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LOMA LINDA UNIVERSITY  
School of Behavioral Health  
Department of Psychology  
in conjunction with the  
Faculty of Graduate Studies

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The Role of Temporal Distraction on Short-Term Memory and Delayed Recognition

by

Susanna Luu

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A Dissertation submitted in partial satisfaction of  
the requirements for the degree  
Doctor of Philosophy in Clinical Psychology

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September 2017

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Each person whose signature appears below certifies that this dissertation in her opinion is adequate, in scope and quality, as a dissertation for the degree Doctor of Philosophy.

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## ABBREVIATIONS

BVMTR	The Brief Visuospatial Memory Test–Revised
FA	Focus of Attention
LTM	Long –Term Memory
LTS	Long-Term Store
MTL	Medial Temporal Lobe
PFC	Prefrontal Cortex
SIRP	Sternberg Item Recognition Paradigm
STM	Short-Term Memory
STS	Short-Term Store
VLPFC	Ventrolateral Prefrontal Cortex

## ABSTRACT OF THE DISSERTATION

The Role of Temporal Distraction on Short Term Memory and Delayed Recognition

by

Susanna Luu

Doctor of Philosophy, Graduate Program in Clinical Psychology  
Loma Linda University, September 2017  
Dr. Colleen Brenner, Chairperson

Memory is a complex process that requires the translation of information from an external sensory experience into an internal representation. Once information has been translated into memory, there is little agreement regarding the cognitive structure of memory storage and maintenance. Baddeley (1966) developed a model based on a multi-storage structure which suggested that as information entered through the sensory system, it was relayed by a cognitive control center and placed into storage units based on information type (i.e. auditory, visual, etc.). Baddeley's (1966) multi-store memory model hypothesized that content translated into memory by two phases: short-term and long-term memory. More recent research supports a unitary model that better accounts for the translation of information from short term memory (STM) to long term memory (LTM) (Jost et al., 2012; Jonides et al., 2008). However, there is still uncertainty of a unitary memory model due to disagreement of the role of distractions during memory translation. The impact of distraction on this process is largely unknown. Understanding the role of distraction during STM encoding and how it affects the formation of LTM can potentially inform treatment for impaired memory. We explored the impact of temporal distractions on short-term memory and delayed recognition for visual content within a modified behavioral task based on Sternberg's recognition task. Results indicated a

negative impact of distractors on memory translation. Implications for future research were discuss to include clinical populations.

## DEDICATION

For my parents. Thank you for teaching me that the sky is limitless and there are no penalties for reaching.

# **CHAPTER ONE**

## **INTRODUCTION**

Memory is a complex process that requires the translation of information from an external sensory experience into an internal representation. Once information has been translated into memory, there is little agreement regarding the cognitive structure of memory storage and maintenance. Baddeley (1966) developed a model based on a multi-storage structure which suggested that as information entered through the sensory system, it was relayed by a cognitive control center and placed into storage units based on information type (i.e. auditory, visual, etc.). Baddeley's (1966) multi-store memory model hypothesized that content translated into memory by two phases: short-term and long-term memory. More recent research supports a unitary model that better accounts for the translation of information from short-term memory (STM) to long-term memory (LTM) (Jost et al., 2012; Jonides et al., 2008). However, there is still uncertainty of a unitary memory model due to disagreement regarding the role of distractions during memory translation. Some believe that when distractors appear, the timing of distractor presentation with respect to initial encoding and the length of the memory delay can greatly influence memory formation. The impact of distraction on this process is still largely unknown. Understanding the role of distraction during STM encoding and how it affects the formation of LTM can potentially inform treatment for impaired memory.

In the literature review, I will provide a brief overview of the definition of STM and LTM, highlight the difficulties in these definitions, explain the major processes of memory translation, and discuss the importance of interference. With a foundation of knowledge of the mechanisms that form memory, I will then discuss two of the most

prominent models of memory: multi-store and unitary-store models. Finally, I will review the neuropsychological findings that suggest associations with memory processes such as activation with the prefrontal cortex, hippocampus, and medial temporal lobe during STM and LTM processes and the role of interference to suggest that a unitary model of memory may be a better fit for memory translation.

### **What are STM and LTM?**

STM is traditionally thought of as the amount of information a person can retain over a brief interval of time (Shipstead, Redick, & Engle, 2012). Some suggest that STM is a temporary storage and is experimentally defined through the longest list of items a person can accurately recall within a short period of time (Shipstead et al., 2012). The idea of a dual store unit was started by Atkinson and Shiffrin (1971). They thought that information was coded deeper into memory as it moves from short-term into long-term memory. They were some of the first pioneers to suggest a multiple unit memory system or a dual memory model. They posited that environmental information was processed by sensory registers in the various physical modalities and entered into the short-term store (STS; Atkinson & Shiffrin, 1971). As information remained temporarily in STM, the length of the stay depended on cognitive control processes. In terms of visual stimuli, a picture goes from the STS to the long-term store (LTS) whereas the verbal label of the picture is transferred from LTS and associated with the picture in STS (Atkinson & Shiffrin, 1971). As the information is transferred or remains in the STS or LTS, a series of control processes help to maintain and regulate information in their proper unit. Cognitive control is thought of as a regulator of information.

There has been further anatomical and distraction-based evidence to suggest STM is a separate unit. Anatomical evidence for STM as a separate unit is demonstrated with anterograde amnesia, where memories can form within a 60 second interval and disappear soon after. This suggests that there is no transfer of information to LTM or a disruption of rehearsal that occurs to transfer information from STM to LTM. Therefore, STM appears to be an independent unit from LTM due to the isolated effects of the anterograde amnesia (Davelaar, Goshen-Gottstein, Ashkenazi, Haarmann & Usher, 2005).

Other forms of evidence come from experimental studies in which manipulations such as distractors disrupt memory encoding. The Brown-Peterson procedure requires participants to listen to a target list of words, then count by 3's until told to stop and recall a word previously given by the examiner. However, when the distractor task (counting by 3's) is given towards the end of a word list, memory for the recent words were worse than memory for words at the beginning. This task demonstrated that recall for words earlier on the list were stored in the long-term memory, while 3-5 words most recently learned were remembered less so because of the distraction. Likewise, recall of the words presented in the beginning of the list suggests that cognitive processes are used to transfer information from STM to LTM. These results show that different factors may affect short-term recall (disruption of rehearsal) and long-term recall. One reason that may explain participant's long-term recall is the semantic similarity between the words. As words have more semantic similarity, deeper associations help to encode the information into LTM store. Together, these findings suggest that long-term memory and short-term memory can vary independently of each other.



Maintenance processes occur to offset the decay of information while in STM. Rehearsal is a process where one would repeat information to keep it in memory and prevent decay. It is estimated that decay of information occurs in approximately 18 seconds without the use of cognitive processes like rehearsal to maintain the information (Revlin, 2012). However, some authors describe decay as several types of information (i.e. words, digits, pictures) competing to be recalled during STM (Oberauer & Kliegl, 2006). Therefore, new content gradually pushes current content out of memory, causing the encoding of this new information, otherwise known as “interference” (Oberauer & Kliegl, 2006).

Although it is postulated that STM may be limited in immediate retrieval, LTM is thought to be limitless. LTM forms by maintaining and retrieving information by associations. Stronger encoding is postulated to include semantic associations connected to the information ( Craik & Watson, 1973). Based on his research, Baddeley (1966) believed that as information was coupled with semantic associations, the information was moved into long-term storage. According to Baddeley (1966), the translation of visuospatial information from STM to LTM requires an extra mechanism known as working memory. Working memory is defined as a limited capacity system that temporarily maintains, stores information, and provides an interface between perception, and long-term memory that generally occurs before information is stored in STM or LTM (Baddeley, 2003). Encoding visuospatial information into LTM is thought to be dependent on working memory’s efficiency and capacity. This is evidenced by the fact that the speed with which visual information is stored into long-term memory is

determined by the amount of information that can fit, at each step, into visual working memory.

Therefore, remembering is more than an activation of a memory trace. Often, retrieval cues are not uniquely related to one specific memory entry. Control processes increase one's flexibility to search memory for behaviorally relevant memory representations while ignoring irrelevant ones (Jost et al., 2012). Over time, memory is thought to have a slow decline of details as new information is learned subsequent to the presented stimuli. This decline in the detailed quality of the memory represents interference. The main assumption of interference theory is that the stored memory is intact but unable to be retrieved due to competition created by newly acquired information (Tomlinson, Huber, Rieth & Davelaar, 2009). The presentation of distractions is one form of interference. As the collection of more information enters into the mind, it replaces the existing information. Rehearsal is one method that can be employed to keep information readily available for retrieval in either STM or LTM. Therefore, for information to remain in LTM, some form of maintenance, such as rehearsal and/or semantic associations is necessary.

### **Memory Processes: Encoding, Maintenance, Retrieval**

The processes of memory formation include encoding, maintenance operations, rehearsal, shifts of attention from one part of the representation to another, and retrieval mechanisms (Jonides et al., 2008). The three that are of interest for the purposes of this research project are encoding, maintenance, and retrieval. It is these three processes that impact the quality of memory and are present during both STM and LTM.

The first of the cognitive processes involved in memory formation is encoding. Encoding includes a component called cognitive focus that is assumed to have immediate access to contents from the present and the past. This process can be implicit or explicit (in awareness or out of awareness; Craik & Tulving, 1975). Each item or piece of information that comes into the cognitive focus assumes the most recent perceptual encoding and displaces the previous items in focus (Jonides et al., 2008). Cognitive focus is the function of the “mind” as it assumes a state of awareness of content. In order to increase cognitive focus, more attention is given to the incoming information to better encode content. For example, in McElree (2001)’s single-item focus model, each incoming item not only had its turn in the focus, but it also replaced the previous item. As each single item came into focus, the mind encodes the information and replaces the information from the last single item with the next single item. Moreover, content with semantic associations tends to encode into memory better than content without semantic associations. For example, in a list of words with “tooth, honey, chocolate, cake” better recognition for sweet words were made because participants had created a category to associate all “sweets” together (Purves et al., 2014). The recognition was so strong that false recognition for the word “sweet” was often made (Purves et al., 2014). Finally, it is important to note that encoding is modulated by the amount of attention one gives the content being encoded. If one gives certain content more attention, the cognitive focus will stay more intensely focused on that specific content with increased retention over time. This directly follows the assumption that there are severe limits on focus capacity, which is modulated by controlling the perceptual present or focused state.

Encoding processes can be further explored using interference paradigms such as the Stroop task (Warren, 1972). The Stroop task requires a participant to read color words printed in a different color. In this particular task, increased interference was found when the base word in the Stroop task was the category name for a set of words being remembered. For example, in the task the word “blue” would be printed in red ink and the participant would be asked to read aloud the printed word, “blue.” By utilizing a category word that was the same as the base, the association for the category word increased and interference increased during immediate retrieval. However, interference declined rapidly within the first 15 sec after presentation of either the present words or when their category name was used as the base item in the color-naming task. Therefore, an association to the content is made as part of the encoding process. For example, if a presentation of the color word “blue” was in red ink and next presented color word was “red” in blue ink and the word “blue” was read out loud, that means “blue” interfered or encoded into memory stronger than the next color word, “red”. Further, interference can occur more often if encoding happens between two similar content items within a category. A study by Zacks and colleagues (1987) that investigated story recognition with two different stories supported this finding. In the group that experienced increased interference, presentation of the recognition questions was provided in the same domain (orally) as the story presentation, compared to questions provided in the written domain (Zacks, Hasher, Doren, Hamm & Attig, 1987). It appeared as if the mere presentation of similar information in the same modality interfered with the previously encoded information. As information is encoded into memory, it begins the cycle of long-term retrieval.

