When Remembering and Perceiving Collide:
The Effect of Visual Distraction on Long Term Memory Retrieval

A DISSERTATION
SUBMITTED TO THE FACULTY OF THE
UNIVERSITY OF MINNESOTA
BY

Xiaoyan Qin

IN PARTIAL FULFILLMENT OF THE REQUIREMENTS
FOR THE DEGREE OF
DOCTOR OF PHILOSOPHY

Advisors: Wilma Koutstaal and Stephen Engel

December 2014

Abstract

In seeking to retrieve goal-relevant information from long-term memory we face many obstacles that place demands on top-down cognitive control. Some of the obstacles are internal: there may be one or many associated mnemonic contenders for a target memory, or target memory representation may itself be weak. Other obstacles are external: our attention may be captured by environmental distracting perceptual events. Yet little is known about if, or how, these internal and external obstacles jointly influence successful memory retrieval.

In three sets of experiments, we investigated the effects of internal interference (selection demand and retrieval demand) and external perceptual distraction on long-term memory retrieval. To test the generality of the effects, and to enhance ecological validity, we examined both semantic and episodic memory retrieval, used both static and dynamic visual distraction, and employed both abstract and semantically meaningful scenes as distraction images.

For both the episodic and the semantic memory tasks, we found, in line with previous research, that as internal mnemonic competition increased, retrieval accuracy decreased and retrieval time increased, and, as the association strength between a given retrieval cue and a target memory increased, retrieval accuracy increased and retrieval time decreased. Unlike previous findings, visual distraction resulted in small effects on memory accuracy (average effect size *d* of .25), whereas it resulted in large effects on memory retrieval time (average effect size *d* of .99, average response cost of 135ms). Notably, there was little evidence

that perceptual distraction imposed greater costs when there were many internal memory contenders (high selection demand) or when the target memory was weak (high retrieval demand).

The non-interactive effects suggest a type of serial gating effect in which external perceptual versus internal mnemonic calls on our attentional resources are met successively (or alternately) rather than simultaneously. From a practical standpoint, particularly where decisions and actions need to be taken quickly, visual distraction should be minimized. Visual distraction may impede our ready and fluent access to even well-learned information, with implications for cognitive performance in contexts ranging from classrooms to emergency rooms, from creative idea generation sessions to witness testimony in legal settings.

Table of Contents

List of Tables

List of Figures

Chapter 1
Introduction

The ability to selectively retrieve goal-relevant memories is important and adaptive. A fundamental aspect of this ability is the capacity to overcome the diverse types of interference that could impede the retrieval of a target memory. The interference can arise from competing mnemonic representations: for example, irrelevant memories might actively compete for processing. Or the interference may arise from distracting environmental stimulations: for example, concurrently present but irrelevant visual stimuli may divert our attention from fully and effectively focusing on memory representations. Here I briefly review relevant literature on the topic of cognitive control of long term memory retrieval while facing both internal and external interference.

1.1 External attention vs. internal attention

Coping with internal and external interference is tightly related to how attentional resources are used. Attention is key to all perceptual and cognitive processes. It has limited capacity and it helps select, modulate, and sustain focus on information that is most relevant for behavior. It has long been considered that attention is not a unitary mechanism; rather, it is reflected in multiple systems and has been categorized into different types (Egeth & Yantis 1997; Lavie et al., 2004; Parasuraman, 1998; Pashler, 1998). Recently, Chun et al. (2011) suggested a useful taxonomy of attention based on the type of information that attention works on: external attention is the selection and modulation of sensory information in the immediate environment, and internal attention is the selection and modulation of internally generated thoughts such as the contents of working memory and long-term memory.

External attention can select and modulate information in different sensory modalities, such as vision and hearing, resulting in enhanced activation of relevant cortical areas (Johansen-Berg & Lloyd 2000; Tootell et al., 1998; Veldhuizen et al., 2007; Wager et al., 2004; Woldorff et al., 1993; Zelano et al., 2005). The independence and interaction between these systems/modalities have also been studied (Arnell & Jolicoeur, 1999; Driver & Spence, 1998; Duncan et al., 1997; Potter et al., 1998). External attention can be allocated over space or time. Spatial attention is conventionally deemed to be modulated by exogenous and endogenous cues (Corbetta & Shulman, 2002; Egeth & Yantis, 1997; Posner et al., 1980). Spatial and temporal attention share some properties though they are based on independent mechanisms (Correa & Nobre, 2008; Doherty et al., 2005). In addition, external attention can be deployed based on stimulus features or the way features are organized into objects (Scholl, 2001; Wolfe & Horowitz, 2004).

Whereas external attention selects and modulates perceptual information in the immediate environment, internal attention involves selecting and modulating internal mental representations. Similar to external attention, internal attention also has capacity limitations in the number of items that can be selected and manipulated at any given moment.

The contents of internal attention can be representations in working memory, long-term memory, task rules, decisions, and responses. Long-term memory is clearly a target of internal attention. Attention helps both long-term memory encoding and how long-term memories are retrieved (e.g., Chun & Turk-Browne, 2007; Yi & Chun, 2005). Notably, retrieval from long-term memory recruits selection processes to select specific memories from among alternative competitors (Badre et al., 2005; Ranganath et al., 2000). Selecting and retrieving one item from among competitors can result in retrieval-induced forgetting of the un-retrieved items (Anderson et al., 2004); this could be seen as an adaptive act of remembering through internal attentional operations (Kuhl et al., 2007).

1.2 The interaction between internal attention and external attention

The division of internal and external attention helps us to organize existing attention research in a way that invokes insights and new questions of how attention works. For example, it raises important questions as to whether, and to what extent, internal and external attention are independent and how they interact with each other when an individual is confronted with two tasks each requiring a kind of attention.

Indeed, the interaction between internal attention and external attention has been studied in a wide range of research. Using a dual task paradigm, several studies found that internal attention could affect external attention; for example, there is interference with visual tracking performance (errors increase and tracking is slowed) by the processing demands of learning, retention, and recall (Johnston et al., 1970; Martin, 1970; McLeod, 1973; Trumbo & Milone, 1971, but see Noble et al., 1967).

Researchers also have examined how a concurrent task that mostly requires external attention affects performance of tasks that require internal attention. Baddeley et al. (1984) conducted a series of experiments using memory learning and recall as the primary task. In one experiment, the authors used a card-sorting task (which requires mostly external attention) as the secondary task. They varied sorting load in high vs. low difficulty levels and found that the loading effect occurred during learning but not during recall. In several other experiments in this series, the researchers consistently found that a secondary task attentional load had little effect on recall accuracy but the latency was affected. The main interpretative claim made on the basis of these experiments is that, unlike memory encoding, memory retrieval is an automatic process and does not demand much attention (also see Craik et al., 1996) since the retrieval accuracy is not much influenced. Nonetheless, it is very clear that a secondary task, whether it requires mostly external attention or not, affects internal processes, as manifested by increased retrieval latency.

In a similar vein of research, researchers tested whether memory retrieval can occur in parallel with other cognitive processes (Carrier & Pashler, 1995). In their experiments, the authors used a concurrent task paradigm. Task 1 was cued recall of paired associates; task 2 was a reaction task with an auditory stimulus. Task 2 preceded task 1 with varying stimulus-onset asynchronies (SOAs). The results showed a main effect of SOA on cued recall. That is, the memory retrieval task was slowed or postponed as a result of the temporally overlapping unrelated external attention task.

The interaction between internal attention and external attention is especially clearly manifested on working memory tasks. Working memory works on internal representations, and it is at the interface between internal attention and external attention (Hollingworth et al., 2008). Research has found that working memory tasks bring interference to both internal and external attention. For example, registering and manipulating information in working memory can lead to psychological refractory effects (Jolicoeur, 1998), interference with simple spatial orienting (Dell'Acqua et al., 2006), and disruption of visual search (Han & Kim, 2004).

The approach in studying the interaction of internal and external attention is limited. Most research on the interaction of internal and external attention has used divided attention or dual task paradigms. In everyday life, when we focus on one thing (e.g., trying to recall where we parked our car today), there is not a secondary task at hand; rather, totally irrelevant and unattended sensory information is constantly present in the environment, which interferes with our current retrieval effort. Along with this scenario, Lavie's (2005) load theory provides some insights into how unattended and irrelevant information affects main task performance. The basic theory states that the amount of processing that unattended stimuli receive depends on the level of difficulty of processing the attended target. If the primary target task is easy, then leftover attentional resources will "spill over" to distractors; if, however, the primary task is very difficult, then there is not much attentional resource available to process distractors.

More importantly, task difficulty in the load theory is classified into two different kinds: perceptual load and cognitive load, which can be conceptually mapped to external attention and internal attention. Specifically, the Eriksen flanker task (Eriksen & Eriksen, 1974) is usually used in these studies in which a target is flanked by distractors that elicit competing responses. Adding more distractors increases perceptual load, resulting in a high load condition. In the high load condition, distractors are less well processed, resulting in less interference. In contrast, in the low load condition, distractors receive more processing and thus can slow target response (Lavie, 1995). Cognitive/internal load can be manipulated through increasing or decreasing the number of items in working memory or other executive processing requirements (Lavie et al., 2004). Increased central load is proposed to lead to increased distractor processing, as attention cannot be focused on the target task but spills over to distractors. It has been found that increased working memory load increased interference from distractors (de Fockert et al., 2001).

1.3 Cognitive control of memory retrieval

The ability to access and utilize goal-relevant information from long-term memory is a critical aspect of everyday behavior. Human memory can be viewed as an infinite database in which a tremendous amount of information is stored but very little of that information is needed at any given moment. Multiple forms of information, including both relevant and irrelevant representations, are activated during retrieval. In such situations, retrieval is selective (e.g., Jost et al., 2012). In such a retrieval interference situation, cognitive control is needed.

Cognitive control mechanisms allow us to guide information processing and to manipulate internal representations through sustained attention to a specific representation. Wagner (2002) suggested that memory encoding and retrieval recruit general cognitive control mechanisms. It has been thought that prefrontal cortex (PFC) is an important locus underlying cognitive control, including control of memory (Fuster, 1997; Schacter, 1987; Shimamura, 1995).

Cognitive control during memory retrieval has been differentiated into two processes in left ventral lateral prefrontal cortex (VLPFC, Badre et al., 2005). Researchers have distinguished between a controlled *retrieval* process that involves top-down control to activate goal relevant information and a post-retrieval *selection* process, which resolves competition from multiple activated representations. The biasing top-down control process favors relevant knowledge (Norman & Bobrow, 1979; Raaijmakers & Shiffrin, 1981). Beyond simply bringing information to mind, post-retrieval decisions are an important step in memory retrieval. When multiple representations are activated, a post-retrieval decision is needed to resolve competition and to select the most relevant information (Fletcher et al., 2000; Moss et al., 2005). In this line of research, competition usually means that a number of related memories are present in response to a given retrieval demand (or retrieval cue). Selection is then highly required under these conditions (Badre et al., 2005; Badre & Wagner, 2002; Fletcher et al., 2000; Zhang et al., 2004). This two-process model of left VLPFC is well supported in fMRI studies (e.g., Badre et al., 2005; Gold et al., 2006). In these studies, different subareas of left VLPFC differentially supported controlled retrieval versus selection processes. Specifically, controlled retrieval was associated with activity in a ventral and rostral portion of left VLPFC, whereas selection was approximately associated with activation in the pars triangularis of the inferior frontal gyrus (e.g., Badre & Wagner, 2007).

There is considerable debate regarding the difference between the suggested retrieval and selection stages of memory recollection; a brief review of previous studies and the debate on this topic is helpful, as it provides important insights about the cognitive control of memory.

The debate is not about the validity of the division between a retrieval and a selection stage; rather it focuses on whether a certain brain region – the left VLPFC – supports retrieval, selection, or both. One group of researchers proposed that left VLPFC resolves competition by selecting the target memory from multiple alternative representations (e.g., Thompson-Schill et al., 1997). Another group of researchers found that the left VLPFC is responsible for semantic memory retrieval when retrieval demand is high (e.g., Martin & Cheng, 2006).

A third group of researchers synthesized these two views and proposed that different subregions within the left VLPFC support controlled retrieval and post-retrieval selection (e.g., Badre et al., 2005). Yet a fourth group of researchers posited that the shared regions in left VLPFC support both selection and controlled retrieval (e.g., Snyder et al., 2011); this group also pointed out that the reason for the inconsistency of previous findings might arise from an invalid operationalization of both selection and retrieval demands.

1.4 Retrieval demand and selection demand

The interference between mnemonic representations depends on different factors, such as the number of competing memories and the associative strength between the retrieval cue and a target memory. The “fan effect” is a well-established illustration: as the number of facts about a particular concept increases, the time to retrieve any given fact also increases (Anderson & Reder, 1999). This effect could arise because association strengths between concepts and facts decrease (Anderson & Reder, 1999) and competition between representations increases (Radvansky, 1999). In addition, the interference can manifest its effect in different stages of memory retrieval. For instance, it is suggested that the associative strength between the retrieval cue and the target memory influences *retrieval* demands, whereas the number of memories associated with a cue and the potency of retrieved competitors are more likely to affect *post-retrieval selection* demands.

