, such as classrooms or other educational environments, in order to determine their potential as an avenue for cognitive intervention.

Limitations and Future Directions

The present investigation provides a number of new insights into value-directed memory and its relationship with working memory and cognitive control. Nonetheless, there were several limitations to the current paradigm that should be addressed in future research. First, value cues were only presented in the form of arbitrary points, limiting the ability to generalize the present results to other types of external value cues (e.g., monetary reward, work-performance evaluations, test performance) and internal value cues (e.g., personal salience, alignment with values). Moreover, the present research, like most value-directed memory research, examined the effects of value cues on sequentially-presented lists of neutral words. In order to increase the ecologic validity and practicality of value-directed memory research, future studies should extend value cues to other common forms of information such as sentences and paragraphs, to using stimuli other than words such as pictures of objects or faces, and to other domains such as audition and proprioception.

The current paradigm uses a ‘gain’ frame such that, to participants, it may seem as though participants start with 0 points and are rewarded for each item they recall. However, many value-based systems operate using a ‘loss’ frame (e.g., school grades, performance reviews), such that it seems as though participants start out with the maximum value and then are penalized for forgetting relevant information. Though the overall outcome of performance is equivalent across these two framings, previous research has shown that participants’ will alter decision making and behavior dependent upon the framing of the task or problem (Van Gelder, De Vries, & Van Der Pligt, 2009; Tversky & Kahneman, 1981). More specifically, a number of studies have shown increases in risky behavior when using loss frames and an increase in risk-averse behavior when using gain frames (see Kuhberger, 1998 for review). It is unclear how variations in frame may affect value-directed control strategies, or what might be considered “risky” in a value-directed context. Perhaps participants in a loss framework would attempt to remember more information than possible, resulting in an inefficient use of limited resources. Future research should aim to address these limitations by investigating the effects of value on memory using both gain and loss framing.

Self-reported strategy use was gathered in an exit survey administered at the end of the value-directed task. In addition to reporting which strategies were used and approximate frequency of strategy use, most participants reported changing their strategy at least once over the course of the experiment. However, because the strategy questions were only given at the end of the experiment, the reported frequency of strategy use was rarely related to performance and inconsistently related to individual differences in working memory capacity. Moreover, it is unclear which trials are associated with which strategies limiting the ability to identify which strategies are most effective. Future research should include strategy questions at multiple time points to link strategy use more tightly with performance and to gain a better understanding of when and why strategies are changed during the learning process.

As discussed in Chapters 1 and 2, value is thought to influence memory automatically over a longer time-scale, through the midbrain dopaminergic-reward system (Adcock, Thangavel, Whitfield-Gabrieli, Knutson, & Gabrieli, 2006; Shohamy & Adcock, 2010), and voluntarily over a shorter time-scale, though value-directed control processes (Castel et al., 2002). Though Chapters 2 and 3 had both immediate and delayed recall components, the present investigation focused exclusively on the outcomes of voluntary value-directed control processes that seconds or minutes after study. Future research could expand upon the findings presented here to examine how value-directed control processes interact with sleep-based consolidation or time-delayed automatic processes to affect memory traces over time. Results from such research could inform a broader understanding of value-directed memory and highlight potential long-term benefits, or drawbacks, associated with value-directed memory interventions.

Closing Remarks

The experiments in this dissertation were conducted to investigate the continuity of value-directed control processes on items in working memory and to understand the role of working memory capacity in this cognitive control process. To this end, participants studied and recalled value-cued words from lists that were sub-, near-, and supra-working memory span in length. The results indicate that the same pattern of value-directed effects present for lengthy lists of words are also evident for near- and sub-working memory span lists of words suggesting that the same memory control processes are can be brought to bear for sub- and supra-span lists. Moreover, lower working memory capacity was related to declines in value-directed memory control for both sub- and supra-span lists. Together, the results indicate that the control processes that contribute to value-directed memory effects function similarly across lists that can be maintained in an active state (sub-span) and those that exceed that capacity-limited space (supra-span) providing support for unitary store models of human memory. Additional research should aim to identify specific working memory component processes (e.g., updating, inhibition) that contribute to optimal value-directed memory, further elucidate the role of strategy, and extend this research to real-world memoranda and other modalities (e.g., visual, motor learning) to inform potential memory interventions and learning practices.

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Appendix A

Exit Survey

Thank you for your participation. As part of our research, we are interested in your input and impressions of the experiment you have just completed. Please answer the following questions to the best of your ability.

1. Did you use any strategies, short cuts, or "tricks" to help you in the memory task? If so, explain.

2. Were point values used in your chosen strategy? Please explain why or why not.

3. What effect, if any, do you feel the point value had on your overall memory performance?

4. Some people try to improve their memory for some words that they studied. What strategy, if any, did you use to **remember** specific words?

5. Some people may try to avoid paying too much attention to specific words. What strategy, if any, did you use to **ignore** specific words?

6. Some people may try to forget words that they studied. What strategy, if any, did you use to **forget** specific words?

7. There were a range of values associated with the studied words. If you were to group the point values, what points would be in the high-value group? What points would be in the low-value group?

High point value:

Low point value:

8. What strategy, if any, did you have to remember words with high point values?

9. What strategy, if any, did you use to remember words with low point values?

10. Using the following scale, indicate how often you used each of the following strategies in the memory task:

Always ←—— Almost Always —— Sometimes —— Almost Never ——→ Never

a) I studied all of the words and tried to remember everything, paying special attention or trying harder on the highest value items
b) I only studied words associated with the highest points. I completely ignored (disregarded, looked away from the screen, etc.) low-value items.
c) When recalling the words, I tried to say as many words as possible, recalling the highest value words first.
d) When recalling the words, I tried to say as many words as possible in whatever order I could remember them.
e) I did not use/look at the point values. I only paid attention to the words, trying to remember as many as possible.

f) I used a strategy not listed.

If you used a strategy not listed, please describe the strategy.

11. Some people switch or adapt strategies over the course of the experiment. Did you switch strategies during the experiment? **YES** or **NO**

If you answered 'yes'

a) Why did you switch or adapt strategies?
b) What strategy did you use most?
c) What strategy did you use first?

12. If given one opportunity to study a lengthy list of words, how many words do you think you would be able to recall confidently?

13. Generally, how would you rate your own memory?

Very Good ← Good — Neither Good Nor Poor — Poor → Very Poor

14. Were there any additional factors that may have affected your performance on any of the tasks, such as your own fatigue, noise in the lab, or other distractors?