With respect to visual encoding, images and visual sensory information are traditionally thought to be temporarily placed in working memory before being encoded into permanent long-term storage (Sperling, 1963). Visual content retrieval was stronger for individuals who used word associations and rehearsal to “better encode” information (Sperling, 1963). In this case, visual memory is encoded through a dual process that includes auditory rehearsal of information and auditory information storage. The encoding specificity principle posits that retrieval is highly dependent on semantic cues assigned to content (Tulving & Thomson, 1973). For example, in a word-list learning task, the target word “chair” can have interference words such as “table” because they are a part of the same category word furniture (Tulving & Thomson, 1973).

Another process in memory formation is called maintenance. During the maintenance phase of memory, the item of focus is held “in the mind” for the purpose of future retrieval after the perceptual input is gone (Jonides et al., 2008). Maintenance occurs after the onset of encoding. Evidence from primate models and from imaging studies on humans show that active maintenance keeps representations alive and protects them from irrelevant incoming stimuli or intruding thoughts (Postle, 2006). With active maintenance, memories are more easily retrieved and protected from decay.

Considerable fMRI data suggests an association with the prefrontal -posterior circuits underlying active maintenance (Jonides et al., 2008; Goldman-Rakic, 1987). Evidence from fMRI data shows activation in the prefrontal area 8 (Rowe, Toni, Josephs, Frackowiak & Passingham, 2000). Activity in areas 9 and 46 has been reported previously during delay periods in working memory studies of visual, verbal, and spatial material even without the need for manipulation of items (Courtney, Petit, Maisog,

Ungerleider & Haxby, 1997; D'Esposito et al., 2000; Postle and D'Esposito, 1999). In a spatial working memory task consisting of randomly placed colored dots, participants were asked to look at the first set of dots and were not told about a delayed recognition component. During the time between stimulus presentation and delayed recognition task, activity in the prefrontal area 8 was activated (Rowe et al., 2000). Areas 46, 9/46, 8, and 9 are seemingly involved in different parts of memory translation. For instance, activation in area 46 is dominated by selection of the target of a response inherent in manipulation and monitoring paradigms. In contrast, activation of more posterior areas (such as posterior parietal cortex) is dominated by sustained passive maintenance (Rowe & Passingham, 2001). Activation of prefrontal area 8 is related to spatial attention and may be associated with the increased attention that occurs during delayed maintenance for spatial content (Courtney et al, 1998). This may suggest some association with a system widely used for maintenance throughout STM and LTM. Perhaps the most striking data is found in the single-cell recordings that show neurons in prefrontal cortex that selectively fire during the delay period in delayed-match-to-sample tasks (Funahashi, Bruce & Goldman-Rakic, 1989; Fuster, 1973). As mentioned above, early interpretations of these frontal activations link them directly to STM representations (Goldman-Rakic, 1987), but more recent theories suggest they are part of a frontal-posterior STM circuit that maintains representations in posterior areas (Pasternak & Greenlee, 2005; Ranganath, 2006; Ruchkin, Grafman, Cameron & Berndt., 2003).

Another process that is active within the maintenance phase of STM is called rehearsal. Rehearsal is the internal repetition of information in an attempt to ward off decay of the memory. Rehearsal is often implicitly assumed as a component of active

maintenance, but formal theoretical considerations of STM typically take the opposite view. For example, Cowan and colleagues (2000) provides evidence that although first-grade children do not use verbal rehearsal strategies, they nevertheless have measurable focus capacities, which suggests some form of rehearsal method for memory maintenance. It may be that people contain a lexical representation of content and search/create through a series of associations for rehearsal, rather than articulation of word repetition ( Craik & Watson, 1973).

Baddeley and colleagues (2003) investigated rehearsal in a two-phase experiment. The first phase required the rehearsal of words, while the second phase required the rehearsal of visual content, prior to word-list and visual memory tasks. The results demonstrated that rehearsal of verbal content was beneficial for retrieval (Baddeley, Thomson, & Buchanan, 2003). In a task that measured retrieval performance at different presentations (slow, 1 word every 2 sec; medium, 1 word every sec; and fast, 1 word every half sec) several words were presented while a single word with a selected letter was held in short-term storage until the next target letter was presented (Craik & Watson, 1973). For example, participants were told to remember all the words that start with “c” as they hear a long list of unrelated words. The results showed that, on average, participants recognized 23 of the 27-target letter-words (Craik & Watson, 1973). During the last retrieval, participants were asked to retrieve as many words as they could from the list. They found that the probability of recalling an item from long-term store remained independent and inverse of its predicted recall value (the probability of the critical words divided by the total word list). This finding was contrary to the hypothesis that recall would be the same duration as its presentation, as consistent with the dual

process model ( Craik & Watson, 1973). Therefore, the longer duration the item is presented, the easier it is for quicker item retrieval. Craik and Watson hypothesized that the longer information stayed present in the STM store, the deeper the encoding process. They also hypothesized that information would have to go through the STS then LTM store in order to be retrieved; therefore, longer stimulus presentation duration makes it more likely that these processes will be accurate. This is very similar to a serial-processing retrieval found in a multi-store model. In terms of the unitary model, it is speculated that the longer presentation time is used to process the information better and create more associations, leading to faster retrieval. The authors interpreted these findings to support rehearsal as part of a unitary model of memory.

Rehearsal can be an ambiguous and difficult process to delineate because it can be challenging to control for what occurs during the retention interval. Many experiments include an attention-demanding task to prevent participants from using rehearsal that would presumably circumvent decay. However, this attention-demanding task introduces interference. As indicated above, interference occurs when incoming information interrupts either rehearsal or another maintenance process. The interfering information eventually replaces the previous content by moving current information into cognitive focus which initiates maintenance of this new, interfering information. Previous studies have demonstrated that working memory for spatial location can be significantly disrupted by concurrent eye or limb movement (Baddeley, 1986; Smyth, Pearson, & Pendleton, 1988). Therefore, shifts of any attention can lead to interference. For example, in a study by Smyth (1996), subjects' eye movements were measured while they were asked to rehearse spatial content. While they maintained a sequence of spatial items in



memory before recalling them in order, Smyth found that eye fixation on visual stimuli did not affect recall (Smyth, 1996). In fact, auditory spatial stimuli presented during the targeted stimuli decreased performance (Smyth, 1996). In their second experiment, the authors found that the effects of auditory spatial stimuli had no effect on retrieval, which indicates that spatial salience of the target content leads to interference when asked to rehearse items even without eye movements (Smyth, 1996). These results indicate that more salient items engage cognitive focus more than less salient items, and may therefore be more impactful in the process of memory maintenance.

The relative success of encoding and maintenance processes can be investigated during retrieval. STM retrieval of information is a quick, simultaneous, and a content-focused process. Within retrieval, memory is gathered from LTM and placed in STM to remain accessible. The current theoretical models emphasize parallel search processes, which are quite different from the earliest STM retrieval models that postulated a serial scanning process (Sternberg, 1966; McElree, 2006). Mathematical models of behavioral data indicate that STM retrieval is a rapid, parallel and content-addressable process. A parallel search differs from earlier models of STM retrieval in that it focuses on several simultaneous searches, rather than set methods of searching through different associations one at a time (Sternberg, 1966; McElree, 2006). A task by McElree and Doshier (1989) administered an altered Sternberg recognition task that manipulated the deadline for responding, and was used to determine retrieval effects on serial scanning. They found that participants had faster retrieval rates for the last item in the study list and a slower retrieval rate for the items initially presented, a finding known as the “recency effect” (McElree & Doshier, 1989). These findings were independent of serial position

and set size (McElree & Doshier, 1989). Therefore, retrieval may be affected by the temporal order in which information was presented. The time course of retrieval (accuracy as a function of response deadline) can be separately plotted for each position within the presentation sequence, allowing independent assessments of accessibility (how fast an item can be retrieved) and availability as a function of set size and serial position. Many experiments yielded a uniform rate of access for all items except for the most recent item, which is accessed more quickly. The uniformity of retrieval rate is interpreted as evidence for parallel access, instead of serial scanning (McElree & Doshier, 1989; Burgess & Hitch, 1999; Paulsen & Moser, 1998).

As part of the retrieval process, a parallel search may occur through a subcategory of declarative memory called recognition (Medina, 2008). Recognition is the ability to identify previously encountered events, objects, and people. The most parsimonious model regards recognition memory as a unitary process directly linked to other forms of explicit memory and hence dependent on the same systems (Haist & Shimamura, 1992; Hirshman & Master, 1997; Donaldson, 1999). When previously experienced events are re-experienced in exact or similar presentation, salient content activates what are known as 'match signals' in response to stored memory representations. Matched memory representations then aid the retrieval processes (Norman & O'reilly, 2003). Once retrieval is activated, a two-component process occurs where recollection or familiarization with the event takes place. Recollection is the retrieval of details associated with the previously experienced events, while familiarity is the feeling that the event happened (Medina, 2008). It is still uncertain whether recollection or familiarity contributes to the accuracy of recognition. There is some evidence to support the activation of hippocampal

neurons regardless of successful recollection (Rutishauser, Schuman, & Mamelak, 2008). However, one study suggested that hippocampal activation does not necessarily lead to conscious recollection (Hannula & Ranganath, 2009). In this object-scene associative recognition study, hippocampal activation was not related to successful associative recollection; it was only when the prefrontal cortex and the hippocampus were activated in concert that successful performance was observed. Similar evidence suggests that such brain regions are tied to LTM. Therefore, the association between prefrontal cortex and hippocampal activation may suggest that recognition is a systematic response that occurs uniformly throughout STM and LTM memory.

### **The Role of Interference**

As mentioned earlier, interference can impact retrieval (Axmacher, Haupt, Cohen, Elger, & Fell, 2009). The mechanisms that explain how interference affects retrieval are the recency and primacy effects. The recency effect is the phenomenon where the last few items in a list tend to be recalled first, regardless of list length (Bjork & Whitten, 1974). However, when item retrieval duration is delayed by a distractor activity longer than the holding time for STM (15-30 sec or more), the recency effects are deleted altogether (Bjork & Whitten, 1974). In this way, distraction can negate serial position effects. Primacy effects reflect the greater likelihood that items presented at the beginning of the list are stored in long-term memory and subsequently more likely to be recalled. Primacy effects are not disrupted when recall is delayed by means of a distractor activity, and they are not invariant to list length. The primacy effect decreases with increasing list length, indicating that retrieval from LTM is a decreasing function of the number of items from the list stored in LTM. If participants are forced to process all

items in the list equally, by requiring them to repeat each item aloud a fixed number of times, there are only slight effects of primacy, if any, in recall (Bjork & Whitten, 1974).

More recently, Bancroft and Servos (2011) and Bancroft and colleagues (2011) provided experimental evidence that interference stimuli are encoded into STM, interfering with the previously stored target stimulus (Bancroft et al., 2013). Using Bancroft and Servo's experimental findings, the authors found that a computational model of prefrontal neurons showed there was an overwriting of information in working memory. Furthermore, their model results indicated that the prefrontal activation acts to protect the contents of STM.

Although somewhat controversial (Cowan, 1999), there is evidence that physical movement such as tapping and eye movements may interfere with encoding (Borst, Niven, & Logie, 2012; Smyth, 1996). Borst and colleagues (2012) found impairment in the maintenance of visual mental images of letters. When letters were presented visually and participants were asked to perform a tapping task simultaneously, there was more impairment in memory performance compared to the condition that required participants to draw the letter. A possible reason for the impairment may be that spatial movement (finger tapping task) interfered with the encoding of the images as visual mental images are created to translate into memory. Further, as interference tasks were presented just before the target, recall for the letters were impaired (Borst et al., 2012). Although visual or oral representations of the letter were rehearsed to prevent decay of content until subsequent letters in the sequence were presented, interference tasks disrupted the rehearsal (Borst et al., 2012).

Pattern cues and PFC activation may be associated with control of interference and aid in improved long-term retrieval of facial content. Jost and colleagues (2012) created a task of long-term retrieval for facial content with irrelevant information as distractors. During their task for long term retrieval of facial representations, results from EEG and fMRI demonstrated the medial and lateral PFC were active while controlling for interference during the task and had a positive correlation with retrieval accuracy (Jost et al., 2012). This data suggests that coactivation of medial and lateral PFC may aid in defending against retrieval interference by helping us ignore irrelevant material. The authors proposed that spatial cues were associated with facial content and that if similar spatial patterns were presented, participants would accurately recognize the target face (Jost et al., 2012). Therefore, the PFC may be associated with controlling for interference by creating associations to mitigate interference of novel content.