Association strength is the connection strength between a cue and a target memory. A cue can associate with many memory traces or a given memory could have more than one cue associated with it, each with a different strength. According to the controlled retrieval hypothesis, cognitive control comes into play when it is difficult to retrieve a response from semantic memory, requiring effortful, controlled retrieval (Martin & Cheng, 2006; Wagner et al., 2001). To provide a concrete example, in a verb generation task, participants are asked to generate possible actions that could be associated with a given noun (e.g., in response to the noun “dog”, we might say “feed” or “walk”). Response times to generate a verb for a given noun are affected by association strength: when the connection between the verb and the noun is weaker, it takes longer to generate the verb (Martin & Cheng, 2006).

One thing clear from the research on cognitive control of memory is that to retrieve a goal-relevant memory, a selection process is in action to select the target from amidst the competitors. High selection demand often impairs our ability to retrieve target memories. Behaviorally, greater competition (i.e., higher selection demand) is associated with longer retrieval/reaction times (e.g., Badre et al., 2005; Snyder & Munakata, 2008; Snyder et al., 2011; Sohn et al., 2003), and higher error rates (e.g., Badre et al., 2005, Sohn et al., 2003). Neurophysiologically, greater competition elicits higher activation in left VLPFC (more specifically, left mid-VLPFC; Badre et al., 2005), or more broadly, higher activity in prefrontal regions including both VLPFC and dorsolateral prefrontal cortex (DLPFC, which might be important for monitoring or evaluation of retrieved information during source memory; Sohn et al., 2003). This interference resolution function by the prefrontal regions seems to be found across memory domains (e.g., semantic memory, working memory, source memory). Importantly, Sohn and colleagues showed that the prefrontal region activity tracked the level of competition.

If not carefully controlled, the degree of competition (selection demand) and association strength could be confounded with each other, making the effect of each factor harder to show (e.g., Badre et al., 2005; Nathaniel-James & Frith, 2002; Persson et al., 2004; Thompson-Schill et al., 1997). To overcome this, Snyder and Munakata (2008) used latent semantic analysis (LSA) to provide un-confounded measures of association strength and competition. LSA is a technique for extracting the similarity of words and passages by analyzing large bodies of text, capturing contextual as well as co-occurrence information (Landauer et al., 1998). Measures based on LSA consistently outperform co-occurrence alone in predicting human data (Landauer et al., 1998), including recall from semantic memory (Griffiths et. al., 2007). LSA provides a powerful tool to provide purer measures of both association strength (LSA strength) and competition (LSA ratio and entropy). In their initial study, Snyder and Munakata (2008) found independent effects of association strength and competition. In a follow-up study (Snyder et al., 2011), the authors investigated the neural basis of selection and controlled retrieval using un-confounded LSA-based measures of competition and association strength. Their findings showed that the same regions of left VLPFC support both selection and controlled retrieval.

1.5 Visual distraction and memory retrieval

As alluded to earlier, interference may arise not only from competing internal memories, but also can arise from external environmental distractors. When trying to retrieve a target memory, current environmental perceptual stimulation can interfere. Although the competition problem is often studied in the context of internal mnemonic representations, there is growing interest in investigating the influence of irrelevant visual distraction on long-term memory retrieval.

Some recent studies found that irrelevant environmental stimuli impair subjects' ability to accurately recall visual details (e.g., Wais et al., 2010). In this research (Wais et al., 2010), participants were asked to either close their eyes or to keep their eyes open while irrelevant visual stimuli were presented during an episodic retrieval task. During the encoding phase, participants were shown 168 different object images, but each image was shown with one to four copies of the same object (e.g., the display might show just 1 pumpkin, or 2, 3, or 4 copies of the pumpkin might be shown). In the retrieval phase, subjects were asked to recall the count of the object – as prompted by an auditory cue – pressing "1", "2", "3", "4", or "new" to indicate their response, in conditions when their eyes were closed, they were looking at a gray screen, or they were looking at pictures of outdoor scenes. Subjects recalled less accurately when their eyes were open compared to when their eyes were closed. This effect was replicated in an fMRI study, where the visual distraction effect on memory accuracy was attributed to disrupted connectivity in a network including the left inferior frontal gyrus, hippocampus, and visual areas. The results suggested that the bottom-up visual information interfered with the top-down selection of mnemonic representations. Furthermore, this group of researchers demonstrated that the functional perturbation of the left VLPFC by repetitive transcranial magnetic stimulation resulted in an exacerbated disruptive effect of the irrelevant visual interference on memory recollection (Wais et al., 2011). These studies suggest that the left VLPFC, or more broadly, the prefrontal regions, which were implicated in studies of memory competition/selection to resolve interference among mnemonic representations, may also be important to resolve interference during memory retrieval that arises from irrelevant external visual information. Here the selection process acts on internally directed information vs. the external perceptual world.

Investigators tested the visual distraction effect on recollection of relevant details in older adults (Wais et al., 2012). Using the same paradigm as in their previous study with younger adults (Wais et al., 2010), the authors asked older adults to recall visual details of previously viewed pictures when their eyes were closed, open and looking at a gray screen, or open and looking at irrelevant visual stimuli. The results indicated that the irrelevant visual information disrupted memory retrieval performance in older adults. Compared to the younger adults, visual distraction disrupted recollection of relevant details more in older adults. This result suggests that memory recollection in older adults is more likely to be distracted by the concurrent presence of irrelevant visual information.

External distraction could arise from different modalities such as visual, auditory, and manual domains. Indeed, investigators expanded the investigation of the influence of visual distraction on memory retrieval to explore the effect of distraction in another modality: that of auditory information (Wais & Gazzaley, 2011). The authors asked participants to recognize the previously viewed images (task-relevant visual details) in three conditions. In one condition, white noise was presented during retrieval; in another condition, ambient sounds recorded at a busy café (auditory distraction) were used; in the control condition, no sounds were presented during the memory task (complete silence). The results revealed that participants in the auditory distraction condition recalled fewer goal-relevant details than participants in the silence and white noise conditions. The authors also compared results when using visual distractors with those observed under auditory distraction and found that the detrimental memory effects of visual and auditory distraction were equivalent. Based on these results, the authors suggested that the influence of distraction on retrieval of visual details is independent of the sensory domain of the distractor and that disruption of episodic retrieval by environmental distractions is the result of interference with *domain-general cognitive control processes*.

The effect of external distraction on internal processes has also been studied in experiments on the "eye closure effect." Indeed, this effect can be readily observed in everyday life. When we have a difficult task at hand, we often spontaneously close our eyes or look away to try to focus more closely on the primary task (Doherty-Sneddon & Phelps, 2005; Glenberg et al., 1998; Longbotham & Doyle, 2002). It has been found in many studies that participants' performance of cognitive tasks was improved when they closed their eyes or moved their gaze away from the experimenter's face (Doherty-Sneddon et al., 2001; Glenberg et al., 1998; Markson & Paterson, 2009; Phelps et al., 2006).

Eye closure may improve memory for everyday events. Compared with eye-open conditions, eye closure improved memory for both live and videotaped events (Perfect et al., 2008). Other work has shown that eye closure helped reduce false memories and to increase the number of recalled details for a staged event compared to a noisy condition (Andrade & Eagan, 2011; Vredeveldt & Penrod, 2013). Mastroberardino, Natali, and Candel (2010) tested children's memory of an emotional event and discovered that when children closed their eyes they generated more correct responses to questions about the event than those whose eyes were open. In a similar study, researchers found that children recalled more correct and fewer incorrect visual details when they were in the blank-screen and eye closure condition than in the visual and auditory distraction conditions (Mastroberardino & Vredeveldt, 2014).

The eye closure effect has also been investigated in eyewitness memory. Vredeveldt, Baddeley, and Hitch (2011) investigated testimony memory for a violent event. They interviewed 80 eyewitnesses under different types of distraction conditions: blank screen (control), eyes closed, visual distraction, and auditory distraction. The authors found that recall was better when distraction was minimal. This supported the notion that eye closure can reduce cognitive load in a domain general fashion. In addition, the authors compared the distraction effects produced by visual and auditory modality stimuli and revealed that visual distraction diminished recall of visual details more than recall of auditory details and that auditory distraction was more likely to disrupt recall of auditory details. This latter finding was deemed to support the *modality-specific* interference hypothesis (Wagstaff et al., 2004).

Despite these findings pointing to the detrimental effects of concurrent environmental distraction on memory retrieval, several important theoretical and empirical questions and limitations remain unaddressed. First, given that there are demonstrated costs of both external interference and of internal interference on memory retrieval, what are the effects of their *combined* presence? Are there differentially greater retrieval costs when a to-be-retrieved memory is weak or has many related competitors? Or are the costs of external perceptual distraction largely constant, regardless of the strength of the target memory and the uniqueness of the retrieval cues? Second, are the costs of external interference observed only on retrieval accuracy, or are there also, or instead, costs associated with the latency or speed of retrieval? Although, as reviewed above, some investigators have found detrimental effects of visual distraction on memory retrieval accuracy (e.g., Wais et al., 2010, 2011), other studies did not find such costs on accuracy (e.g., Rae & Perfect, 2014), but did not examine retrieval time. In fact, retrieval time may be a more sensitive measure (Baddeley et al., 1984). Third, several of the prior studies of visual distraction only looked at recall of a comparatively narrow and specific form of perceptual detail (count of objects on the screen, e.g., Wais et al., 2011) on episodic memory. It will be important to also look at other forms of detailed information and use other forms of memory. Fourth, while closing eyes has proved to be an effective way to avoid visual processing and to be beneficial to cognitive performance, it should be noted that eye closure may introduce problems as an experimental manipulation. Eye closure is not always feasible in everyday situations where we must continue to monitor the immediate environment while retrieving memory contents. In addition, besides eliminating visual distraction, closing one's eyes may elicit other differences in comparing a distraction condition with an eye closure condition. For instance, eye closure may allow greater contextual or emotional reinstatement. These differences may be undesirable, as they will make it difficult to determine the unique effects of perceptual distraction. Based on these considerations, it is highly desirable to use a condition that is maximally close to the distraction condition yet is made of a neutral perceptual content.

In the current study we address each of these questions and limitations. First, we will for the first time examine the joint effects of internal and external interference on cognitive performance. For episodic memory, we use a systematic manipulation of association strength and a parametric manipulation of selection demand together with perceptual distraction; for semantic memory, we use an independent manipulation of both association strength and retrieval competition together with perceptual distraction. Second, we will examine both memory accuracy and memory retrieval time. Third, to test the generality of the effects of visual distraction, we will explore both episodic memory, probing memory for both specific perceptual detail and categorical information of specific spatiotemporal events, and a semantic memory task, involving retrieval of longer-term conceptual knowledge. Additionally, in separate experiments we explore the effects of both static and dynamic visual distraction, and employ both abstract and semantically meaningful scenes as distraction images. Fourth, to overcome the reinstatement and other confounds introduced by eye closure, we will compare a distraction condition with a neutral gray screen in our experiments.

1.6 Present work

In the present research, we will explore the interaction between external attention and internal attention by examining the effects of irrelevant visual distraction on long-term memory retrieval. Here I will briefly overview the studies we conducted on this topic.

In Experiment 1, we manipulated the selection/competition demand in three levels and the distraction in two levels (distraction vs. gray screen) to study the effect of both mnemonic interference and irrelevant visual distraction on an episodic memory retrieval task. We found that as mnemonic competition increased, the retrieval accuracy decreased and response time increased. The visual distraction also slowed retrieval time, but had little effect on retrieval accuracy.

In Experiment 2, we manipulated the retrieval demand (association strength) in two levels and the visual distraction in two levels in an episodic memory task. We found that as association strength increased, the retrieval accuracy increased and response time decreased. The visual distraction slowed down the retrieval time, but had little effect on retrieval accuracy.

In Experiment 3, we used a semantic memory task with an existing manipulation of selection demand and association strength. The irrelevant visual distraction was also manipulated in two levels. Both selection demand and association strength had similar effects on response time as found in previous experiments with episodic memory. And participants took longer to respond in the visual distraction condition.

The current research will refine our knowledge about the relationship between memory retrieval under different contexts, with different levels of mnemonic competition and association strength and various forms of perceptual distraction. It thus can help to address a fundamental theoretical question about how cognitive control operates in the face of internally arising challenges in combination with externally arising challenges to successful memory recollection. Given that memory retrieval in the face of perceptual distraction relates to situations that everyone experiences and that there is relatively little direct research on this topic, this research could have wide applications, especially in educational and legal domains.

Chapter 2
Experiment 1: The effect of visual distraction on episodic memory retrieval with a manipulation of selection demand

2.1 Introduction

In this series of experiments, the aim was to investigate the effects of selection demand and visual distraction on episodic memory retrieval performance. We used the paired-associate paradigm in an episodic memory task. Unlike previous studies, we parametrically manipulated the selection/competition demand in three levels and distraction status in two levels. Also, the recognition of the distraction images was later tested to assess to what degree participants attended to the irrelevant distractors and whether the recognition of the distractor images was dependent on the selection demand level. We hypothesized that as the selection demand increased, the retrieval performance would be worse, and the visual distraction would also decrease the retrieval performance. Previous research has not studied the joint effects of internal interference and external distraction. We hypothesized that if sources of internal and external interference exert separate or serial effects on memory retrieval accuracy or time, then we would observe slight to no interactive effects of the two types of interference. Alternatively, we would observe an interactive effect.