Further physiological evidence in support of interference in memory is demonstrated through findings of behavioral and electrophysiological dissociation between recognition during active maintenance and recognition during intervening items (James, Morand, Barcellona-Lehmann, Michel, & Schneider, 2009). James and colleagues (2009) developed a continuous recognition task composed of 120 concrete black on white drawings all of which were repeated once, either immediately following a 2-second stimulation-free interval or after the initial presentation. Participants indicated new pictures by pressing a button. The authors found that pictures immediately repeated after an unfilled interval were better recognized than pictures repeated after intervening items. After 30 min, however, the immediately repeated pictures were significantly less well recognized than pictures repeated after intervening items. Rehearsal was a processing

advantage at immediate repetition, but a disadvantage for long-term storage. Given retrieval performance had an electrophysiological correlate, the EEG showed that immediate repetition induced a strikingly different electrocortical response after 200–300 ms, compared to that period of time directly after new stimuli or delayed repetitions (James et al., 2009). These results demonstrated that novel information immediately initiated the consolidation process, but memories remained vulnerable to interference during active maintenance with a decrease in activation of EEG activity thought to be generated in the MTL (medial temporal lobe; James et al., 2009). The MTL is an area of the brain thought to be associated with long-term memory formation. However, MTL activations increased as increases in encoding content continued to improve during off-line processing (James et al., 2009). The consolidation phase of novel information maintenance is vulnerable to interference.

Further support for physiological associates with the PFC was recognized during another experiment in the study cited above by Jost and colleagues (2012). In that paradigm, the investigators measured PFC activation through EEG and fMRI while controlling for interference in a task of facial content retrieval (Jost et al., 2012). The topography of slow EEG potentials and the fMRI BOLD signal in the posterior storage areas was active during presentation of both relevant and irrelevant stimuli. Similar to the results from the other experiments in that study, these results demonstrated that interference triggered control processes mediated by the medial and lateral PFC, which are presumably involved in narrowing target representations by focusing on the task-relevant material and ignoring irrelevant stimuli (Jost et al., 2012). The PFC appears to have a strong role in the process of interference.

## Memory Models

Most models of memory fall between two extremes: Multistore models view STM and LTM as architecturally separate systems that rely on distinct representations, and unitary models which view memory as a continuous process with no separate units (Jonides et al., 2008). According to Baddeley's multi-store model, there are separate buffers for different forms of information. These buffers, in turn, are separate from LTM. A verbal buffer, the phonological loop, is assumed to hold information that can be rehearsed verbally (e.g., letters, digits). The visual buffer, the visuospatial sketchpad, maintains visual information and can be further fractionated into visual/object and spatial stores (Regov & Baddeley, 2006; Smith et al., 1995; Jonides et al., 2008). The episodic buffer draws on the other buffers. LTM was added to the multi-store model to account for the retention of multimodal information (Baddeley, 2000). In addition to the storage buffers described above, a central executive is proposed to organize the interplay between the various buffers and LTM, and is implicated in controlled processing.

Evidence for a two-component multi-store memory architecture comes from amnesic patients with deficits in STM, but not LTM (Baddeley, 2003; Shallice & Warrington, 1970). Baddeley and Warrington (1970) looked at immediate and delayed digit sequence recall tasks and found that amnesic patients had normal digit span/STM (4-5 digits; a measure of working memory) and defective LTM recall. This may suggest a dichotomy between STM and LTM (Baddeley & Warrington, 1970). However, when looking at well-known amnesic patients like, K.F. (a patient with intact LTM, but STM amnesia; Shallice & Warrington, 1970), the idea of STM as a necessary means for encoding LTM is not supported. K.F.'s STM amnesia provides evidence that LTM can

exist without STM. To support a unitary model, patients with STS impairment should show little capacity for long-term learning or for everyday cognitive activities. Such patients were identified, but had few cognitive problems beyond grossly impaired STM. It is often claimed that patients with medial temporal lobe (MTL) damage demonstrate impaired LTM but preserved STM, which supports a multi-store model (Baddeley & Warrington, 1970; Scoville & Milner, 1957; Jonides et al., 2008). Furthermore, this study showed a double dissociation: verbal tasks interfered with verbal STM but not visual STM, and visual tasks interfered with visual STM but not verbal STM, lending support to separable memory systems (Baddeley, 1986; Baddeley & Hitch, 1974; Jonides et al., 2008). Conversely, the opposite pattern was found in patients previously diagnosed with conduction aphasia (Shallice & Warrington, 1970). This hypothesis fits the existing literature by assuming an exclusive STM deficit.

Further, there is evidence to support an episodic buffer that includes the discovery of chunking information (Baddeley, 2000; Jonides et al., 2008). Chunking is the consolidation and grouping of information by adding associations between content (Cowan, 1999). Cowan (1999) posited that content held in memory for short durations (generally in the STM) can include four to seven items. As more associations are made, encoding and retrieval are strengthened (Cowan, 1999). For example, in the traditional digit-span task, participants are read or shown a list of digits and asked to recall them in order. Recognition of familiar sequences in the list, such as one's telephone number or address, and the ability to do verbal rehearsal have a large effect on success in this task (Engle, 2002). Therefore, mechanisms such as rehearsal help associate and transfer information into long-term store.



More recently, research has gravitated towards a unitary model. According to a unitary-store model, STM and LTM rely largely on the same representations, but differ by (a) the level of activation of these representations and (b) some of the processes that normally act upon them (Jonides et al., 2008). Some postulate that STM and LTM are not separate units due to the variability in discrete durations for each type of memory (Brown, Neath & Chater, 2007). The exact duration of STM to be more or less a certain duration has been debated with several studies showing similar patterns of recall for information no matter the duration (Brown et al., 2007). Nairne and Dutta (1992) looked at the detailed pattern of recall errors and found that participants had similar recall after 24 hours when compared to their immediate recall.

Additional evidence to contradict a separate STM comes from distraction-based research from Robert Bjork and William B. Whitten (1974). They presented subjects with word pairs to be remembered; however, before and after each word pair, subjects had to do a simple multiplication task for 12 seconds. After the final word-pair, subjects were asked to do the multiplication distractor task for 20 seconds. They found that the recency effect (the increased probability of recall of the last items studied) and the primacy effect (the increased probability of recall of the first few items) still remained (Bjork & Whitten, 1974). These results appear inconsistent with a multistore memory since in this model, items presented at the beginning of the list would be stored in LTM and would therefore be expected to exhibit best retrieval performance. Given that the recency effect remained, the multi-store model is not supported by this data. Therefore, a more appropriate explanation is that participants created associations for the items retrieved from LTM, which better fits a unitary memory model. Although the distraction task was

predicted to replace word-pairs as hypothesized in a multistore memory process, Bjork and Whitten (1974) found that the results were better attributed to encoding and maintenance for long-term memory retrieval as a unitary model. Maintenance appears to occur in both the traditional STM encoding and LTM process, which may question the potential impact of the temporal presentation of interference tasks that occurs during this maintenance phase.

Although some data from neuropsychology supports a separate short-term and long-term system, there is also biological evidence to support a unitary model (Jonides et al., 2008). Traditionally research has focused on amnesic patients and the contrast between STM and LTM impairment. One critical contrast highlights patients who show severely impaired LTM with apparently normal STM (Cave & Squire, 1992, Scoville & Milner, 1957) and those who show impaired STM with apparently normal LTM (e.g., Shallice & Warrington 1970). Although the distinct impairments in STM and LTM suggest a multistore system, questions have been raised on whether neuropsychological data truly supports separate memory units. The role of the medial temporal lobe (MTL) may provide an explanation. The MTL has been historically linked to long term declarative memory storage and retrieval (Gabrieli, Brewer, Desmond & Glover, 1997). However, Ranganath & Blumenfeld (2005) have summarized evidence showing that MTL is engaged in short-term tasks (Ranganath & D'Esposito, 2005; Nichols, Kao, Verfaellie, & Gabrieli, 2006). MTL activation has been associated with using novel relations for STM retrieval (Klimesh, Doppelmayr, Yonelinas et al., 2001; Jonides et al., 2008). Novel relations are the details or features of a person, place, event, or thing that helps memory encoding and retrieval. An example of this includes the ability to relate a

list of words to one's personal experiential context to create novel relations. Moreover, MTL activation has been found to specifically play a part in binding novel relations to episodic memories (Klimesch et al., 2001). In particular, there is growing evidence to suggest that the MTL is involved in establishing memory representations that include episodic memories (Klimesch et al., 2001). Episodic memory is memory for autobiographical events (times, places, associated emotions, and other contextual who, what, when, where, why knowledge) and explicitly retrieves that information (Tulving & Thomson, 1973). Thus, if STM is preserved in amnesic patients with MTL lesions, this reflects an ability to maintain and retrieve information without using novel relations for retrieval. Instead, one can theoretically retrieve remote memories previously consolidated before the amnesia-inducing lesion (Jonides et al., 2008). Taken together, the MTL appears to operate in both STM and LTM to bind novel relations to items and therefore aid in the retrieval of those memories.

Some evidence suggests that more specific types of memory fit with the multi-store model, but this is still uncertain and data could possibly support a unitary model better. Other forms of memory such as procedural memory, declarative memory, episodic memory, and semantic memory are outcomes from memory translation; however, it may be difficult to understand which memory model best fits in forming these types of memories. Procedural memory is a non-consciously accessible memory formed through skill conditioning, while declarative memory is consciously accessible information (Wood, Baxter & Belpaeme, 2012). Although some speculate that procedural memory is unconscious, it becomes difficult to understand whether unconscious awareness is possible in a dual-store model because there is no definitive way to measure

unconscious awareness and awareness is dependent on subjective report which may or may not be accurate (Baddeley, 2001). Thus, the procedural–declarative division may fit a framework comprising of multiple memory subsystems with the term non-declarative covering a set of additional, non-conscious memory functions comprising adaptations to previously learned behavior systems (Wood et al., 2012). Non-declarative procedural memory is thus subdivided into four types: skills and habits, priming, classical conditioning, and non-associative learning (Baddeley, 2001). It appears that procedural memory may be a LTM that is consistently in “STM” because of its accessibility; however, it is difficult to determine this process due to varying performance outcomes from studies that test memory translation (Wood et al., 2012). A more parsimonious explanation is a unitary-store model due to the fluid function of procedural memory. The idea of no separate units from which memory would move back and forth for accessibility (i.e. information moving from LTM to STM for present use) better explains the process behind procedural memory because it captures memory accessibility without conscious awareness. Procedural memory does not appear to require conscious awareness or attention to modulate information for retrieval. Therefore, it seems as though procedural memory may be less consistent with a multi-store model as we understand it now, which requires conscious attention to pull the memory for a particular procedure from LTM to STM for present use (Baddeley & Warrington, 1970).

Episodic memory (personally experienced event information, spatially and temporally organized) and semantic memory (context independent information, facts, and concepts) both fall within the broader category of declarative memory. The multi-store model put forth by Baddeley and Hitch (1974), suggests that information can be

processed into different memory storage systems based on the type of sensory information presented (e.g. visuospatial scratch pad, phonological loop). Based on the mechanisms that process information into memory, there is evidence to show that declarative memory is better suited for a unitary model because the role of interference is conflicted (Bjork & Whitten, 1974). For example, in a set of picture-word interference tasks, distractor words that belong to the same semantic category as the pictures produced more interference than either unrelated words or nonsense trigrams (Rosinski, 1977). The results were interpreted as reflecting two different sensory modalities that access information in a single store unit (Rosinski, 1977). Although most of the existing studies exploring declarative memory are informative, the majority are older and more definitive research is needed to corroborate with recent findings.

Some evidence points to a model in which STM consists of temporary activations of long-term representations to support a unitary model. According to this and similar models, STM can be viewed as functionally consisting of LTM representations that are either in the focus of attention or at a heightened level of activation. Unitary-store models focus on central capacity limits, regardless of modality, but they do allow for separate resources (Cowan, 2000) or feature components (Lange & Oberauer, 2005; Oberauer & Kliegl, 2006) that occur at lower levels of perception and representation. Multi- and unitary-store models thus both converge on the idea of modality-specific representations (or components of those representations) supported by distinct posterior neural systems. That is, the same neural representations initially activated during the encoding of a piece of information show sustained activation during STM (or retrieval from LTM into STM; Wheeler, Petersen, & Buckner, 2000) and are the source of long-term representations.

Functionally, memory in the short term seems to consist of items in the focus of attention along with recently attended representations in LTM. In a review by Cowan (2000), he concluded from several studies that memory capacity in general is four items, plus or minus one. These items in the focus of attention number no more than four, and they may be limited to just a single representation (consisting of items bound within a functional context). While expanding upon the idea of four or more items under attentional focus, we can postulate how attention switches between information to form memories. In one study, the main finding that one-back items in a set of items presented were recognized equally rapidly and more accurately than single presentation items infer that immediate repetition of pictures during learning prevented consolidation from repetition (James et al., 2009). Further participants were able to accurately identify up to nine items with no retroactive detrimental effect on initial consolidation during the one-back items (James et al., 2009). This demonstrates that perhaps consolidation occurs at the beginning of memory and encodes into LTM without decay; therefore, LTM encoding can occur at any time without the need of passing through the STM. Immediate consolidation of information into LTM is support for a unitary, rather than a multistore model of memory.

There is evidence to suggest that the unitary-store model is supported when encoding visual content. In a study that looked at visual STM and LTM using paired association between faces of famous people and words, they found that similar networks of brain regions activated for LTM were active during STM encoding and recall (Lewis-Peacock & Postle, 2008). This directly tested the idea that there may be patterns of brain activity initiated when participants perceived and evaluated visual stimuli (drawing on semantic and episodic LTM). During a delay period after presented stimuli for STM

retrieval, brain activity demonstrated patterns similar to the learning trial for LTM activity. These results suggest that short-term retention of information can be supported by the temporary activation of LTM representations.

### **Unitary-Store Model: Neuroanatomical Evidence**

Several different brain regions are posited to be linked to the translation of memory from STM to LTM. Likewise, LTM is dependent upon the synthesis of new proteins (Costa-Mattioli & Sonenberg; 2008). This occurs within the cellular body, and concerns particular transmitters, receptors, and new synapse pathways that reinforce the communicative strength between neurons within certain brain regions such as the hippocampus, medial temporal lobe (MTL), and prefrontal cortex (PFC). The production of new proteins devoted to synapse reinforcement is triggered after the release of certain signaling substances (such as calcium within hippocampal neurons) between cell communication (Costa-Mattioli, Sonenberg & Sonenberg, 2008).

As mentioned, new protein formations devoted for synapse reinforcement occurs in the hippocampus when LTM is formed. A prominent theory of hippocampal function proposes that the hippocampus is involved in relating or binding together separate pieces of information to form an episodic representation (Olson, Page, Moore, Chatterjee & Verfaellie, 2006). Specifically, many studies have established that hippocampal neuronal responses carry information, particularly spatial information, about one's environment. The extensive literature on place fields (areas of brain activation) establishes that hippocampal neurons encode a rat's position in space, although there is also evidence that

they signal information about other types of relationships between stimuli (Eichenbaum, Schoenbaum, Young & Bunsey, 1996).

To investigate the role of the hippocampus in recognition memory, research has utilized focal hippocampal lesions. It is predicted that hippocampal lesions induce anterograde amnesia for episodic information, but certain types of recognition memory tasks should be relatively spared. This rare occurrence should be most evident for tests that can be solved by discriminating the familiarity or recency of discrete items. By contrast, tests that can only be solved by using spatial or associative information should be more impaired, even when task difficulty is equated. Of note, is a patient with perirhinal cortex damage and a delayed global memory deficit, who was found to have bilateral shrinkage of the hippocampus but apparent preservation of adjacent regions (Mayes, Van Eijk, Gooding, Isaac & Holdstock, 1999). This patient showed a persistent deficit in episodic memory, but preserved recognition memory, particularly in tests that can be solved by judging the prior occurrence of individual items. When recognition memory deficits were observed, they were most evident in associative recognition memory tasks (such as recognizing that item A has been paired with item B but not with item C, in contrast to recognizing the prior occurrence of individual items A, B or C (Mayes et al., 1999).

Further, monkey models have provided evidence for sensory input reaching the hippocampus. Stimuli were first processed through their respective cortical regions, then reached the perirhinal (P) 35/36 (i.e. Brodmann's areas 35/35) or parahippocampal TH/TE, next the entorhinal or polysensory (cingulate, retrosplenial, frontal, and STS dorsal), and eventually to the hippocampus (Brown & Aggleton, 2001). Visuospatial



information is sent to the parahippocampal TH/TE, perirhinal 35/36, entorhinal cortex, and lastly to the hippocampus. Activation in the above-mentioned neural pathways was associated with the recognition of spatial and verbal content in monkey and rat models (Brown & Aggleton, 2001). Further, hippocampal and PFC activation were associated when familiar stimuli were presented, even if stimuli were novel (Hannula & Ranganath, 2009). Hippocampal activation alone has a direct impact on LTM recognition, but when paired with other regions, such as MTL or PFC, it may have a more substantial impact in immediate memory (Brown & Aggleton, 2001).

Another region associated with memory processes is the medial temporal lobe (MTL). The MTL was traditionally thought to be important for LTM encoding, but has recently been found to support working memory maintenance for novel items in STM (Ranganath & D'Esposito, 2001; Stern, Sherman, Kirchoff & Hasselmo, 2001; Nichols et al., 2006) and associations between item features (Hannula et al., 2006; Olson et al., 2006; Piekema et al., 2006). The function of the MTL in memory was discovered through the study of patients with MTL lesions. These patients failed to remember new events that were set in an autobiographical context (an episode), and as a result, had impaired recognition (Brown & Aggleton, 2001). The MTL is active during memory tasks that require the maintenance of novel items (Hannula & Ranganath, 2009) and faces (Ranganath & D'Esposito, 2001). Therefore, patients with MTL lesions may exhibit impairment on tasks with novel items because the stimuli were no longer associated with the contextual information required for recognition.

Further evidence for the involvement of the MTL in memory was reported by James et al. (2009). They found that picture stimuli presented after an unfilled interval

were better recognized than pictures repeated after intervening items. However, during a 30-minute delay, the immediately repeated pictures were significantly less well recognized than pictures repeated after intervening items (James et al., 2009). Both tasks activated the MTL, and thus, MTL activity was associated with ongoing consolidation process after immediate repetition (James et al., 2009). These results suggest that rapid, initial consolidation may be important for detailed information retrieval from long term memory and complex mental manipulations (James et al., 2009). Furthermore, the degree to which the MTL is recruited during STM tasks predicts subsequent LTM formation (Ranganath et al., 2005), indicating that MTL involvement in STM plays an important function. Hence, MTL-mediated dynamic binding of items may form the basis of new LTM encoding (Nee & Jonides, 2013).

Another area of the brain involved in memory processes is the prefrontal cortex (PFC). It is commonly held that the PFC plays a role in cognitive control (Koechlin, Ody, & Kouneiher, 2003; Botvinick, et al., 2001; Miller & Cohen, 2001). According to Miller and Cohen (2001), task goals are maintained in the PFC in the form of active connections with other brain structures. These connections guide the flow of information in many cognitive systems, such as visual processing and response execution.

Emerging data indicates that the hippocampus, MTL, and PFC interact with one another during memory processes. Nee and Jonides (2013) postulated that all three of the aforementioned brain regions should demonstrate qualitatively distinct activation during different stages of memory. Using a paradigm that investigated memory formation from initial encoding to long-term retrieval, the authors found inferior parietal and inferior temporal activations when the Focus of Attention (FA) was accessed, the MTL

was active during working memory, and the ventrolateral prefrontal cortex (VLPFC) was activated when LTM was accessed (Nee & Jonides, 2013). Similar patterns have been documented in related studies (Nee & Jonides, 2013; Öztekin, McElree, Staresina & Davachi, 2009, 2010) and provide support for the theory that communication among these distinct neuroanatomical areas is involved in memory formation (Nee & Jonides, 2013).

### **Neuropsychological Tasks of Visual Memory**

To investigate recognition and memory, researchers have used the Sternberg Item Recognition Paradigm (SIRP) in which a small group of items, called the “positive set”, is presented for the participant to memorize (Brodziak, Kołat, & Różyk-Myrta, 2014). After a delay, a single item is presented that may or may not have been shown before. The subject is asked to respond ‘yes’ or ‘no’, indicating their recognition of the item. This procedure is repeated over several trials in which numbers are distractors used to interfere with maintenance of the targeted stimuli (Brodziak et al., 2014). Since this task has the potential to delineate the effects of distractors throughout immediate and delayed recognition, perhaps it may also provide information on the role of interference throughout the processes of encoding, maintenance and retrieval.

The Brief Visuospatial Memory Test–Revised (BVMTR) is a standardized and well-established measurement of immediate and delayed recognition of visuospatial information as it relates to memory translation (Brodziak et al., 2014). There have been limited studies to highlight the association between visuospatial memory in the BVMTR and a modified version of Sternberg’s task; however, this may lead to additional

information on an exclusive measure of visual memory. Further, finding a potential association may provide evidence to support the validity and consistency of such tasks.

Matrix Reasoning is one of four subtests in Perceptual Reasoning Index on WAIS -III given to assess Gf (or fluid intelligence). Results suggest that the temporary retention of visual mental images and of visual information may be supported by the same visual short-term memory store (Borst et al., 2012; Stephenson & Halpern, 2013). Jaeggi and colleagues (2010) investigated the transfer effects on working memory capacity and Gf comparing the two training groups' performance to controls who received no training of any kind. The results indicated that both training groups improved more on Gf than controls (Jaeggi et al., 2010). Further working memory capacity was significantly correlated with matrix reasoning performance (Jaeggi et al., 2010). For example, training with another task of working memory (N-Back) improved Matrix reasoning performance (Jaeggi et al., 2010). This indicated that general fluid intelligence is positively related to STM improvement. The exact direction of impact is still uncertain and can be explored further with our study. In a task with a series of abstract figures arranged in a grid, one piece of the grid is missing. Participants were asked to select the missing piece from several options (Shipstead et al., 2012). Results indicated that participants with memory training had an increase in STM performance for visual content and a positive association with fluid intelligence in a sample of children (Shipstead et al., 2012). Therefore, since adults have similar brain mechanisms, a positive correlation between STM and fluid intelligence may occur in an adult sample.

## Summary and Specific Aims

Memory is a complex process with little agreement regarding the cognitive structure of memory storage and the different processes for retrieval. Past evidence has pointed to a multi-storage structure (Baddeley, 1966), where content is translated into memory by two phases: short-term and long-term memory (Baddeley, 1996). More recent research supports a unitary model that better accounts for the translation of information from STM to LTM (Jost et al., 2012; Jonides et al., 2008). Evidence regarding different memory processes such as encoding, maintenance and retrieval occurring throughout STM and LTM suggests a unitary store model. More specifically, LTM encoding occurs during immediate memory presentation (James et al., 2009).