2.2 Experiment 1a

In this sub-experiment, we first asked participants to study pairs of names and accompanying images in five blocks. A name could be paired with one type of image, two types of images, or three types of images, resulting in three selection (competition) levels. Then in a retrieval phase, participants were asked to recall the type of image that was associated with a given name. In the control condition, participants attempted to recall the learned association while presented a gray background screen (no distraction condition). In the experimental condition, a static full-screen image, depicting repeated instances of an unfamiliar abstract object, was presented during retrieval (visual distraction condition). Most previous studies used familiar environmental stimulation or concrete scene objects as visual distraction. In this experiment, we used unfamiliar abstract object images as visual distraction because 1) from an ecological point of view, there are abstract objects in the environment that could become visual distraction to our primary task in everyday life and 2) we can learn how the abstract visual distraction affects memory retrieval when there is minimum overlap between the content of visual stimulation and the content of the to-be-recalled memory.

2.2.1 Methods

2.2.1.1 Subjects

Twenty-five University of Minnesota students (age range 18-23, mean age = 19.28 (SD=1.28), mean years of education = 13.72 (SD=1.12), 7 male) took part in this study for extra course credit. In this and all following experiments, all participants were native English speakers with normal or corrected-to-normal vision, and all were screened for depressive symptoms that could affect their cognitive and memory performance using the Brief Symptom Inventory (BSI, Derogatis & Melisaratos, 1983). In this and all following experiments, informed consent was obtained from all participants in accordance with the University of Minnesota Institutional Review Board. In the current experiment, two additional students participated but their data were excluded from the analyses because one had a high score on the depression subscale of the BSI (score greater than 11) and the other was not a native English speaker.

2.2.1.2 Stimuli and materials

One hundred and sixty-eight color images of faces (Minear & Park, 2004), objects, and houses were used. Each type of image consisted of 4 subtypes. For faces, there were images of male and female students (young adults) and male and female middle-aged adults. For objects, there were images of tables, chairs, lamps, and sofas. For houses, there were A-frame, castle, ranch, and modern types. There were 14 pictures of each subtype. Each image was shown at 320 x 240 pixel resolution.

We selected 96 first names that were highly common in the 1990s (see table 2-1) from http://www.ssa.gov/oact/babynames/decades/index.html. Half of them were female names, half were male names.

The distraction images consisted of 105 abstract color images that depicted an unfamiliar abstract object with multiple parts. The images were selected from the stimuli used in Koutstaal et al. (1999). Each abstract image was repeated 8 times, in identical format, on a gray background and was at 1024 x 768 pixel resolution (see figure 2-1).

Table 2-1. The ninety-six names used in Expt. 1a.

Name	Gender	Name	Gender
Emily	Female	Jonathan	Male
Anna	Female	Nathan	Male
Christina	Female	Edward	Male
Ashley	Female	Alex	Male
Courtney	Female	Christopher	Male
Rachel	Female	Brian	Male
Leah	Female	Robert	Male
Elizabeth	Female	Aaron	Male
Amy	Female	Sean	Male
Melissa	Female	Logan	Male
Erin	Female	Joshua	Male
Taylor	Female	Benjamin	Male
Nicole	Female	William	Male
Shelby	Female	John	Male
Kimberly	Female	Richard	Male
Amber	Female	Scott	Male
Molly	Female	Mark	Male
Victoria	Female	Patrick	Male
Tiffany	Female	Kevin	Male
Kayla	Female	Dylan	Male
Jessica	Female	Jordan	Male
Mary	Female	Jacob	Male
Rebecca	Female	Paul	Male
Jenna	Female	Matthew	Male
Allison	Female	Eric	Male
Kelsey	Female	Michael	Male
Brittany	Female	Jeremy	Male
Julia	Female	Austin	Male
Olivia	Female	Joseph	Male
Jennifer	Female	Anthony	Male
Heather	Female	Shane	Male
Samantha	Female	Luke	Male
Amanda	Female	Andrew	Male
Katherine	Female	Timothy	Male
Lauren	Female	Peter	Male
Kelly	Female	Isaac	Male
Michelle	Female	James	Male
Megan	Female	Justin	Male
Brianna	Female	Jason	Male
Chelsea	Female	Stephen	Male
Abigail	Female	David	Male
Haley	Female	Brandon	Male
Erica	Female	Dustin	Male
Paige	Female	Daniel	Male
Sarah	Female	Ryan	Male
Stephanie	Female	Cody	Male
Monica	Female	Ian	Male
Natalie	Female	Nicholas	Male

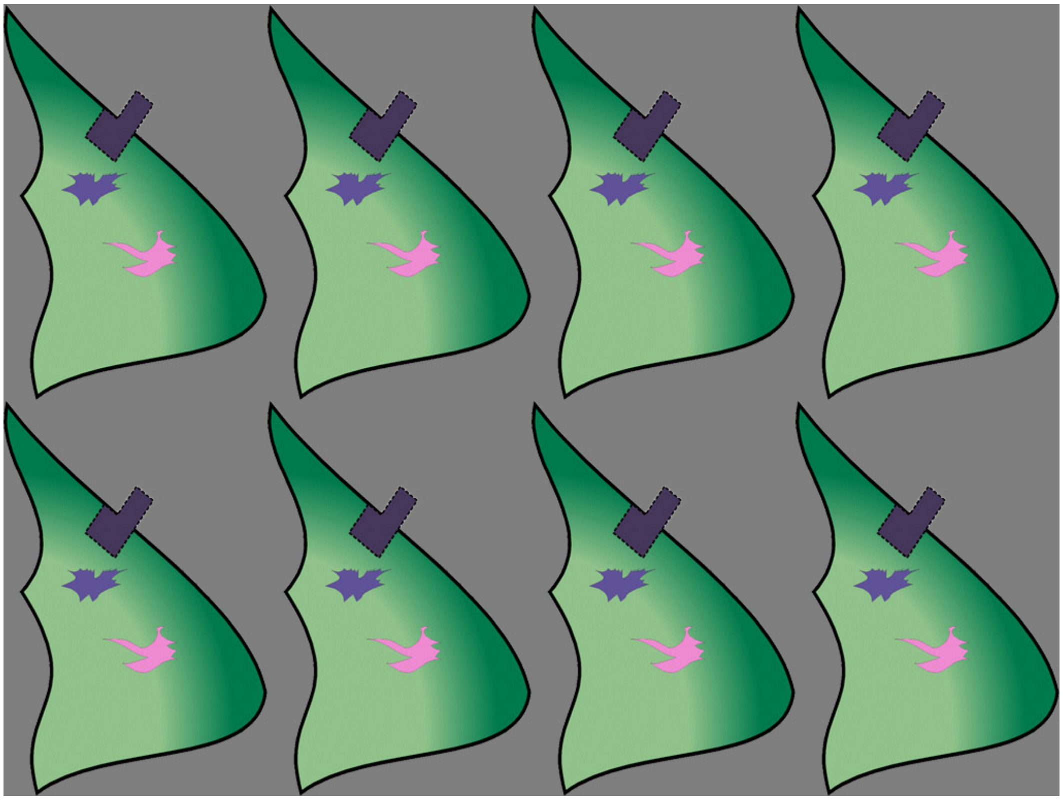

Figure 2-1. A sample abstract distractor image in Expt. 1a.

The episodic memory task consisted of a study and a retrieval phase. In the study phase, we manipulated the selection/competition level (i.e., the number of competitors) in three levels. In selection level 1, each of the 48 names was paired with a unique image, resulting in 48 trials. In these 48 trials, each type of image (i.e., face, object, house) was used 16 times, and each subtype of image was used 4 times, without repetition. In selection level 2, each of the 24 names was paired with two different images (2 competitors), one at a time, resulting in 48 trials. In this level, for counterbalancing purposes, 8 names were paired with a face and an object image, 8 names were paired with a face and a house image, and the last 8 names were paired with an object and a house image. Each subtype of image was used 4 times without repetition. In selection level 3, each of the 24 names was paired with 3 different images (3 competitors; one of each type), one at a time, resulting in 72 trials. Each subtype of image was used 6 times without repetition. In all levels, female and male names were assigned equally often to each image subtype. All images were unique.

There were 168 trials during study. In each trial, a name appeared in the center of the screen and the associated image was displayed in one of four positions around the name (i.e., on the top, to the right, on the bottom, or to the left of the name). The four positions were used equally often within each selection level.

During retrieval, participants were shown the names only and were asked to recall what type of image had been associated with the name during the study phase (i.e., a face, object, or house) at a specific cued position, as indicated by the words “left”, “top”, “right”, or “bottom” (see Figure 2-2). There were a total of 210 trials, of which 168 trials were experimental trials and 42 were catch trials (in a catch trial, the image had never appeared at study in the designated position for a given name). For half of the trials, a distraction image appeared as a static background while participants were attempting to recall the associated type of image (see Figure 2-2 left). Each of these trials had a unique distraction image. For the other half of the trials, a gray background appeared; these were the control trials (see Figure 2-2 right).

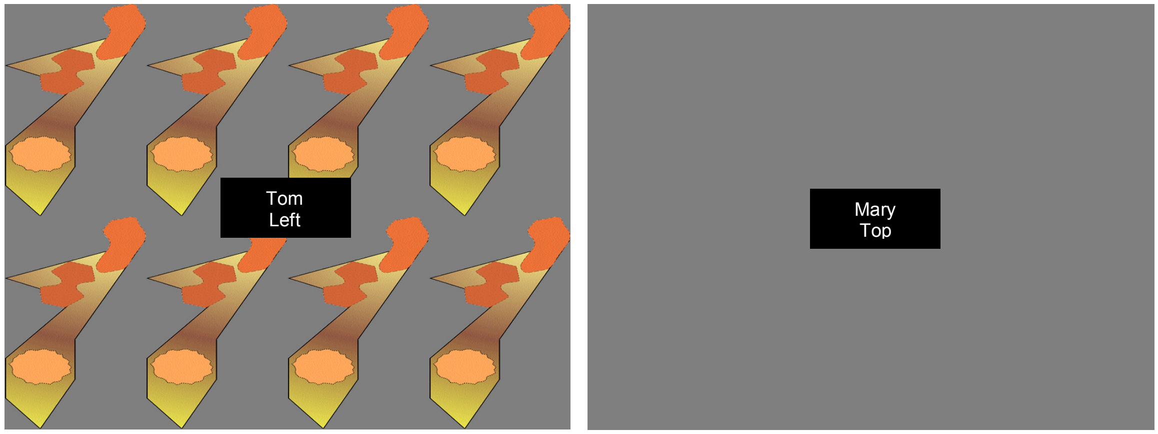

Figure 2-2. Two sample trials in the retrieval phase of Expt. 1a. Left, a sample distraction trial. Right, a sample non-distraction trial.

2.2.1.3 Procedure

All participants were tested individually. Participants were given written instructions to read and paraphrase before each task. In the study phase, there were five encoding blocks with the same 168 trials in each but presented in a newly randomized order each time. Participants were told to attend carefully in each trial.

During the first three encoding blocks participants were asked to passively view and covertly study the association between each name and accompanying image. In each trial, a name appeared in the center of the screen. At the same time, an image appeared in one of the four possible positions. Specifically, the image could be presented to the left of the name, at the top of the name, to the right of the name, or at the bottom of the name. Only one image appeared in each trial. Participants were asked to make associations and form a pair of information when the name and the image appeared, using the following strategy: If they saw a face, they were to say silently, “xx knows this face/person”; if they saw an object, they were to say silently, “xx likes this object”; if they saw a house, they were to say silently, “xx visits this house”, where “xx” indicates the name they would see on the screen. During the first and the second block, the stimuli appeared on the screen for 3 sec, and the inter-trial interval (ITI) was 250ms. During the third block, the stimuli were displayed for 2 sec, and the ITI was 250ms.

During the fourth and fifth study block, participants were asked to vividly think about the image that had earlier been associated with each name before they saw the actual image. In each trial, a name appeared in the center of the screen along with an empty box/frame in one of the four positions (left, top, right, and bottom). During this time, participants were asked to actively generate the image that they had earlier learned in the corresponding position of the box/frame for that name. After 2 seconds, the correct image was presented in the position of the box/frame. After the actual image was presented, participants made a response to indicate the type of the presented image, pressing “1” if it was a face, “2” if it was an object, and “3” if it was a house. Participants had 2 seconds to respond after the image appeared in the box/frame. They were told to re-study the pair when they saw the actual image if they had generated the wrong image in their mind before the correct image appeared. There was pause after each block of the encoding phase and participants were encouraged to take a brief break at that time.

After the encoding phase, participants completed a filler task to prevent possible rehearsal of the studied materials. In the filler task, they were asked to count backwards from 300 by 7's. The task took about 1 min for most of the participants.

After the filler task, participants read and paraphrased the instructions for the memory retrieval task. In this task, they were asked to recall the associations that they had studied before the counting task. In each trial, a name was presented in the center of the screen and a position word (i.e., the word "left", "top", "right", or "bottom") was presented directly beneath the name. To ensure that participants could clearly see the name and the position word, especially during the distracting trials, both the name and the word were presented in white font in a solid black box. This was done for all subsequent experiments. On each trial, participants were asked to recall what type of image was presented in the designated position for that name in the study phase. They were asked to vividly recall the image and to indicate their response by pressing "1" if they thought a face had been shown in that position for that name, "2" if they thought an object had been shown in that position for that name, "3" if they thought a place/house had been shown in that position for that name, "4" if they thought there was nothing in that position for that name (if it was a catch trial, the correct answer would be 4), and "5" if they could not remember anything. To prevent participants from using strategies to avoid the visual distraction, it was emphasized that they should not try to close their eyes or attempt to look away while recalling the associated images and that their attention should be fixated on the screen all the time. Participants were given a maximum of 10 sec to respond to each trial.

A brief post-experimental questionnaire was used to ask participants: (1) the percentage of time they believed they had generated the correct type of image (i.e., a face, object, or house) during the last two study blocks, and (2) how often they believed they had recalled the type of image correctly during the retrieval task.

To test participants' memory of the distraction pictures, a recognition memory task was administered at the end. In this task, participants were asked to recognize the background images they were shown during the memory retrieval task. Half of the images were old, that is, they had been presented as distracting images in the previous task; others were new, that is, they had not appeared in the previous task. The non-studied lure images were selected from the same general set of images from where the target images were chosen. Thus, the lures and targets were very similar in terms of shape or form. In each trial, participants were shown an image and were asked to answer the question "Did you see this image?" by pressing "1" for the answer "Yes, it is old" and pressing "2" for the answer "No, it is new". In each trial, an image appeared for a fixed time of 3 sec. There were 210 trials in this task.

Participants were debriefed and thanked before they left the testing room.

2.2.2 Results

Figure 2-3 left panel shows retrieval accuracy as a function of competition level and distraction status. In all analyses, catch trials and "don't know" trials were excluded. From Figure 2-3 we can see that, as competition increases, retrieval accuracy decreases. The distraction appears to have little to no effect on accuracy. A 3 (competition level: 1, 2, and 3) x 2 (distraction status: distraction and non-distraction) repeated analyses of variance (ANOVA) showed that the effect of competition was significant, $F(2, 48) = 17.77$, $p < .001$. The main effect of distraction was not significant, $F(1, 24) = 0.95$, $p = 0.34$. There was no competition level x distraction level interaction, $F < 1$. In addition, there was a significant linear effect of increasing selection demand, $F(1, 24) = 27.79$, $p < .001$.

Figure 2-3 right panel shows the retrieval response time as a function of competition level and distraction status. In this analysis, catch trials and "don't know" trials were excluded, and only the accurate trials above 400ms and within 3 standard deviations of the condition mean were used. We can see that as competition increases, the retrieval time also increases, and overall the distraction condition takes longer than the non-distraction condition. A 3 x 2 ANOVA revealed a main effect of competition, $F(2, 48) = 6.73$, $p = 0.003$. The main effect of distraction was not significant, $F(1, 24) = 2.15$, $p = 0.16$. The interaction was not significant, $F < 1$. In addition, there was a significant linear effect of increasing selection demand, $F(1, 24) = 11.57$, $p = .002$.

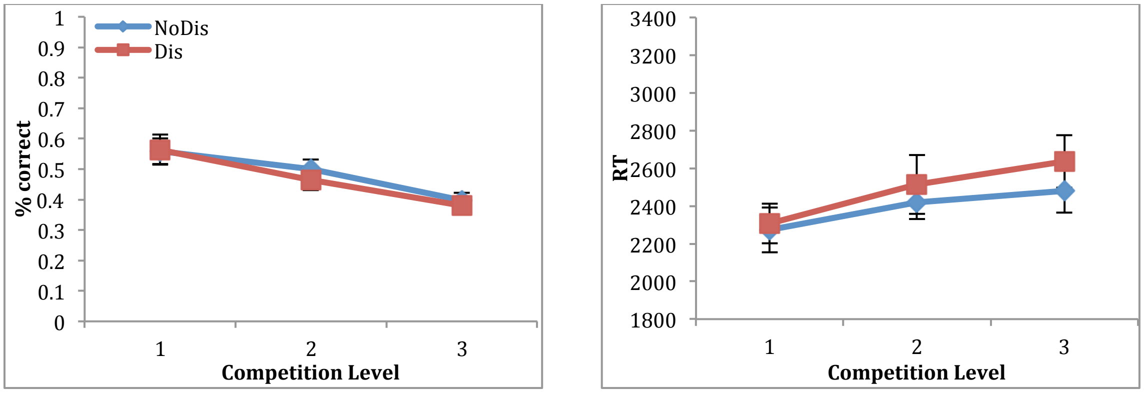

Figure 2-3. Retrieval accuracy (left) and retrieval time (in ms, right) in Expt. 1a.

Figure 2-4 left panel shows the accuracy data for the recognition task as a function of whether the item was new (that is, lure items) or in which of the three competition levels the distraction image had earlier appeared. We used false alarm rates for lures. An analysis that compared false alarm with the mean hits of the three conditions found no significant difference, $t(24) = -0.85$, $p = 0.40$. This indicates that memory of the distractor images was not above chance. Figure 2-4 right panel shows the response times during the recognition task, similarly as a function of whether the item was new or had earlier appeared in each of the three retrieval competition levels. A one-way ANOVA revealed no significant difference between conditions, $F(3, 72) = 1.69$, $p = 0.18$.

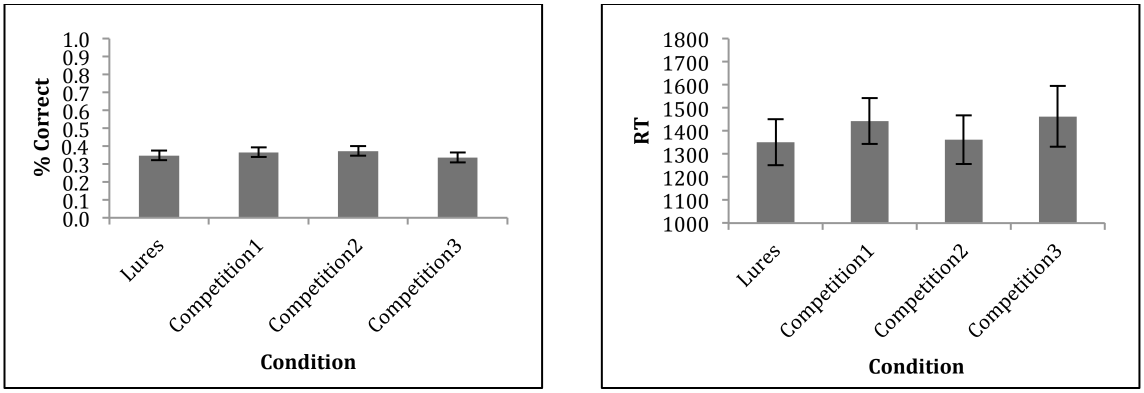

Figure 2-4. Recognition accuracy (left) and response time (in ms, right) in Expt. 1a.

2.3 Experiment 1b

In this sub-experiment, we used a very similar design as in Experiment 1a with some refinements. Participants in Expt. 1a often asked the number of tasks and the length of the experiment during the experiment, due to the relatively long session. We informed participants of the length and structure of the whole experiment in this experiment so they could have a reasonable expectation. Because some participants took longer than others to complete the filler task, we now limited the duration of the filler task to 1 min to equate everyone's time spent between the study phase and recall phase. Finally, to reduce task complexity, we dropped the catch trials during the retrieval phase.

2.3.1 Methods

2.3.1.1 Subjects

Twenty-four University of Minnesota students (age range 18-29, mean age = 19.67 (SD=2.28), mean years of education = 13.81 (SD=1.40), 7 male) took part in this study for extra course credit. All were screened with the same criteria as in the previous experiment.

2.3.1.2 Stimuli and materials

The stimuli were the same as in Expt. 1a. To reduce task complexity, we dropped all catch trials, thus there were 168 trials in total during the retrieval phase.

2.3.1.3 Procedure

All participants were tested individually. The procedure was the same as in Expt. 1a except a few minor changes. First, since it was a long experimental session and it involved several different parts, to provide participants with a better overview of what they would expect, we explicitly informed participants at the outset how many parts there would be. Second, although most subjects could complete the filler task in about 1 min, some people took longer than that. To ensure that there was a consistent interval between the study and the retrieval phases across subjects, we timed 1 min for every subject in this task and asked participants to stop after 1 min. Third, since there were no catch trials, there were four rather than five response options during the retrieval task. Participants were asked to vividly recall the image that had been associated with each name and to indicate their responses by pressing “1” if they thought a face had been shown in that position for that name, “2” if they thought an object had been shown in that position for that name, “3” if they thought a place/house had been shown in that position for that name, and “4” if they could not remember anything.

2.3.2 Results

Figure 2-5 left shows retrieval accuracy as a function of competition level and distraction status. As in Expt. 1a, “don’t know” trials were excluded. The data show that as competition increases, retrieval accuracy decreases. The distraction has a slight effect on accuracy, especially for competition level 1 and 3. A 3 x 2 repeated ANOVA showed that the main effect of competition was significant, $F(2, 46) = 24.95$, $p < .001$. The main effect of distraction was not significant, $F(1, 23) = 0.45$, $p = 0.51$. The interaction between the two factors was significant, $F(2, 46) = 4.02$, $p = 0.03$, mainly due to the relatively larger difference between the distraction and non-distraction condition at competition level 2. In addition, there was a significant linear effect of increasing selection demand, $F(1, 23) = 35.11$, $p < .001$.

Figure 2-5 right shows the retrieval response time as a function of competition level and distraction status after removing “don’t know” trials and retaining only the accurate trials above 400ms and within 3 standard deviations of the condition mean. We can see that as the competition level increases, the retrieval time also increases, and that retrieval in the distraction condition takes longer than retrieval under non-distraction. A 3 x 2 repeated ANOVA showed a main effect of competition level, $F(2, 46) = 12.30$, $p < 0.001$, and a marginally significant main effect of distraction, $F(1, 23) = 3.65$, $p = 0.069$. The interaction was not significant, $F < 1$. In addition, there was a significant linear effect of increasing selection demand, $F(1, 23) = 19.05$, $p < .001$.

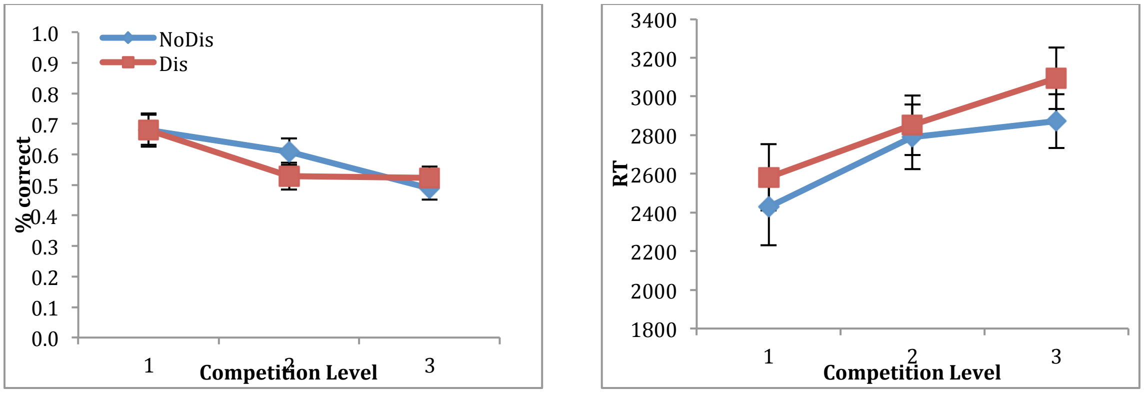

Figure 2-5. Retrieval accuracy (left) and retrieval time (in ms, right) in Expt. 1b.

Figure 2-6 left shows the accuracy data for the recognition task as a function of whether the item was a lure or was presented as a distraction image under each of the three levels of retrieval competition. We used false alarm rates for lures. An analysis that compared false alarm with the mean hits of the three conditions found no significant difference, $t(23) = 0.04$, $p = 0.97$. This indicates that memory of the distractor images was not above chance. Figure 2-6 right shows response times in the recognition task as a function of image condition. No significant results were found in a one-way ANOVA, $F < 1$.

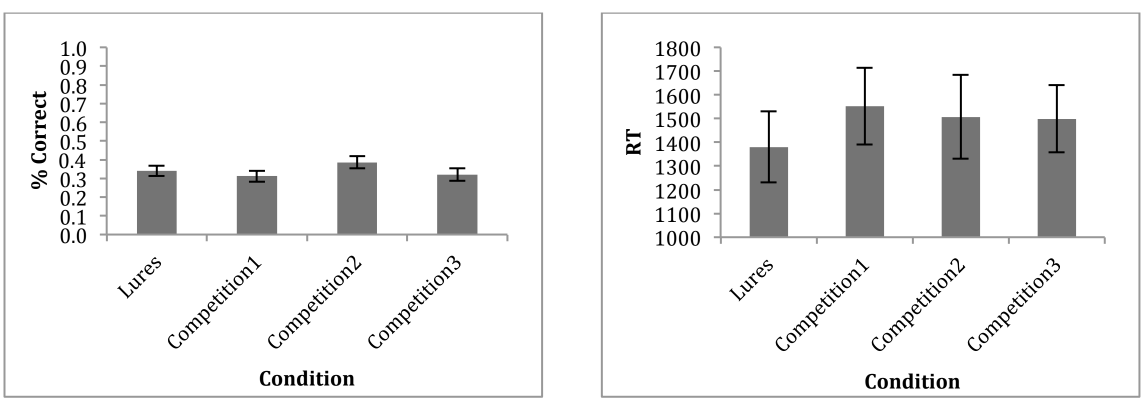

Figure 2-6. Recognition accuracy (left) and response time (in ms, right) in Expt. 1b.