However, there is still controversy between these models due to the disagreement about the role of interference during memory translation (Bancroft et al., 2013). The impact of distraction on this process is largely unknown. However, we do know that neuroanatomical evidence such as MTL activation during STM maintenance (Ranganath & D'Esposito, 2001; Stern et al., 2001), interference and encoding associations with PFC activation (Ranganath & D'Esposito, 2001; Stern et al., 2001) and with PFC/hippocampal activation (Nee & Jonides, 2013) during STM encoding and LTM retrieval suggests a unitary model. The temporal presentation of the interference and accuracy of retrieval may provide a way to further study this translation process. Understanding the role of distraction during STM encoding and how it affects the formation of LTM can potentially inform treatment for impaired memory. Further, comparing our behavioral task with established measures of visual memory and fluid intelligence will give exploratory information on correlations of cognitive functioning and STM.

In this study, we attempt to investigate the temporal role of distractors on STM performance and LTM recognition. The following are our aims:

Specific Aim 1: Determine whether distractors affect STM performance during a modified SIRP task; and whether placement of the distractor during the STM delay interval differentially affects performance as measured through accuracy and reaction time.

Hypothesis 1a: Distractors (early and late) will negatively impact performance (accuracy and reaction time) compared to no-distractor trials. Bancroft and colleagues (2013) provided evidence to suggest that interference during any stage of encoding was a part of STM and LTM (Bancroft et al., 2013). A repeated measures ANOVA was conducted to compare STM accuracy between distractor trials (none, early, and late) and trial type (matched and non-matched). Additionally, a second repeated measures ANOVA was conducted to compare STM reaction time between distractor trials (non, early, and late) and trial type (matched and non-matched). A main effect of distractor for STM reaction was expected, where no distractor trials would have faster reaction times than early and late distractor trials.

Hypothesis 1b: Distractors late in the STM delay will negatively impact performance more than those presented early in the delay interval (Jonides et al., 2008). Jonides and colleagues (2008) highlighted how STM and LTM are a part of a unitary system and temporal differences in encoding

is the determining factor between STM and LTM. Therefore, late distracters will impede in the LTM memory encoding. Pairwise comparisons within the repeated measures ANOVAs for STM reaction time and accuracy was expected to indicate differences between distractor trials. Further, we expected early distractor trials to be more accurate and faster than late distractor trials.

Specific Aim 2: Determine whether there is a relationship between performance on the STM task and performance on the surprise delayed recognition task.

Hypothesis 2a: Across all trial types (no, early, and late distracters), Delayed Recognition Task performance (accuracy) will improve when participants were previously accurate on the STM task. A Repeated Measures ANOVA compared LTM performance when participants were previously correct on the corresponding STM trial and performance when participants were previously incorrect on the corresponding STM trial

Hypothesis 2b: Participants will be more accurate on delayed recognition trials that included no distractors in the STM task compared to trials that contained early or late distractors (Bancroft et al., 2013). Bancroft and colleagues (2013) provided evidence to suggest that interference during any stage of encoding became a part of STM and LTM. Further interpretation of the interaction between STM-accuracy and STM-distractor type will be discussed.

Specific Aim 3: Investigate whether STM accuracy is associated with the BVMT-R, an established measure of visual memory.

Hypothesis 3a: The behavioral performance on the STM task will be associated with BVMTR performance. This is an exploratory hypothesis, given there is limited research to support a modified visuospatial memory oriented version of the Sternberg (1966) task with an established measure of visual memory. This was conducted with correlation analyses of STM task and BVMTR.

Specific Aim 4: Investigate whether performance on STM accuracy is associated with Matrix Reasoning, a measure of visual higher order thinking.

Hypothesis 4a: The behavioral performance on the STM task will be associated with Matrix Reasoning performance (Shipstead et al., 2012). This was conducted with correlation analyses between STM task performance and Matrix Reasoning performance.



## **CHAPTER TWO**

### **METHODS**

#### **Participants**

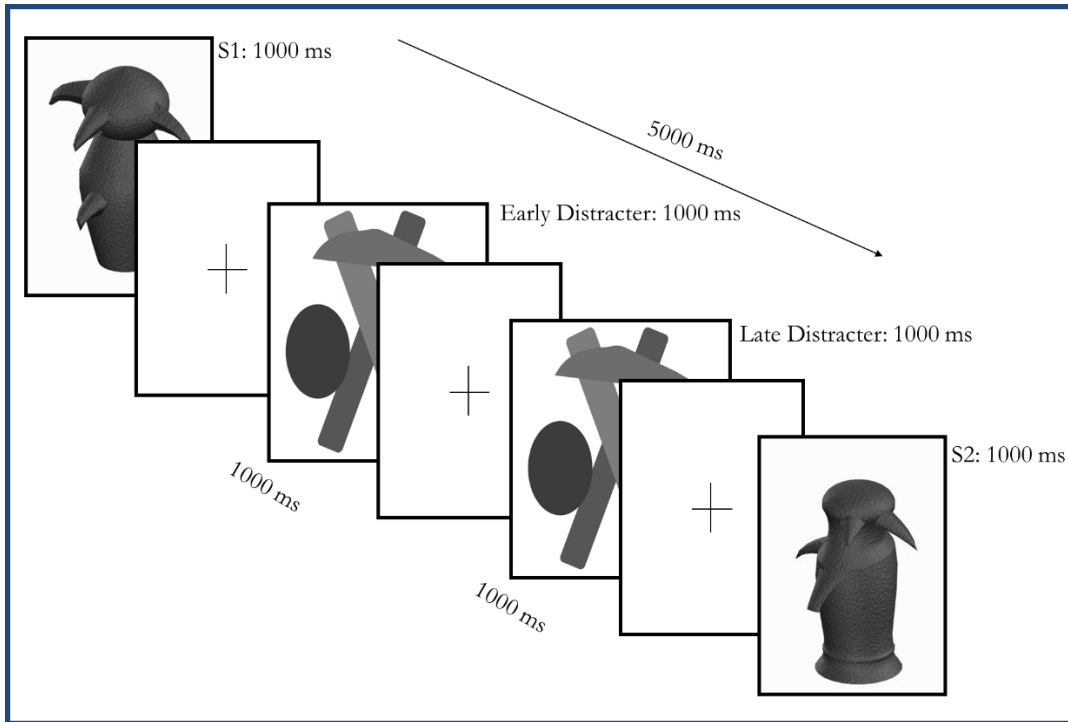
Ninety-one undergraduates (18 male; mean age 21) at the University of British Columbia provided informed consent. Participants had normal or corrected vision of 20/40 or better, were free of self-reported history of head injury, neurological disorders, attention-deficit disorder, learning disorders, substance-related disorders, Axis-I disorders or illicit substance use within 24 hours of testing. Those participants (N = 10) who reported having consumed alcohol within 24 hours of testing all had fewer than four drinks. Participants were further excluded from the study for smoking during the break between tasks (N = 1) or an obvious lack of attention to the tasks (N = 1). Further, participants that ran out of time during test administration (N=13) were missing data from the BVMT-R assessment and matrix reasoning. Mean scores from measures and demographic details are presented in Table 1.

**Table 1.** Descriptive statistics of performance on neuropsychological and behavioral tests.

	N	Minimum	Maximum	Mean	SD
Age	78	18	43	21.15	4.31
BVMTTotal	78	8	36	25.13	6.10
BVMTScaled	78	20	61	42.37	9.91
BVMT2	78	2	12	9.09	2.51
BVMT3	78	3	12	10.37	2.02
Matrix_Reasoning	78	11	25	20.09	3.19
MR_Scaled	78	6	15	11.50	1.97
STM-No Distractors	91	7	24	18.38	3.65
STM-Early Distractors	91	7	24	18.03	3.46
STM-Late Distractors	91	7	23	17.86	3.13
Delayed Recognition STM-No Distractors	91	3	22	10.80	3.42
Delayed Recognition STM-Early Distractors	91	3	18	10.32	3.22
Delayed Recognition STM-Late Distractors	91	4	18	9.69	2.74

### Stimuli

Greyscale images of Greebles were used as novel object stimuli (Gauthier & Tarr, 1997). A single viewpoint was used for each of the 288 unique Greeble stimuli, all presented at a visual angle of 14.90°. The distracter stimulus was a slide with overlying greyscale geometric figures, presented at a visual angle of 17.19°, see *Figure 1*.



**Figure 1.** Behavioral Task.

## Measures

### *Spatial Reasoning*

Matrix Reasoning subtests of the Wechsler Intelligence Scale for Adults-Third Edition (WAIS-III; Wechsler, 1997). The items are presented in a matrix with all but one of the cells containing colored figures. Below the matrix are five boxes that each contain a figure. The Matrix Reasoning subtest presents figures in a matrix where each figure either remains constant or changes in each cell. The participants' task is to choose the answer from one of the five boxes to complete the sequence.

### *Visuospatial Memory*

The Brief Visuospatial Memory Test-Revised (BVM-T-R; Benedict, 1996). It is a

measure of visual memory with three learning trials. The participant is shown an 8/11 plate containing six geometric visual designs in a 2 x 3 matrix. The stimulus is presented for 10s and the participants are instructed to reproduce as many designs as possible after the stimulus is removed from view. Participants are shown two additional learning tasks and a delayed recall of 25 minutes, followed by 12 individual designs for recognition (6 target and 6 non-target designs). The BVMTR was constructed to test for visuospatial processing and memory and have been correlated strongly with tests visual memory (revised Hopkins Verbal Learning Test,  $r = .74$  for delayed recall; Visual Reproduction subtest of the Wechsler Memory Scale—Revised,  $r = .80$  for delayed recall, respectively) rather than verbal memory and visuospatial construction, and most weakly with expressive language (Benedict et al., 1996).

### ***Behavioral Visuospatial STM and LTM Task***

Greebles were selected as stimuli for visual memory. Within the STM version, the Greeble stimulus (S1) was displayed for 1000 ms followed by a 5000 ms delay interval with a fixation cross. Distracter stimuli delay were presented for 1000 ms either early (1000 ms after S1) or late (3000 ms after S1) in the. The second Greeble stimulus (S2) was then presented for 1000 ms. Participants indicated on a 1-4 scale their confidence in recognizing S2 as the same or different from S1 (Surely Same (1), Maybe Same (2), Maybe Different (3), Surely Different (4)). The inter-trial interval varied from 5500 to 6500 ms. One hundred forty-four trials were divided into 72 match and 72 mismatch trials. There were 24 trials for each of the three conditions: no distracter, early distracter, and late distracter.

## **Overall Procedure**

The study procedures were divided into two parts consisting of a modified behavioral task and a short battery of neuropsychological measures given after the behavioral task. The following is a description of the behavioral task that was separated into two parts, the first as the learning and STM task and the latter as the unprompted LTM recognition task.

### ***Part 1 Procedure***

The first Greeble stimulus (S1) was displayed for 1000 ms followed by a 5000 ms delay interval with a fixation cross. Distracter stimuli were presented for 1000 ms either early (1000 ms after S1) or late (3000 ms after S1) in the delay interval. The second Greeble stimulus (S2) was then presented for 1000 ms. Participants indicated on a 1-4 scale their confidence in recognizing S2 as the same or different from S1 (Surely Same (1), Maybe Same (2), Maybe Different (3), Surely Different (4)). The inter-trial interval varied from 5500 to 6500 ms. One hundred forty-four trials were divided into 72 match and 72 mismatch trials. There were 24 trials for each of the three conditions: no distracter, early distracter, and late distracter.

During the break between Part 1 and Part 2, a demographic and personality questionnaire was administered.

### ***Part 2 Procedure***

Following the DMTS task and a 12-minute delay, participants were given an unexpected delayed recognition task. Stimuli included the 72 Greebles used in 'match'

trials and 72 new Greebles, all presented for 2000 ms. Participants indicated on a 1-4 scale their confidence in having seen the objects in the first task (Surely Old (1), Maybe Old (2), Maybe New (3), Surely New (4)).

Next, a short neuropsychological examination was conducted using the Matrix Reasoning subtest of the Wechsler Intelligence Scale for Adults-Third Edition (WAIS-III; Wechsler (1997) for the assessment of spatial reasoning. No other subtests of the WAIS-III were used. The Brief Visuospatial Memory Test-Revised (BVRT-R; Benedict (1996) was administered to assess visual memory.