2.4 Experiment 1c

In this sub-experiment, we used a very similar design as in Experiment 1b. Based on the load theory, recognition of the distractors might be dependent on the level of processing in a primary task. However, there was extreme similarity between the targets and lures in the recognition task in Expt. 1a and 1b and the recognition performance was low. This may prevent us from seeing any effects of selection demand level on distractor processing. Thus, in this experiment, in a hope to boost recognition accuracy, we rotated lures either 90 or 180 degrees so that they became more distinctive from the targets. In addition, only three response options were used during retrieval; to further simplify the task demands and the response mappings, the "do not remember" response option was eliminated and participants were asked to provide their best answer even if they were not sure.

2.4.1 Methods

2.4.1.1 Subjects

Thirty-two University of Minnesota students (age range 18-28, mean age = 20.44 (SD=2.59), mean years of education = 14.23 (SD=1.51), 13 male) took part in this study for extra course credit. All were screened with the same criteria as in the previous experiments. Data from three additional students were excluded because one had a high depression subscore on the BSI (greater than 11), one did not meet our age inclusion criterion (criterion: 18-30; the participant was aged 52), and one fell asleep during the experiment.

2.4.1.2 Stimuli and materials

The stimuli were the same as in Expt. 1b except that in the recognition task, we visually rotated the non-studied lure items either 90 or 180 degrees (see Figure 2-7). By doing this, the lures were rendered more visually distinct from the previously presented (“old”) distraction images. We hoped this would boost recognition performance.

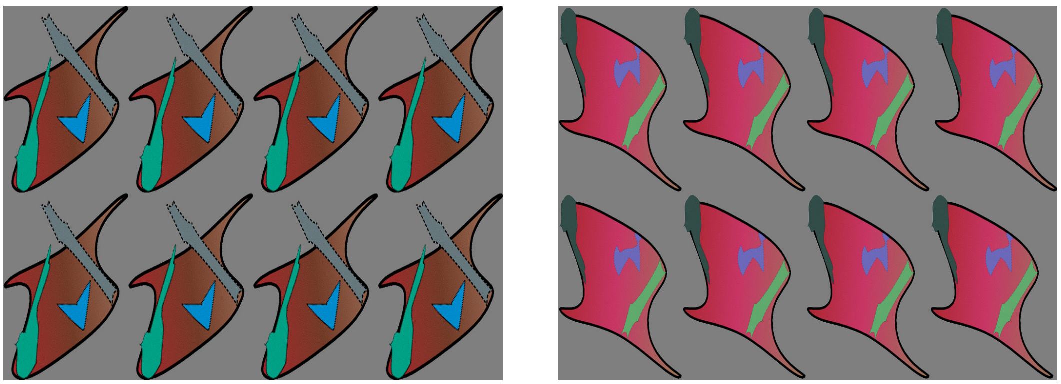

Figure 2-7. A sample target distractor image (left) and a sample rotated lure image (right) from the recognition task.

2.4.1.3 Procedure

All participants were tested individually. The procedure was the same as in Expt. 1b except that the “do not remember” response option was omitted from the retrieval phase, leaving only three response options. Participants were asked to press “1” if they thought a face had been shown in that position for that name, “2” if they thought an object had been shown in that position for that name, and “3” if they thought a house had been shown in that position for that name.

2.4.2 Results

Figure 2-8 left shows retrieval accuracy as a function of competition level and distraction status. It shows that as competition increases, retrieval accuracy decreases. The distraction has no effect on accuracy. A 3 x 2 repeated ANOVA showed that the main effect of competition was significant, $F(2, 62) = 12.30$, $p < .001$. The main effect of distraction on retrieval accuracy was not significant, $F(1, 31) = 2.10$, $p = 0.16$. The interaction between the two factors was not significant, $F < 1$. In addition, there was a significant linear effect of increasing selection demand, $F(1, 31) = 20.66$, $p < .001$.

Figure 2-8 right shows retrieval response time as a function of competition level and distraction status including only the accurate trials above 400ms and within 3 standard deviations of the condition mean. As competition increases, the retrieval time also increases, and retrieval under visual distraction takes longer than in the non-distraction condition. A 3 x 2 repeated ANOVA showed a main effect of competition level, $F(2, 62) = 8.26$, $p < 0.001$, and a significant main effect of distraction, $F(1, 31) = 15.33$, $p < 0.001$. The interaction was not significant, $F < 1$. In addition, there was a significant linear effect of increasing selection demand, $F(1, 31) = 11.18$, $p = .002$.

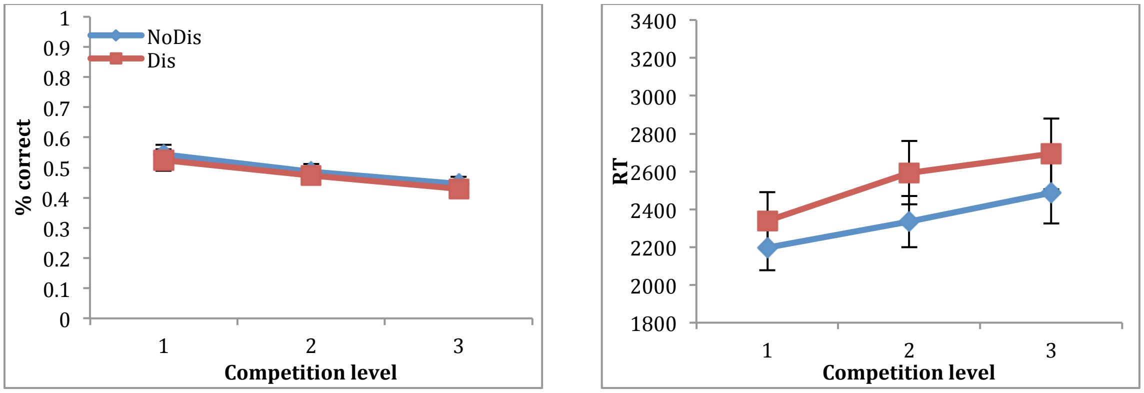

Figure 2-8. Retrieval accuracy (left) and retrieval time (in ms, right) in Expt. 1c.

Figure 2-9 left shows the accuracy data for the recognition task as a function of whether the item was a lure, or was presented as a distraction image under each of the three levels of retrieval competition. We used false alarm rates for lures. An analysis that compared false alarm with the mean hits of the three conditions found a significant difference, t(31) = -2.23, *p* = 0.03. Follow-up paired t-tests showed that images from competition 2 condition were recognized significantly better than images in competition 1, t(31) = -2.23, *p* = 0.03. Figure 2-9 right shows the response time in recognition task as a function of image condition. One-way ANOVA revealed no significant difference between conditions, *F*(3, 90) = 1.11, *p* = 0.35.

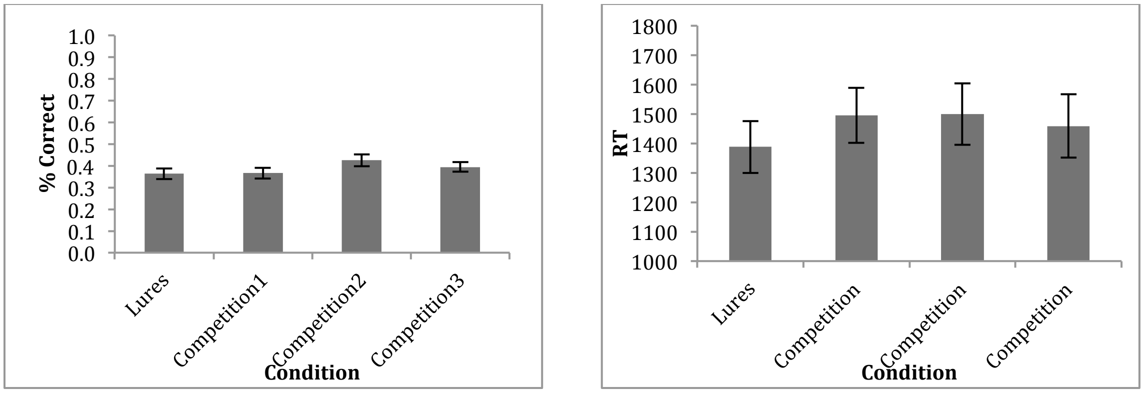

Figure 2-9. Recognition accuracy (left) and response time (in ms, right) in Expt. 1c.

2.5 Experiment 1d

In this sub-experiment, the design was similar to that used in Experiment 1c. However, with the consideration that visual distraction in the previous experiments was not effective enough and to make the distraction type and style more diverse, we changed the distraction images to nature or urban scenes. Additionally, to further strengthen the distraction manipulation, we introduced a dynamic distraction style in which the scene images were diagonally flashed at a rate of 500ms in the distraction condition during retrieval.

2.5.1 Methods

2.5.1.1 Subjects

Thirty-one University of Minnesota students (age range 18-25, mean age = 19.71 (SD=1.30), mean years of education = 14.05 (SD=1.05), 12 male) took part for extra course credit, screened according to the same criteria as in the earlier experiments. Seven additional students participated but their data were excluded due to various reasons (three had high depression scores, one was 45 years of age, two did not pay attention during the experiment, and one had participated in a study using the same stimuli recently).

2.5.1.2 Stimuli and materials

The stimuli were the same as in Expt. 1c except that we changed the distraction stimuli that were presented during the memory retrieval phase. Instead of the abstract stimuli used in the previous three experiments, the distraction stimuli were replaced with pictures of nature or urban scenes (see Figure 2-10). As before, one half of the trials during the retrieval task were accompanied by distracting images, and one half of the retrieval trials were presented on a simple gray background (control trials). For counterbalancing purposes, for each selection/competition level, half of the distraction trials had nature pictures and the other half had urban pictures. The distraction images were of 420 x 210 pixel resolution.

Figure 2-10. Sample pictures of nature/urban scenes. Left, urban scene; right, nature scene.

Additionally, to make the distraction manipulation more effective (that is, more distracting), the distraction presentation format was changed from static image presentations (as in Expt. 1a-1c) to dynamic exposures. Specifically, in each distraction trial, two images of the same picture briefly appeared or "flashed" along a diagonal line (upper-left and lower-right, or upper-right and lower-left) every 500ms, with the two distraction images alternating, and repeatedly "flashing" first on one diagonal and then on the next (see Figure 2-11). Each distracting image was shown at a size of 320 x 240 pixels. The maximum time for a retrieval trial was set to be 10 sec, so the distraction flashed a total of 20 times, 10 times along each diagonal (This diagonally-oriented distraction procedure was adopted so as not to interfere with the spatial orientation of the to-be-encoded stimuli, which were shown to the left, top, right, or bottom of the presented names). The recognition task was still an old/new judgment task.

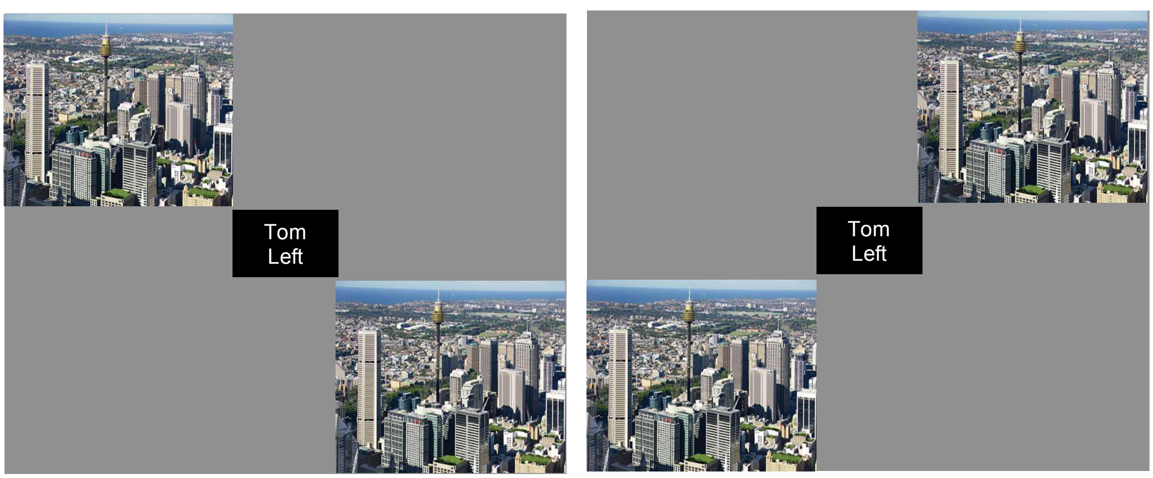

Figure 2-11. A sample distraction trial in Expt. 1d. Left, distraction images "flash" along upper-left and lower-right line. Right, distraction images "flash" along another diagonal line. The image is not drawn to scale.

2.5.1.3 Procedure

All participants were tested individually. The procedure was similar to that in Expt. 1c. However, since the distraction was more distracting now, to avoid a strong “carry-over” effect from a distraction trial to an immediately following non-distraction trial, the ITI in the retrieval task was set to 1 sec instead of 500ms as in the previous experiments. In the recognition task, the ITI was also 1 sec.

2.5.2 Results

Figure 2-12 left shows retrieval accuracy as a function of competition level and distraction status. As competition increases, retrieval accuracy decreases. The distraction has no effect on accuracy. A 3 x 2 repeated ANOVA showed that the main effect of competition was significant, $F(2, 60) = 11.18$, $p < .001$. The main effect of distraction was not significant, $F(1, 30) = 0.56$, $p = 0.46$. The interaction between the two factors was not significant, $F < 1$. In addition, there was a significant linear effect of increasing selection demand, $F(1, 30) = 13.95$, $p < .01$.

Figure 2-12 right shows retrieval response times as a function of competition level and distraction status including only the accurate trials above 400ms and within 3 standard deviations of the condition mean. As competition increases, the retrieval time also increases, and retrieval under distraction takes longer than in the non-distraction condition. A 3 x 2 repeated ANOVA showed a main effect of competition, $F(2, 60) = 23.24$, $p < 0.001$; the main effect of distraction was not significant, $F(1, 30) = 2.49$, $p = 0.13$. The interaction was not significant, $F < 1$. In addition, there was a significant linear effect of increasing selection demand, $F(1, 30) = 32.49$, $p < .001$.

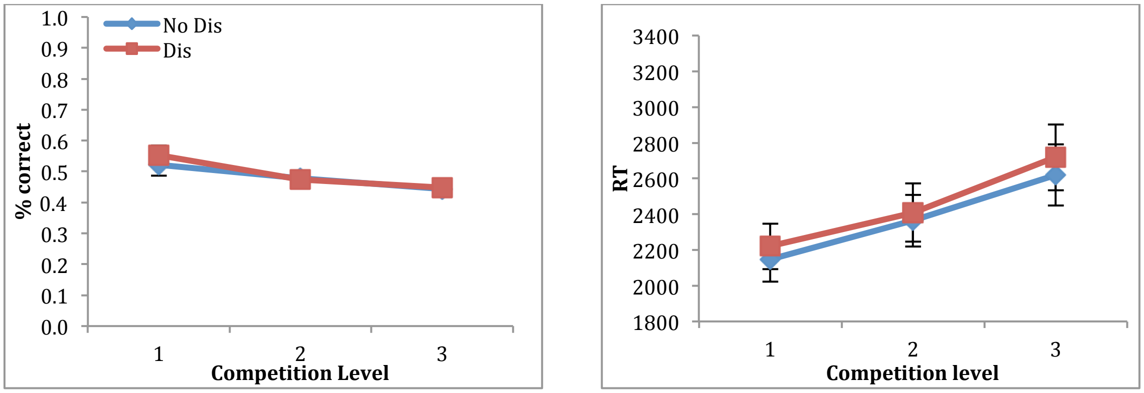

Figure 2-12. Retrieval accuracy (left) and retrieval time (in ms, right) in Expt. 1d.

Figure 2-13 left shows the accuracy data as a function of whether the item was a lure, or was presented as a distraction image under each of the three levels of retrieval competition. We used false alarm for lures. An analysis that compared false alarm with the mean hits of the three conditions found a significant difference, $t(30) = -3.54$, $p < 0.01$. Follow-up paired t-tests showed that images from competition 2 conditions were significantly better recognized than images in competition 1, $t(30) = -2.05$, $p = 0.05$. Figure 2-13 right shows the response time in the recognition task as a function of image condition. A one-way ANOVA revealed a significant difference between conditions, $F(3, 75) = 5.99$, $p < .01$. Pairwise comparisons showed that recognition of images in competition 1, 2 and 3 were all significantly longer than lures, p's > .01.

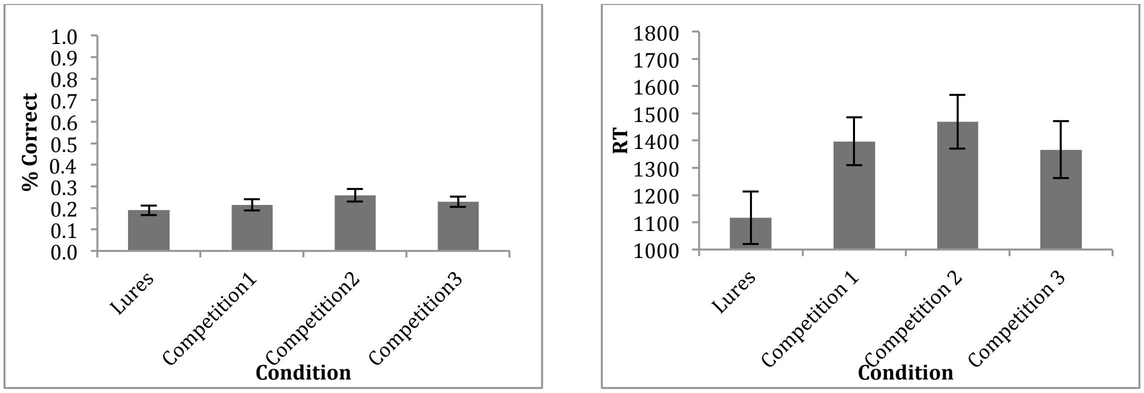

Figure 2-13. Recognition accuracy (left) and response time (in ms, right) in Expt. 1d.

2.6 Experiment 1e

We considered that the number of to-be-remembered target pairs was too many and it might be very difficult for participants to focus and to study the pairs well, and the study phase was too long. Accordingly, in this sub-experiment, we reduced the number of to-be-remembered stimuli. Also, in order to encourage participants to better study to-be-associated pairs, we provided feedback during the first three learning blocks and asked participants to actively generate the response during the last two study blocks. We extended the time between study and retrieval to 10 min. In addition, the final recognition task now used a two-alternative forced choice format (2AFC). Other aspects of the design were similar to that used in Experiment 1d.

2.6.1 Methods

2.6.1.1 Subjects

Twenty-eight University of Minnesota students (age range 18-26, mean age = 19.71 (SD=2.02), mean years of education = 14.05 (SD=1.65), 14 male) took part in this study for extra course credit. All were screened according to the same criteria as in the previous experiments. Eight additional students participated but their data were excluded from the analyses because of various reasons (three of them had high depression scores, one did not respond during the first block of the study phase, two of them encountered computer problems and did not finish the session, one was not a native English speaker, and one did not pay attention during the experiment due to noises of floor waxing outside the testing room).

2.6.1.2 Stimuli and materials

In this experiment, we reduced the number of stimuli. Eighty-four color images of faces, objects, and houses were used. As before, each type of image consisted of 4 subtypes. There were 7 pictures in each subtype. Each image was at 320 x 240 pixel resolution.

We selected 48 names from the previous set. Half of them were female names, half were male names. Distraction images were selected from those in Expt. 1d and the distraction style was the same as in Expt. 1d. There were 42 such images, 21 of the distracting images were nature scenes, and 21 were urban scenes.

The episodic memory task again included study and retrieval phases. In the study phase, the selection/competition level was manipulated in three levels. For selection level 1, each of the 24 names was paired with a unique image, resulting in 24 trials. In these 24 trials, each type of to-be-learned image (i.e., face, object, house) was used 8 times, and each subtype of image was used 2 times. For selection level 2, each of the 12 names was paired with two different images (2 competitors), one at a time, resulting in 48 trials. In this level, for counterbalancing purposes, 4 names were paired with a face and an object image, 4 names were paired with a face and a house image, and the other 4 names were paired with an object and a house image. Each subtype of image was used 2 times. For selection level 3, each of the 12 names was paired with 3 different images (3 competitors; one in each type), resulting in 36 trials. Each subtype of image was used 3 times. In all levels, female and male names were assigned equally often to each subtype of image. There was no repetition of any of the to-be-learned images.

The study and retrieval task were the same as in previous experiments except that the number of trials in both the study and retrieval phases was now 84. The distraction style was the same as that in Expt. 1d.

2.6.1.3 Procedure

The procedure for this experiment was similar to that used in the previous experiments with four exceptions: (1) In the current study phase, participants were asked to study the association between a name and an image and press a key to indicate the type of each image during the first three blocks. In each trial, a name appeared in the center of the screen for 1 sec. Then an image appeared in one of the four possible positions for 3 sec. Only one image appeared in each trial and the name remained on the screen throughout the whole trial. Participants were asked to make associations and form a pair of information between the name and the image that was presented. To ensure that participants paid close attention, they were asked to press “1” if it was a face, “2” if it was an object, “3” if it was a house, after the image appeared. The ITI was 1 sec. During the fourth and fifth study block, participants were asked to vividly think about each image for a certain name before they saw the actual image. In each trial, a name appeared in the center of the screen along with an empty box or “frame” in one of the four positions for 3 sec. During this time, participants were asked to actively generate the image that they had learned previously in the position of the box/frame for that name and to press the corresponding key to indicate its type. Then response feedback consisting of the words either “correct” or “incorrect” appeared on the screen for 1 sec. Afterwards, the actual image was presented in the position of the box/frame for 2 sec. Participants were encouraged to re-study the pair when they saw the actual image if they generated the wrong image. The ITI was also 1 sec. The task paused after each block and participants were encouraged to take a brief break at that time. (2) Participants were asked to take a 10-min break after the study phase. During this time, they could use the restroom or have some water or simply relax. (3) The ITI during the retrieval phase was 2 sec. (4) The final recognition phase was changed from an “old/new” single probe format to a two-alternative forced choice format, as the results from the previous recognition tasks showed that participants tended to be very conservative, that is, they were biased to answer “no, it is new” in each trial, resulting in better performance for lures. In the current recognition task, for each trial, two images (one old, one lure) were placed side by side and the participants were asked to decide which of the two images had appeared in the previous task. They pressed “1” if they believed that the left image was old, “2” if they believed the right image was old. The position of the correct image was counterbalanced across trials. The background of this recognition task was set to gray. The ITI was 1 sec. There were a total of 42 trials.

2.6.2 Results

Figure 2-14 left shows retrieval accuracy as a function of competition level and distraction status. As competition increases, the retrieval accuracy decreases. The distraction has no effect on accuracy. A 3 x 2 repeated ANOVA showed that the main effect of competition was significant, $F(2, 54) = 16.43$, $p < .001$. The main effect of distraction was not significant, $F(1, 27) = 0.11$, $p = 0.74$. The interaction between the two factors was not significant, $F < 1$. In addition, there was a significant linear effect of increasing selection demand, $F(1, 27) = 29.79$, $p < .001$.

Figure 2-14 right shows the retrieval response times as a function of competition level and distraction status including only the accurate trials above 400ms and within 3 standard deviations of the condition mean. As competition increases, the retrieval time also increases, and retrieval times in the distraction condition are longer than in the non-distraction condition. A 3 x 2 repeated ANOVA showed a main effect of competition, $F(2, 54) = 7.89$, $p < 0.01$; the main effect of distraction was also significant, $F(1, 27) = 14.61$, $p < 0.01$. The interaction was not significant, $F < 1$. There was a significant linear effect of increasing selection demand, $F(1, 27) = 9.30$, $p = .005$, and a significant quadratic effect of increasing selection demand, $F(1, 27) = 4.87$, $p = .04$.

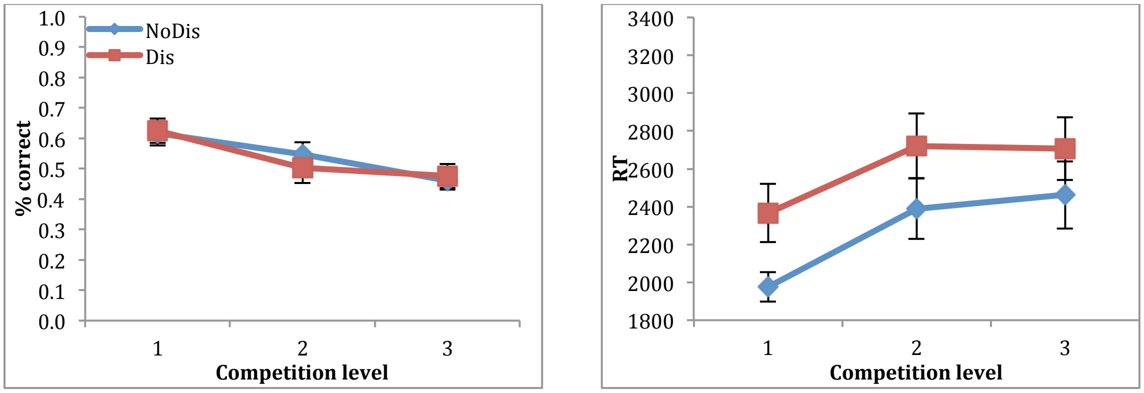

Figure 2-14. Retrieval accuracy (left) and retrieval time (in ms, right) in Expt. 1e.

The mean accuracy (proportion correct old responses) for the 2-alternative forced choice recognition task is 0.58. Figure 2-15 left shows the accuracy data as a function of the retrieval competition level at which the distraction image had earlier appeared. A one-way ANOVA showed a significant difference between conditions, $F(2, 52) = 4.45$, $p = 0.02$. Pairwise comparisons showed that distractor images from competition 1 and 2 trials were recognized significantly more often than were images from competition 3 trials, $p = 0.05$ and $p = 0.014$, respectively. Figure 2-15 right presents the RT data. There was no significant difference between conditions, $F < 1$.