### **Data Analysis**

Covariates were not used due to the homogeneity of the sample (i.e. similar variability in age, IQ, and education). Data hygiene was conducted to ensure homogeneity within the data. Data points within skewness and kurtosis value of acceptable limits of  $\pm 2$  were kept (Trochim & Donnelly, 2006; Field, 2000 & 2009; Gravetter & Wallnau, 2014). Outliers were identified using the outlier labeling method where a formula was applied to the first and third quartile of the variable and multiplied by a “g” value. Extreme values from the high and low end that met or exceeded these values were considered outliers and removed from the dataset (Hoaglin, Iglewicz & Tukey, 1986). In cases where sphericity could not be assumed, Greenhouse-Geisser corrections were reported.

Repeated Measures ANOVAs was conducted to evaluate accuracy and reaction time data for aims 1-4. To address aim 1, two Repeated Measures ANOVAs were used, to first investigate differences in STM accuracy within three different Distractors (none,

early, late) and Trial Types (match, non-match). Interactions between the different distractor types and trial types were included in the analysis. Then a second repeated measures ANOVA was conducted to find differences in STM reaction time with three different Distractors (none, early, late) and Trial Type (match, non-match).

To address aim 2, a third Repeated Measures ANOVA was used to measure Delayed Recognition accuracy with three STM-distractor types (none, early, late) and STM performance (correct, incorrect). Interactions between the different STM-distractor types and STM-trial types on delayed recognition performance were included in the analysis.

Finally, Pearson product moment correlation coefficients with Bonferroni correction was used to test aim 3 and 4 to evaluate the relationship between accuracy and values on the matrix reasoning and BVMTR performance. A power analysis was conducted with GPower to determine the power of the statistical value. A sample size of 91 has significance at a power of .88 and large effect size of .48.

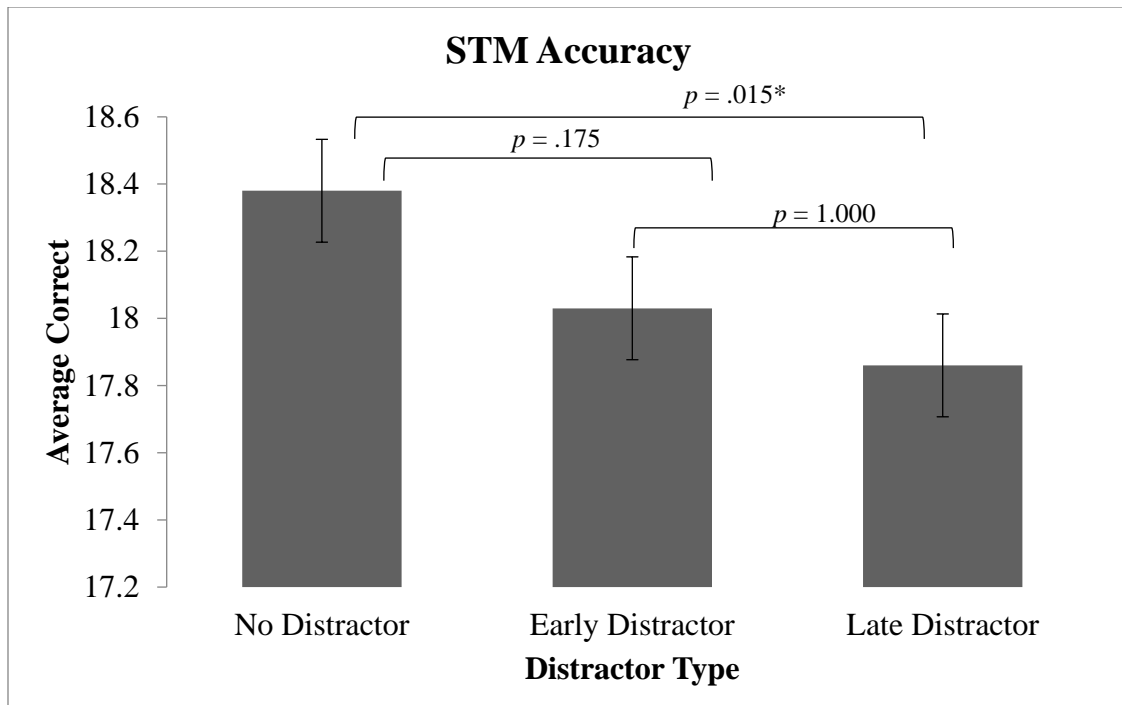
## CHAPTER THREE

### RESULTS

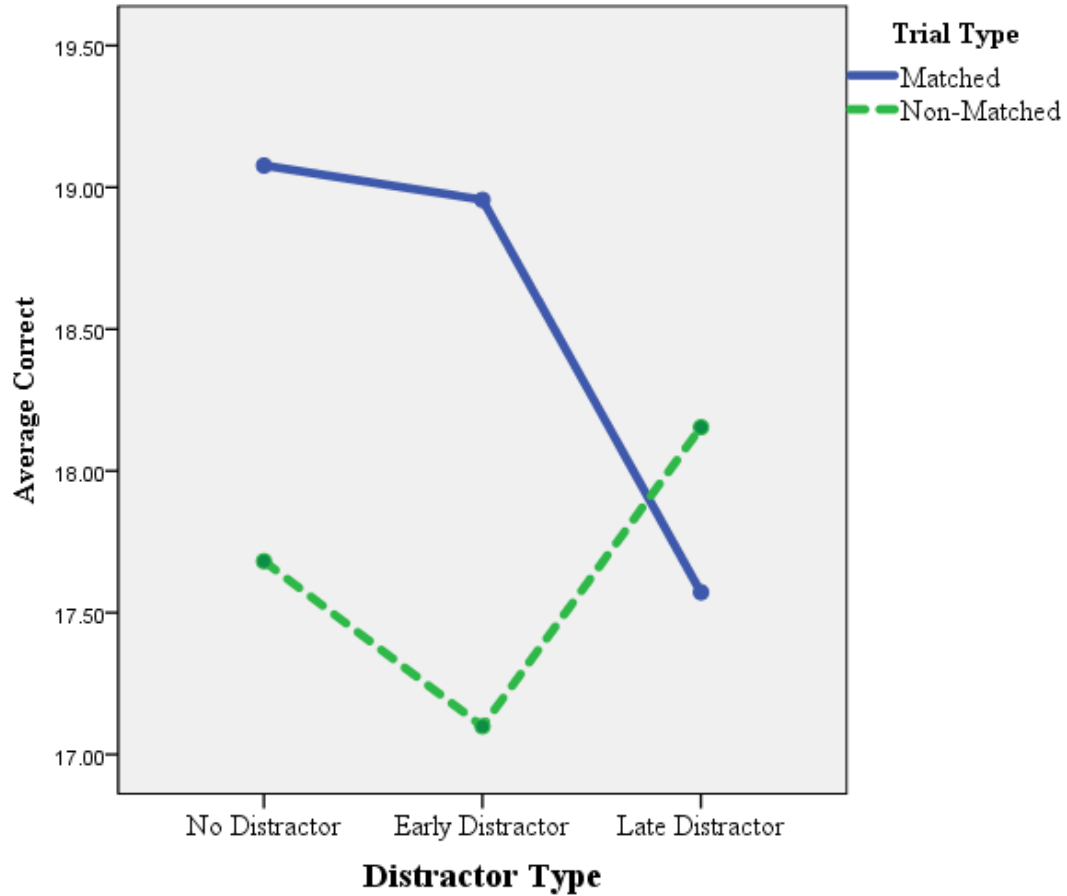
Repeated measures analyses of variance (RM-ANOVA) were conducted with IBM SPSS v.20. If sphericity is observed, the RM-ANOVA procedure provides a powerful test of repeated measures. In cases where sphericity could not be assumed, Greenhouse-Geisser corrections were reported.

To address hypothesis 1a regarding accuracy, two Repeated Measures ANOVAs were conducted to compare the effect of Distractor Types (none, early, late) and Trial Type (match vs non-match) on STM accuracy. There was a main effect of Distractor type, *Wilk's Lambda* = .910,  $F(2, 89) = 4.40$ ,  $p = .015$ ,  $\eta^2 = .090$ . To address hypothesis 1b, three paired samples t-test were used to make post hoc comparisons between conditions. These comparisons indicated that participants were significantly more accurate on no distractor trials compared to late distractor trials,  $p = .015$  (see Figure 2). There was also a significant distractor x trial type interaction, *Wilk's Lambda* = .711,  $F(2, 89) = 18.13$ ,  $p = .000$ ,  $\eta^2 = .289$ . STM accuracy for no and early distractor trials during matched trial types were more accurate than non-matched trials. However, for late distractor trials, non-matched trials were more accurate than matched trials (see Figure 3). The main effect of Trial Type (match or non-match) was not significant *Wilk's Lambda* = .969,  $F(1, 90) = 2.835$ ,  $p = .096$ .



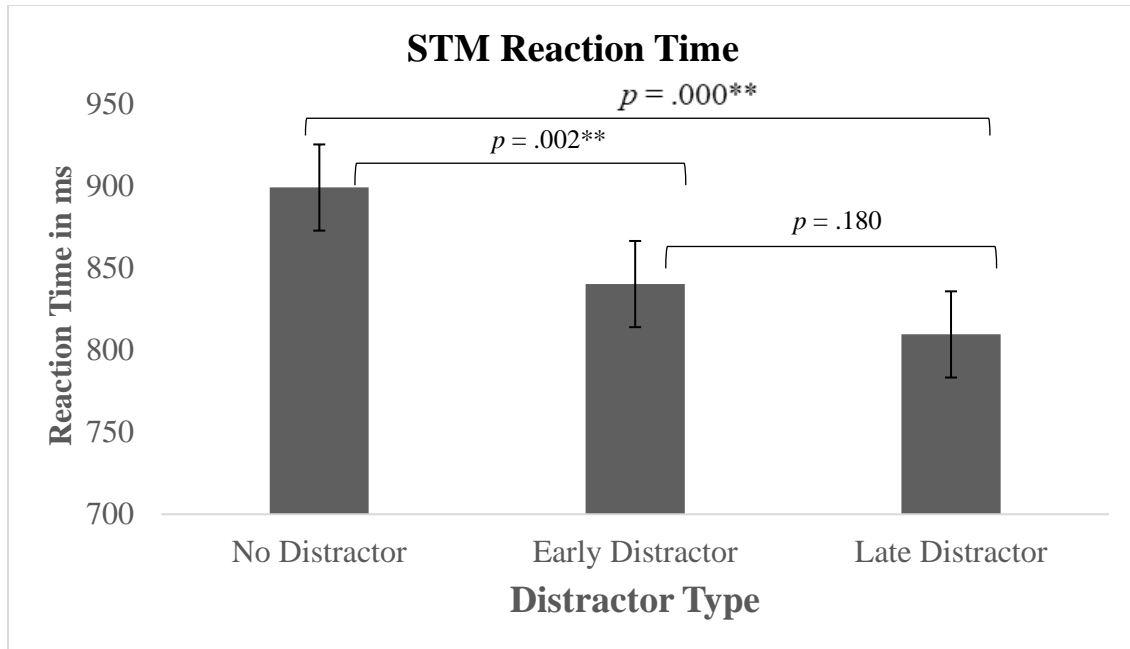


*Figure 2.* STM Accuracy by Distractor Type.