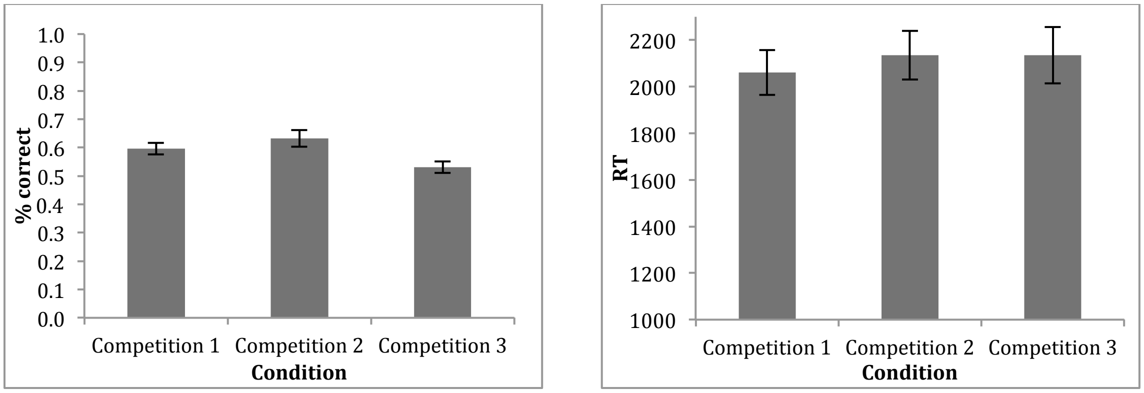

Figure 2-15. Recognition accuracy (left) and response time (in ms, right) in Expt. 1e.

2.7 Discussion

In Experiment 1, we manipulated selection demand in three levels and distraction status in two levels in an episodic memory task. In general the results were consistent with our hypotheses such that the results showed that as selection demand increases retrieval accuracy decreases and retrieval time increases. The visual distraction presented during retrieval increases retrieval time, no matter whether it is static or dynamic, abstract or contextual. On average, retrieval was 134.73 ms slower under visual distraction than without it. In contrast, retrieval accuracy is not influenced much by the presence of distraction. On average, the difference in retrieval accuracy under visual distraction versus without it was only 0.01. However, there was no interaction between selection demand and distraction status. This may point to an independent effect of internal and external interference on episodic memory performance. Interestingly, in the recognition task in Experiment 1e where we used an unbiased 2AFC paradigm, memory performance was enhanced for the distractor images under low selection (selection 1 and 2) compared with high selection (selection 3) condition.

These results are largely consistent with previous research on selection demand and memory retrieval such that as competition increases, retrieval time for a particular target memory increases and accuracy decreases (e.g., Anderson & Reder, 1999; Badre et al., 2005; Snyder & Munakata, 2008; Snyder et al., 2011; Sohn et al., 2003). Since most previous research only manipulated selection demand in two levels, it was unclear if these findings held when there were more levels of competition, our research filled this gap.

Our results are also in general consistent with research on visual distraction and memory retrieval in that irrelevant visual information present in the environment disrupts memory of visual details. However, unlike some previous studies (e.g., Wais et al., 2010), we did not find an effect of visual distraction on retrieval accuracy. A possible reason for this discrepancy might be that we did not include an eye-closed condition. It could be that the non-distraction condition in our experiment (gray screen) was still distracting to some extent because there was still visual stimulation coming to the eyes. Indeed, the findings in Wais et al. (2010) indicated that the difference between the gray screen and visual distraction condition was much smaller than the difference between the eye closure and visual distraction condition. Furthermore, the difference between the gray screen and visual distraction condition was not statistically significant in one of their two experiments. As we noted earlier, the use of a gray screen as no-distraction condition is not necessarily a weakness, rather it could be a strength, as we can more analytically focus on the effects of visual distraction while holding the opportunities for contextual reinstatement and other possible differences constant between the distraction condition and the non-distraction condition.

In Experiment 2, we will manipulate the association strength and investigate how it affects long-term memory performance and how it interacts with irrelevant visual distraction.

Chapter 3
Experiment 2: The effect of visual distraction on episodic memory retrieval with a manipulation of association strength

3.1 Introduction

Besides selection demand, the associative strength between a given retrieval cue and a target memory can also greatly influence how well we recall a target memory. The associative strength between a retrieval cue and the target memory influences retrieval demands and it has been found that as the association strength decreases, the recall time for a target memory increases (e.g., Anderson & Reder, 1999). In this series of experiments, the aim was to investigate the joint effects of association strength and visual distraction on episodic memory retrieval performance. We again used the paired-associate episodic memory retrieval paradigm that we developed in Experiment 1. Association strength was manipulated in two levels and distraction status also in two levels. Recognition of the distraction images was tested at the end.

3.2 Experiment 2a

In this sub-experiment, we first asked participants to study pairs of names and images in three encoding blocks. In each block, half of the pairs were studied multiple times, whereas the remaining half of the pairs were studied once, creating high and low association strength items, respectively. In a subsequent retrieval phase, participants were asked to recall the type of image that was associated with a given name. In the no-distraction condition, participants recalled the image type while looking at a gray background screen. In the visual distraction condition, a dynamic flashing distraction of urban or nature scene stimuli was presented during retrieval.

3.2.1 Methods

3.2.1.1 Subjects

Thirty University of Minnesota students (age range 19-29, mean age = 21.83 (SD=2.36), mean years of education = 15.45 (SD=1.48), 7 male) participated in this study for extra course credit or $10/hr. In this and all subsequent experiments all participants were native English speakers with normal or corrected-to-normal vision, and were screened for depressive symptoms that could affect their cognitive and memory performance with the Brief Symptom Inventory (BSI, Derogatis & Melisaratos, 1983). Informed consent was obtained from all participants in accordance with the University of Minnesota Institutional Review Board. In the current study, three additional students participated but their data were excluded from analyses because one had a high depression score (greater than 11), one encountered computer problems and did not finish, and one did not finish the session due to a personal situation.

3.2.1.2 Stimuli and materials

We used 48 names and each name was randomly paired with a unique image of a face, an object, or a house, resulting in 48 pairs. Each type of image was used 16 times. The pairing was different for each subject. For each subject, half of the pairs (24 pairs) were presented once (low association strength) during a study block, resulting in 24 trials, and half of the pairs (24 pairs) were presented 4 times (high association strength), resulting in 96 trials. This resulted in 120 trials per study block. The female names and male names were equally often assigned to each type of image. The name was always presented in the center of the screen, and the image could appear in any one of the four positions (top, right, bottom, left) around the name. For each type of image in each level, each of these four positions was used twice.

There were three encoding blocks with 120 trials in each. The order of trials was randomized in each block. Across the encoding phase, the low association strength pairs were studied a total of 3 times and high association pairs were studied 12 times.

During retrieval, the name cue was presented in the center of the screen and participants were asked to recall the type of image associated with that name. For half of the trials, we used the same dynamic visual distraction as in Expt. 1e. For non-distraction trials, a gray background was shown. Twelve images of nature and 12 images of urban scenes were selected from the previous set of distractor stimuli to be used as distraction images. During the final recognition task, 24 old distraction images and 24 lures were presented in a two alternative forced choice task.

3.2.1.3 Procedure

All participants were tested individually. Participants were given written instructions to read and paraphrase before each task. The three blocks of the encoding phase each took the same format. Participants were asked to make associations between stimuli on the screen. In each trial, a name first appeared in the center of the screen for 1 sec. Then an image appeared in one of the four possible positions around the name for 3 sec. When the image appeared, participants pressed "1" for face, "2" for object, "3" for house. The name remained on the screen for the whole time. Participants were told that they would be tested on the associations later. Each study block took about 10 min, and participants took a brief break after each block.

There were 48 trials in the retrieval phase. In each trial, a name appeared in the center of the screen, and participants recalled the type of image that was associated with the name, pressing "1" "2" or "3" for face, object, and house respectively. Each trial was 10 sec long with an ITI of 2 sec. We used the dynamic distraction paradigm as in Expt. 1e. As before, participants were instructed not to close their eyes or look away throughout the retrieval task.

The final recognition task was very similar to that used in Expt. 1e (2AFC). It had 24 trials. The ITI was set to be 1.5 sec.

Participants were debriefed and thanked before they left the testing room.

3.2.2 Results

Figure 3-1 left shows retrieval accuracy as a function of association strength and distraction status. As association strength increases, retrieval accuracy also increases. The distraction has little to no effect on accuracy. A 2 (association strength: high vs. low) x 2 (distraction status: distraction vs. non-distraction) repeated ANOVA showed a main effect of association strength, $F(1, 29) = 44.72$, $p < .001$. The main effect of distraction was not significant, $F < 1$. The interaction between the two factors was not significant, $F < 1$.

Figure 3-1 right shows retrieval response times as a function of association strength and distraction status, including only the accurate trials above 400ms and within 3 standard deviations of each condition mean. As association strength increases, the retrieval time decreases, and memory retrieval in the distraction condition takes longer than in the non-distraction condition. A 2 x 2 repeated measures ANOVA showed a main effect of association strength, $F(1, 29) = 33.11$, $p < 0.001$; the main effect of distraction was also significant, $F(1, 29) = 9.10$, $p = 0.004$. The interaction was not significant, $F(1, 29) = 1.42$, $p = 0.24$.

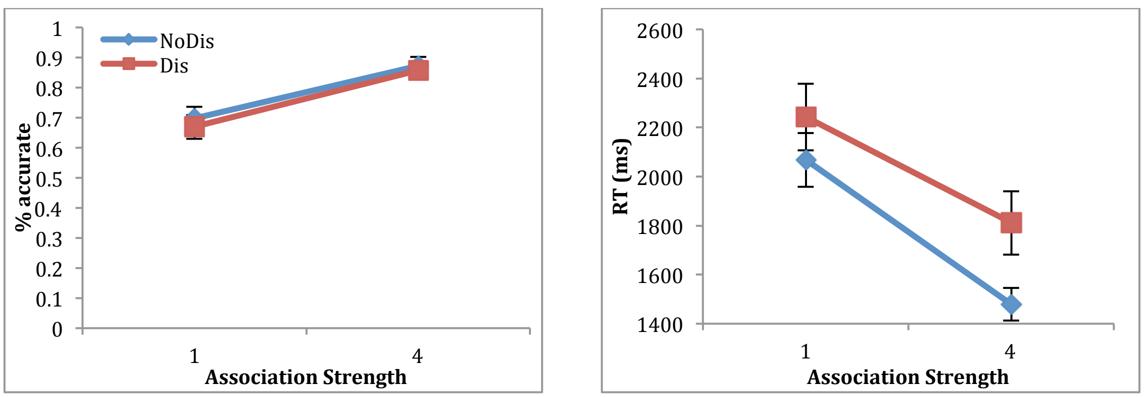

Figure 3-1. Retrieval accuracy (left) and retrieval time (in ms, right) in Expt. 2a.

The mean accuracy in the 2AFC recognition task is 0.65. Figure 3-2 left shows the accuracy data as a function of the association strength condition in which the distraction image had earlier appeared. One sample t-test revealed that recognition in both conditions was significantly above chance (0.5), p's < .001. Paired samples t-test showed no significant difference between distractor images in the low vs. high association strength conditions, $t(29) = -1.2$, $p = 0.24$. Figure 3-2 right shows the response time in the recognition task as a function of the association strength condition. Paired samples t-test showed no significant difference between the two conditions, $t < 1$.

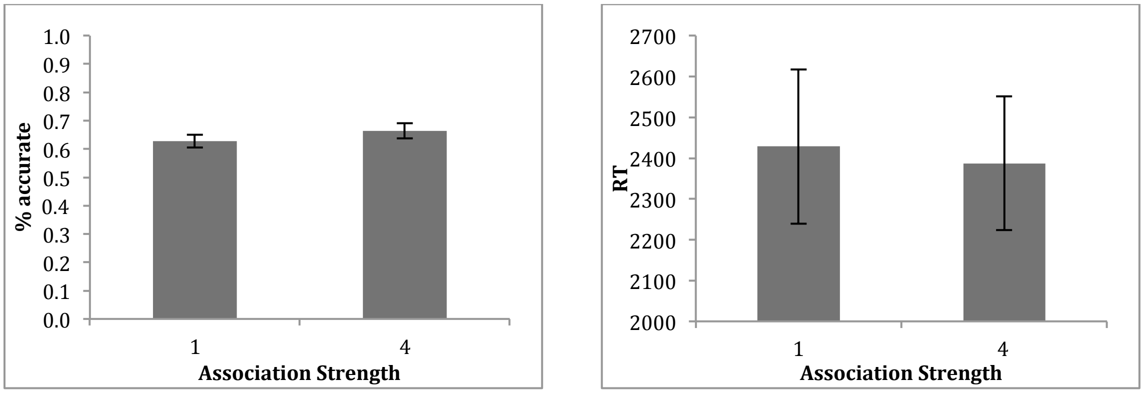

Figure 3-2. Recognition accuracy (left) and response time (in ms, right) in Expt. 2a.