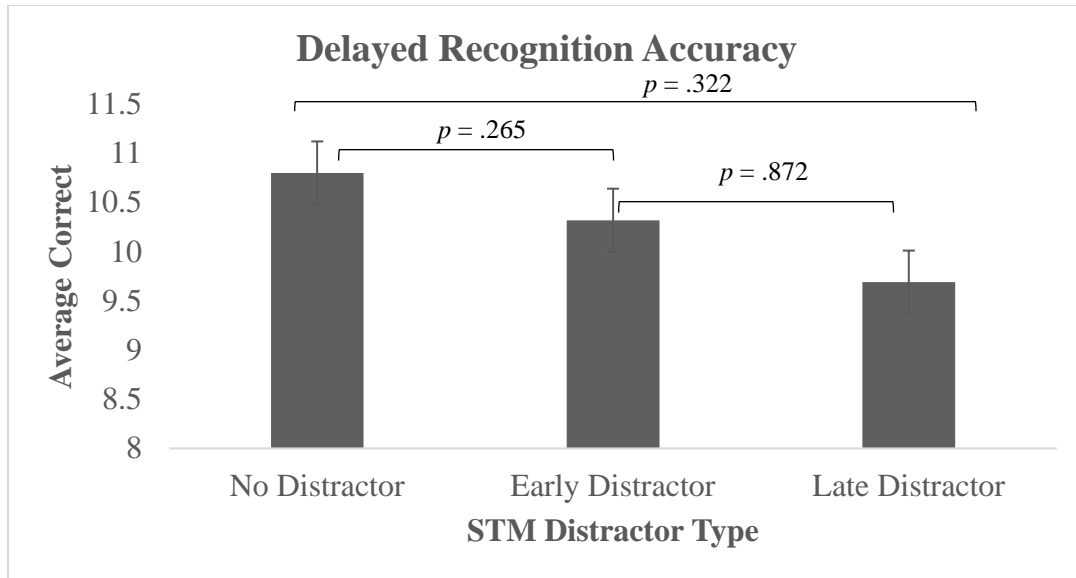
**Figure 3.** Interaction Effects of Distractors and Trial Type on STM Accuracy.

A second Repeated Measures ANOVA was conducted to examine the effect of Distractors (none, early, late) and Trial Type (match, non-match) on STM reaction time to address hypothesis 1a regarding reaction time. The results indicated a significant main effect of STM Distractor, *Wilk's Lambda* = .764,  $F(2, 84) = 12.97, p = .000, \eta^2 = .236$ . To address hypothesis 1b a within-subjects comparison indicated that participants had significantly longer STM reaction time during no distractor trials than with early distractors,  $p = .002$  and late distractors,  $p = .000$ ) which did not significantly differ from each other ( $p = .18$ , see Figure 4).



**Figure 4.** STM Reaction Time by Distractor Type.

To address aim 2, we examined whether Delayed Recognition accuracy was affected by the distractor type of the corresponding STM trial (none, early, late) and the participant's accuracy on the corresponding STM trial (correct, incorrect). Results indicated a significant main effect of STM-accuracy, *Wilk's Lambda* = .189,  $F(1, 89) = 383.14$ ,  $p = .00$ . Delayed recognition accuracy that was previously correct on STM ( $M = 10.27$ ,  $SE = .276$ ) was significantly greater than delayed recognition accuracy that was previously incorrect on STM ( $M = 2.850$ ,  $SE = .171$ ). There was no significant main effect of STM-distractor type on delayed recognition accuracy, *Wilk's Lambda* = .982,  $F(2, 88) = .788$ ,  $p = .503$ , see Figure 5. Further, there was a significant interaction between STM-distractor x STM-accuracy on delayed recognition performance, *Wilk's Lambda* = .812,  $F(2, 88) = 10.21$ ,  $p = .000$ ,  $\eta^2 = .188$ , see Figure 6. Paired-samples t-tests for each distractor type indicated a significant difference between STM-correct and STM-incorrect

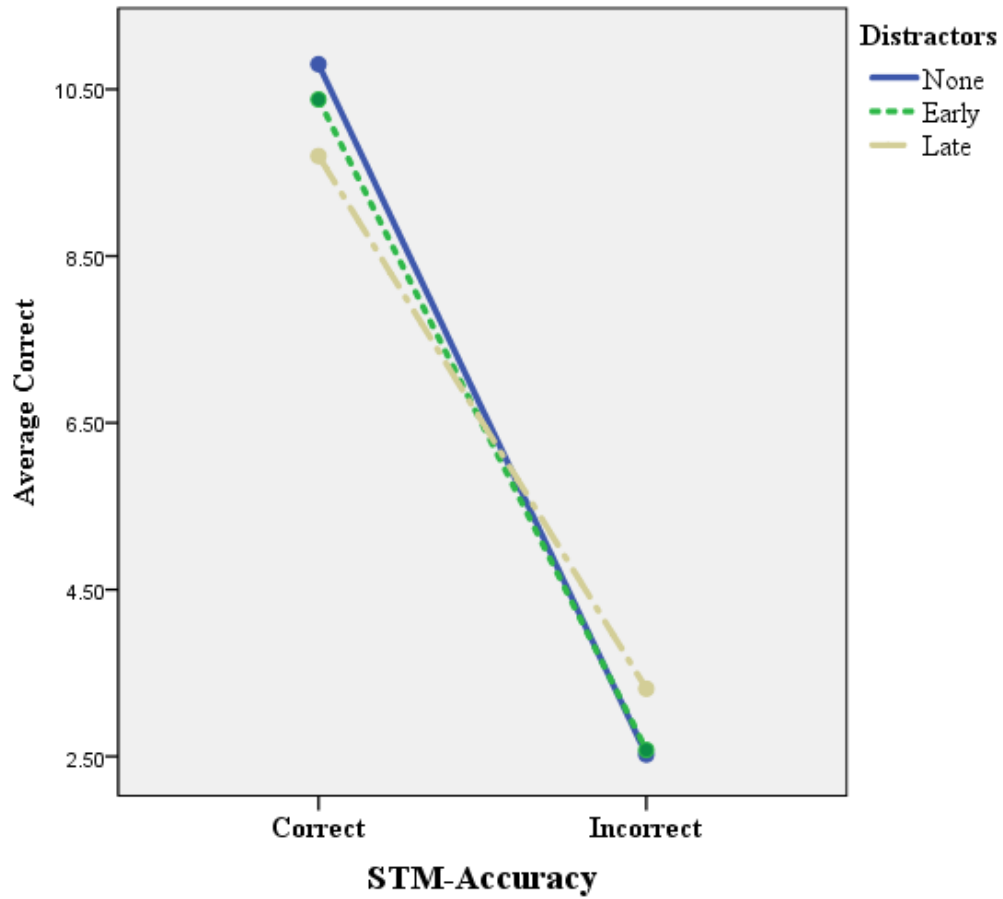


**Figure 5.** Delayed Recognition Accuracy by STM-Distractor.

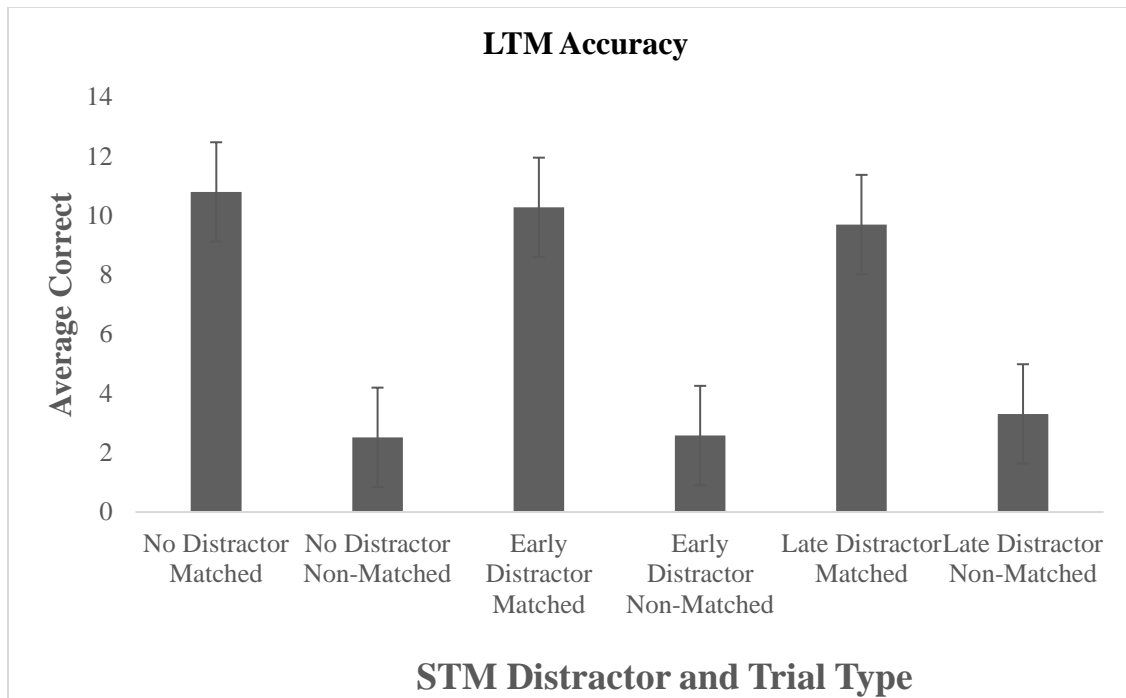
for all distracter types, although the difference was larger for no distracter (STM-correct  $M = 10.80$ ,  $SD = 3.43$ , STM-incorrect  $M = 2.52$ ,  $SD = 3.19$ ), and early distracter trials (STM-correct  $M = 10.38$ ,  $SD = 3.19$ , STM-incorrect  $M = 2.58$ ,  $SD = 1.98$ ), compared to late distracter trials (STM-correct  $M = 9.70$ ,  $SD = 2.75$ , STM-incorrect  $M = 3.31$ ,  $SD = 1.91$ , see Figure 6-7). The results demonstrated a decline in performance with late distractors.

Finally, Pearson product moment correlation coefficients with Bonferroni correction ( $p = .017$ ) were used to evaluate the relationship between STM accuracy and values on the matrix reasoning and BVMTR performance (Aims 3 and 4). There was no significant association between BVMTR and STM accuracy (Pearson correlation for early distractor,  $p = .30$ , late distractors,  $p = .67$ , and no distractors,  $p = .48$ ) No significant associations were found with Matrix Reasoning and memory performance

(Pearson correlation for early distractors,  $p = .18$ , late distractors,  $p = .15$ , and no distractors,  $p = .25$ ).



**Figure 6.** Interaction Effects of Delayed Recognition Accuracy by STM Distractor and Trial Type.



**Figure 7.** Delayed Recognition Accuracy by STM Distractor and Trial Type.

## CHAPTER FOUR

### DISCUSSION

In this study, we investigated the role of distractors and their temporal position during the memory delay interval of a short-term memory and delayed recognition task. This study employed a novel delayed match-to-sample behavioral task using visual stimuli called greebles. Greebles have a visual complexity similar to faces and are not easily translated into verbal or semantic units, making these purely visual memory tasks (Gauthier & Tarr, 1997). In addition, visual distractor stimuli were placed either early or late in the delay interval during the short-term memory task to investigate the impact of the temporal position of the distractor on the corresponding process in the stream of translating information from an external stimulus to an internal representation.

Our results indicated a significant main effect of distractor type (none, early, late) on short-term memory accuracy for both match and non-match trial types. While there were no significant differences in STM accuracy between no-distractor and early-distractor trials, there was a significant decrease in STM accuracy between no-distractor and late-distractor trials. These results suggested that the presentation of late distractors in the memory delay interval had a negative impact on short-term memory performance. Therefore, our first hypothesis of distractors having a negative impact on short-term memory performance was only partially supported. Further, a significant interaction effect was found between distractor and trial type on STM accuracy performance. These findings indicated that for no- and early distractor trials, participants were more accurate on matched compared to non-matched trials. However, if the distractor was presented late

in the delay interval, participants were more accurate on non-matched compared to match trials (see *Figure 2*).

These findings suggested there was interference created by a distractor within the maintenance process during the latter phase of the behavioral task. This is similar to findings presented by Bancroft and colleagues' (2013) that found interference occurred shortly after distractors, when non-targeted stimuli (the distractors) were encoded into memory (Bancroft et al., 2013). Since non-targeted stimuli (the distractors) were presented shortly before targeted stimuli (the second greeble stimulus) in the late distractor condition, it is likely that the detriment in performance was due to interference.

One possible explanation for how interference decreased STM accuracy in late distractor trials may be that participants performed poorly due to insufficient time to recover the target information that was displaced by the interfering distractor. For example, in a study that looked at recollection of visual stimuli, Wais and colleagues (2010) found that the introduction of visual distractors when participants were asked to recollect visual information yielded an interference effect as lower accuracy performance compared to trials with no attention towards visual distractors. In this sense, participants' cognitive focus may have miss-identified the distractor for a prompt and created false confidence to respond accurately. Our findings are also consistent with those of Oberauer (2002), who presented two numbers for participants to remember, only one of which required active processing. Increasing set-size increased reaction time only for the actively manipulated number, but there was no increase for the passively remembered number. These data suggest that shifting the focus of attention from one mental object to another within the focus region yielded "object switching costs", as the manipulated



items competed for resources within this node. It is possible that our task required the greeble stimuli to be held in the focus of attention throughout the delay interval, and that distracters replaced the stimulus as the focus of attention during their presentation (Barrouillet, Portrat, & Camos, 2011; Unsworth & Engle, 2007). Once the distracter disappeared, participants were required to call the original stimulus into the focus of attention again to facilitate the template-matching decision. On late distracter trials the presentation of the probe may have occurred before this process was completed (Oztekin, Davachi, & McElree, 2010). The switch costs associated with replacing the distracter with the stimulus in the focus of attention so temporally close to the probe may have led to more incorrect responses, especially for match trials, on the STM task (Oberauer, 2002; Oztekin et al., 2010).

Additionally, we compared STM reaction time over three different distractors (none, early, late) and trial type (match or non-match). The results showed decreasing reaction time with the addition of distractors; with no distractor trials yielding the longest reaction time ( $M = 899.21$ ) followed by early distractors ( $M = 840.35$ ) and late distractors ( $M = 809.64$ ). It appears that the late distractors, regardless of trial type, resulted in participants reacting faster compared to early or no distractor trials. While these results were unexpected, the reason for such quick reaction times may be due to late distractors acting as prompts to response (Nee & Jonides, 2013). This may have reduced reaction time, but did not necessarily improve retrieval accuracy. Moreover, there was no significant difference between early and late distractors in terms of STM reaction time,  $p = .180$ . These results suggest that distractors, regardless of their temporal placement in the delay interval, may have acted as response cues. Similarly, Nee & Jonides (2011,

2013) serially presented verbal and visual information prior to a brief mask and a probe stimulus and reported that participants responded quicker and more accurately in response to trials with a previously presented probe and where the focus of attention was on the last item compared to earlier items.

In another study that developed a modeling system to predict reaction times for decision-making, Drugowitsch and colleagues (2014) found that people make rapid decisions when they have acquired sufficient evidence. The distractors may have acted as cues that triggered participants to feel they had sufficient evidence to react faster and make a rapid decision. However, these results are contrary to other studies that found visual cues delayed response selection for visual recognition or reaction time (Souza, Rerko, & Oberauer, 2016; Ward et al., 2016). Given the increase in reaction time for trials without distractors compared to trials with distractors, and lack of significant difference between the early and late distractor types, our hypothesis of distractors having a negative impact on STM performance was supported, but in the opposite direction than originally proposed.

In regards to our hypothesis 2a which investigated delayed recognition accuracy with three STM-distractor types (none, early, late) and STM performance (correct, incorrect), results indicated significant differences based on previous STM-accuracy. Thus, our hypothesis that delayed recognition performance was dependent upon STM accuracy was supported. That is, if encoding did not occur during STM, then it was unlikely that the memory could be recognized at a later time.

To address hypothesis 2b, this study looked at the differences in delayed recognition performance as a function of previous STM performance and previous STM

distractor type. We predicted that there would be higher delayed recognition accuracy on previous STM-no distractor trials compared to other distractor types. Our analyses did not support this hypothesis, as we found no significant difference in STM-distractor type on delayed recognition accuracy (figure 5). However, there was a significant interaction between STM-distractor type and STM-accuracy on delayed recognition performance, indicating that participants were more accurate on delayed recognition trials that were previously presented as no-distractor trials in the STM task and in which the participant responded to correctly. This same response pattern that we found in both STM and delayed recognition performance is similar to results reported by Bjork and Witten (1974). They found similar interference patterns in working memory and long-term memory retrieval. It is possible that a buffer of time is necessary to recover the target stimulus into focused attention after it has been displaced by a distractor, such as in the case of the “object switch cost” (Oberaur, 2002).

Uniquely, the results indicated that as the interference-causing distractor occurs early in the delay interval, participants may have time to move the target stimulus into focused attention again before having to make a decision. It is possible that this process led to a deeper level of processing of the initial stimulus ( Craik & Lockhart, 1972; Rose & Craik, 2012). Stimuli that are encoded more deeply are recalled more accurately on delayed recall tasks (Rose & Craik, 2012; Rose, Myerson, Roediger, & Hale, 2010), indicating that deeper processing during the immediate memory task may have enabled a more stable long-term memory trace with which to guide delayed recognition performance. On the contrary, if the distractor occurred late in the delay interval, participants have less time to recover the target stimulus into focused attention before the

probe stimulus is presented and a decision must be made (Oberaur, 2002). Distracters presented late in the delay interval may have interfered with the ability to perform the template matching task, and the absence of the additional processing associated with template matching procedure may have contributed to a less stable long-term memory trace. Therefore, it is possible that successful delayed recognition performance required additional processing during the STM task in the form of a completed shift of the stimulus back into the focus of attention (i.e. early distracters) so that the effortful act of template matching could lead to a more enduring memory trace.

With respect to a possible biological basis for this phenomenon, Oztekin and colleagues' (2010) reported a similar effect in that trials with the most recent serial position were associated with the least amount of the hippocampus activation. It may be that hippocampus activation, which is widely known to be associated with LTM encoding, is associated with bringing the target stimulus back into the attentional focus prior to decision-making. Further evidence suggested that along with the hippocampus, the MTL and PFC are activated in the retrieval of both STM and LTM (Nee & Jonides, 2013). During imaging, participants were asked to perform a behavioral task that consisted of item-recognition for faces with black boxes over spaces with faces (a mask), and probes. Although their behavioral data only differentiated between items in the focus of attention and those not, the differential areas of fMRI activation between items seemingly held in the three different neuroanatomical areas such as the hippocampus, MTL, and the PFC that was previously associated with processing STM and delayed retrieval. They also reported a triple dissociation of fMRI activation patterns based on early, intermediate and recently presented items (Nee & Jonides, 2013). Although we did

not have access to neuroanatomical data in the current study, research suggests activation in these three areas may be associated with the kind of memory translation required by the current memory tasks.

Finally, Pearson product moment correlation coefficients with Bonferroni correction ( $p = .017$ ) were conducted to evaluate the relationship between accuracy and values on BVMTR performance and on matrix reasoning. There was no significant association found between BVMTR and memory performance ( $p > .17$ ). And, no significant associations were found with Matrix Reasoning and memory performance ( $p > .017$ ). These results suggest that for this sample, perceptual reasoning had limited to no association with memory performance, as assessed by the current memory paradigm and neuropsychological measures. Since no associations were found between the test measures and STM performance, it is possible that the neuropsychological tests were not related to the form of memory required by our behavior memory paradigm. A possible explanation may be that our behavioral task was capturing a different type of visual memory than that captured in these neuropsychological measures.

### **Study Limitations**

There are several limitations to this study. First, this study used archival data. As such, we were unable to include a more heterogeneous sample that would have included individuals from a variety of educational backgrounds and ethnicities, and greater balance of gender. Modifications to the behavioral task may have added another level of explanation by including additional presentation times for distractions. Extra distraction presentation times (i.e. adding a middle distraction) could provide information about

possible timeframes that memory is most at risk for interference. Further, expanding the distractor variation to include target-similar (e.g. complex visual stimuli) and target-dissimilar distraction stimuli (e.g. auditory stimuli) would have provided further details on the negative impact of distractors from different sensory modalities on memory.

Additionally, a broader neuropsychological measure of perceptual reasoning may have provided a better estimate of visual intelligence. Relying solely on Matrix Reasoning as a single measure of the perceptual reasoning domain may have made it difficult to fully assess this construct.

Furthermore, testing with the same behavioral task to assess memory patterns in children and older adults may be helpful to understand the trajectory of memory. Testing different age groups can provide information for age norms and adjusting the stimuli to reflect different complexity levels can better fit the developmental age of the participant. For example, in a child population, the stimuli may have less detail and take on a more round or smooth appearance to accommodate appropriate developmental capacities for processing visual information. As such, children before the age of 12 years old may have difficulties processing complexities in visual stimuli that are similar to faces (Tanaka, Kay, Grinnell, Stansfield, & Szechter, 1998). Although the greeble images are universally understood as complex images, reassessing the qualities and complexity of the distraction can aid in understanding the learning and retrieval of visual information. For example, testing the differences between the families of greebles may increase understanding on processing information for more complex figures versus less detailed greebles. This may lend to information about the visual memory systems and face recognition (Gauthier & Tarr, 1997).

## **Clinical Implications**

Clinical implications of our results arise from the descriptive data on a cognitive paradigm for memory in a healthy young adult population. Results from this study may suggest how to optimally address memory concerns by providing a baseline of performance from a healthy college population; however, future research in clinical populations is necessary to understand how these populations would perform. Given this study's strong focus on memory processes, data collected from the behavioral task may provide information on how memory is formed and how distractors can negatively impact memory encoding and retrieval. Our results indicated correct stimulus encoding was necessary in order to recognize information later on; therefore, initial learning/encoding into memory is important to sustain recognition at a later time. We also know that the initial environment for successful memory recognition should be free of distractors (Thomas & Hasher, 2012), especially distractors that occur just prior to decision-making. Thomas and Hasher (2012) found that distractors can be especially impairing for older adults compared to young adults. Therefore, similar to results from Thomas and Hasher (2012), we know that distraction can interfere with learning information and having a distraction free environment, especially in the later part of memory translation, may provide optimal conditions for learning. However, at this stage we remain uncertain about the impact of distractors in a clinical population with memory impairments. Future research on the role of temporal distractors on a clinical population with cognitive impairment or neuropsychological issues may provide further information on how distractors affect the kinds of memory impairment specific to different neuropsychological conditions and psychiatric disorders.

Research on specific clinical populations using our cognitive paradigm may lead to valuable information about what processes are disrupted in different conditions. For instance, if a group of patients with clinical levels of depression were to show disrupted performance on early distractor trials, we may interpret this data to indicate that individuals with depression may require a longer period of time to initially encode information. Further, based on our results, it is likely that depressed individuals will also show disrupted delayed recognition of the information as well. Similarly, if a group of clinical patients were to demonstrate worse performance on all trials that include a distractor (early and late) for both STM retrieval and delayed recognition, we may interpret this to indicate that this particular clinical population is especially susceptible to the effects of interference. This may indicate that no amount of time would allow them to pull the information back into the focus of attention. Thus, the addition of compensatory strategies early on (i.e. writing notes) may help these people rehearse the information to mitigate the effects of interference.

Further, practical applications for our cognitive paradigm for clinical populations include remembering therapeutic skills/strategies to use later in life. Encoding information to memory during a therapy session and the ability to recognize that information at a later date and location when necessary can be challenging if one has memory issues, difficulty with concentration, and emotion dysregulation. Understanding how memory impairment occurs can help clinicians to structure therapy sessions for better information recall and skill application in their patient's daily life. Moreover, additional study is recommended to determine whether memory performance during the most distracting of conditions (just prior to decision-making) can be improved with



practice. This may lead to the understanding of which types of strategies may help with mitigating the impairing effects of distractors and if strategies can apply in a clinical population to reduce switch-cost effects. Moving forward, memory compensatory strategies should continue to focus on the maintenance phase of memory and any reminders (cues) similar to the stimuli that can provide accurate and quick retrieval. Further research in memory maintenance in visual memory in a clinical population is necessary for a well-rounded informed recommendation for treatment.

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