3.3 Experiment 2b

The retrieval task so far asked for categorical information: participants in each of the preceding experiments were asked to indicate the class or type of information (that is, face, house, or object) that had been associated with a given name (or, in Experiment 1, that had been associated with the combination of a given name and screen location). While it is important to remember category-related information in everyday life, we often need to also remember detailed information. For instance, we may be asked to recall the color, form, or texture of an object. To test participants' memory of more detailed information, in this experiment, we manipulated the color of images in a pair and tested participants' memory of both the color format of an image as well as categorical information.

3.3.1 Methods

3.3.1.1 Subjects

Twenty-six University of Minnesota students (age range 19-28, mean age = 22.12 (SD=2.50), mean years of education = 16.00 (SD=1.81), 10 male) took part in this study for extra course credit or $10/hr. Two additional students participated but their data were excluded. One had a high depression score (greater than 11) and the other was not a native English speaker.

3.3.1.2 Stimuli and materials

The stimuli and materials were the same as in Expt. 2a with one main change. Since we wanted to test memory of detailed information, we manipulated the color of the images in the name-image pairs. One half of the to-be-learned images of faces, places, and objects were presented in color during the encoding phase, and the other half were shown in gray scale. To be noted, although we here examined recollection of detailed visual information in episodic memory, we looked at a different type of detail information (a combination of categorical information and color perceptual details) than was looked at by Wais and colleagues (e.g., Wais et al., 2011), who tested "count" information in most studies.

The encoding phase was the same as in Expt. 2a. After the encoding phase, participants took part in a key-mapping practice task for 5 min, to familiarize themselves with the keys they were going to use during the retrieval task. The retrieval task was similar to that used in Expt. 2a except that the visual distraction flash rate was faster, at 250ms. Also, the response options were increased to allow participants to indicate both the type of image that was associated with each name, and whether it had been presented in color or as a gray scale image (see Procedure).

3.3.1.3 Procedure

All participants were tested individually. The encoding procedure was the same as in Expt. 2a except that participants were informed that some of the images in a pair would be shown in color, and some would be in gray scale. In the key-mapping practice task after the encoding, 6 cartoon images, 3 in color, 3 in gray, were shown in 120 randomly intermixed trials. The image size was at 320 x 240 pixel resolution. Each trial started with a 1 sec fixation. When the image appeared, participants pressed “1” for a color face picture, “2” for a color object picture, “3” for a color house picture, “4” for a gray scale face picture, “5” for a gray scale object picture, and “6” for a gray scale house picture. Each trial was self-paced. After participants made their response, feedback indicating their response was either “correct” or “incorrect” appeared for 750ms. This practice task took about 5 min.

In the retrieval phase, participants were asked to recall the specific image that was associated with the name and to indicate the type and format (color or gray scale) of the recalled image by pressing the same keys they had practiced during the key practice task. Half of the trials were accompanied by visual distraction, comprised of diagonally flashing scene images at a rate of 250ms. Participants were asked to be attentive all the time.

The 2AFC recognition task was the same as in Expt. 2a.

3.3.2 Results

Figure 3-3 left shows retrieval accuracy as a function of association strength and distraction status. As association strength increases, retrieval accuracy increases. The distraction has a slight effect on accuracy for low association strength but not high association strength. A 2 (association strength: high vs. low) x 2 (distraction status: distraction vs. non-distraction) repeated measure ANOVA showed a main effect of association strength, $F(1, 25) = 59.32$, $p < .001$. The main effect of distraction was not significant, $F(1, 25) = 1.07$, $p = 0.31$. The interaction between the two factors was marginally significant, $F(1, 25) = 3.74$, $p = 0.06$.

Figure 3-3 right shows the retrieval response times as a function of association strength and distraction status, including only the accurate trials above 400ms and within 3 standard deviations of each condition mean. As association strength increases, retrieval time decreases, and retrieval in the distraction condition is slower than the non-distraction condition. A 2 x 2 repeated ANOVA showed a main effect of association strength, $F(1, 25) = 8.64$, $p = 0.007$; the main effect of distraction was also significant, $F(1, 25) = 5.32$, $p = 0.03$. The interaction was not significant, $F < 1$.

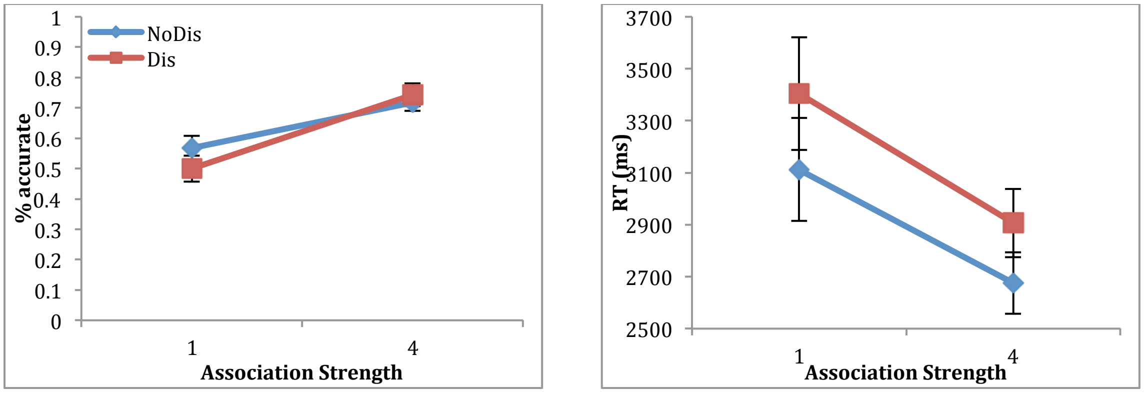

Figure 3-3. Retrieval accuracy (left) and retrieval time (in ms, right) in Expt. 2b.

The mean accuracy in the 2AFC recognition task is 0.62. Figure 3-4 left shows the recognition accuracy data. One sample t-test showed that recognition in both conditions was significantly above chance, *p's* < .01. Paired samples t-test showed no significant difference between distractor images earlier shown in the low vs. high association strength conditions, t(25) = -1.04, *p* = 0.31. Figure 3-4 right shows the response times in the recognition task as a function of image condition. Paired samples t-test showed no significant difference between the two conditions, t < 1.

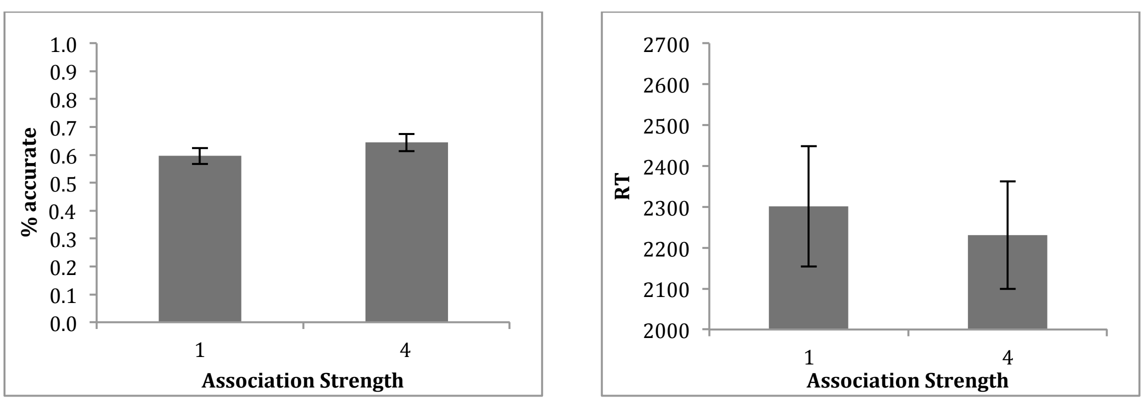

Figure 3-4. Recognition accuracy (left) and response time (in ms, right) in Expt. 2b.

3.4 Experiment 2c

In this experiment, the design is the same as Experiment 2b except that recall of category information and color information was not mixed. Instead, participants recalled category information first in one run and then recalled color format in the second run. We did this because: 1) there were too many response options in Expt. 2b which could add burden to participants to remember and choose the right option (especially if used later in a neuroimaging context). In Expt. 2c, there were 3 responses to choose from in the first run and only 2 to choose from in the second run. 2) In Expt. 2b we tested for more detailed memory but it was always the combination of type and color format information. In Expt. 2c we can better differentiate accuracy and retrieval time for the category information from that for the perceptual detail information.

3.4.1 Methods

3.4.1.1 Subjects

Twenty-seven University of Minnesota students (age range 18-22, mean age = 19.33 (SD=1.21), mean years of education = 13.87 (SD=1.22), 9 male) took part in this study for extra course credit, screened as in each of the previous experiments. Two additional students participated but their data were excluded from analyses because one did not have complete data and the other was not a native English speaker.

3.4.1.2 Stimuli and materials

The stimuli and materials were the same as in Expt. 2b. The study phase and the recognition task also were the same as before. The retrieval task was changed to two separate recall runs. In the first run, participants were asked to recall the image type associated with each name (face, place, or object); in the second run, they recalled the presentation format of the images (color or gray scale).

3.4.1.3 Procedure

Participants were tested individually. They first studied the to-be-remembered name-image pairs in 3 blocks. After a 5 min break, they were asked to do the first run of retrieval. In this run, in each trial a name appeared in the center of the screen in a solid black frame, and participants were asked to recall the type of image that was associated with that name, pressing “1” “2” “3” for face, object, and house respectively. Each trial had a maximum of 4 sec to respond. The ITI was 2 sec. In the second run, in each trial a name was again presented in the center of the screen for 4 sec, and participants were asked to press “1” if they thought a color image was associated with that name, or “2” if they thought a gray scale image was associated with that name. For the purposes of counterbalancing, the distraction trial in the first run became the non-distraction in the second run, and vice versa. In this way, all studied name association pairs were tested twice, once with visual distraction at retrieval, and once without distraction.

In the final 2AFC recognition task, each trial was set to 3.5 sec and the ITI was 1.5 sec.

3.4.2 Results

Figure 3-5 left shows retrieval accuracy as a function of association strength and distraction status in retrieval run 1 (classification recall). As association strength increases, retrieval accuracy increases. The distraction has no effect on accuracy. A 2 (association strength: high vs. low) x 2 (distraction status: distraction vs. non-distraction) repeated measures ANOVA showed a main effect of association strength, $F(1, 26) = 33.74$, $p < .001$. The main effect of distraction was not significant, $F < 1$. The interaction between the two factors was not significant, $F < 1$.

Figure 3-5 right shows the retrieval response time as a function of association strength and distraction status, including only the accurate trials above 400ms and within 3 standard deviations of each condition mean, in retrieval run 1. As association strength increases, the retrieval time decreases. A 2 x 2 repeated ANOVA showed a main effect of association strength, $F(1, 26) = 48.23$, $p < 0.001$; however, unlike in each of the previous experiments the main effect of distraction on retrieval latency also was not significant, $F < 1$. The interaction was not significant, $F(1, 26) = 1.11$, $p = 0.30$.

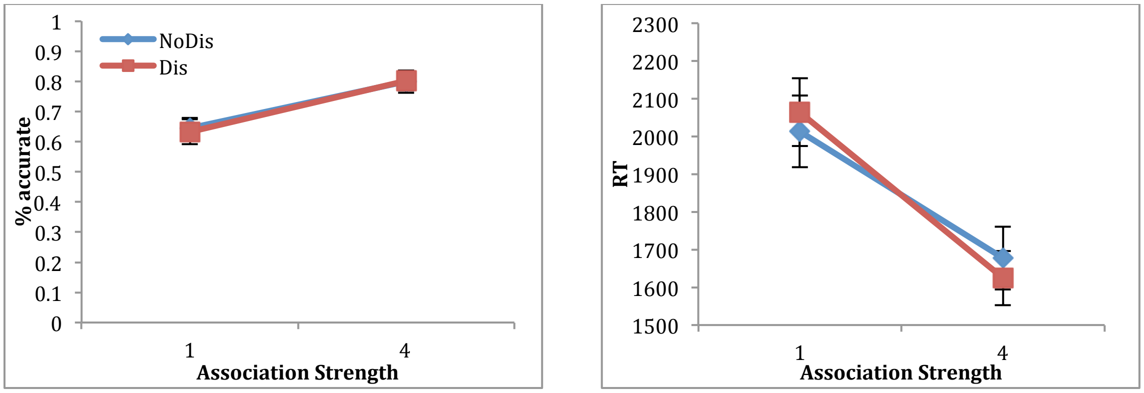

Figure 3-5. Retrieval accuracy (left) and retrieval time (in ms, right) in run 1 of Expt. 2c.

Figure 3-6 left shows retrieval accuracy as a function of association strength and distraction status in retrieval run 2 (color format decision). As association strength increases, retrieval accuracy increases. The distraction has little or no effect. A 2 x 2 repeated measure ANOVA showed a main effect of association strength, $F(1, 26) = 20.62$, $p < .001$. The main effect of distraction was not significant, $F < 1$. The interaction between the two factors was not significant, $F < 1$.

Figure 3-6 right shows the retrieval response times as a function of association strength and distraction status, including only the accurate trials above 400ms and within 3 standard deviations of each condition mean, in retrieval run 2. As association strength increases, the retrieval time decreases in the no-distraction condition, but not in distraction condition. A 2 x 2 repeated ANOVA showed no main effect of association strength, $F < 1$ and (again, unlike in each of the previous experiments) no main effect of distraction, *F* < 1. The interaction was also not significant, *F*(1, 26) = 1.16, *p* = 0.29.

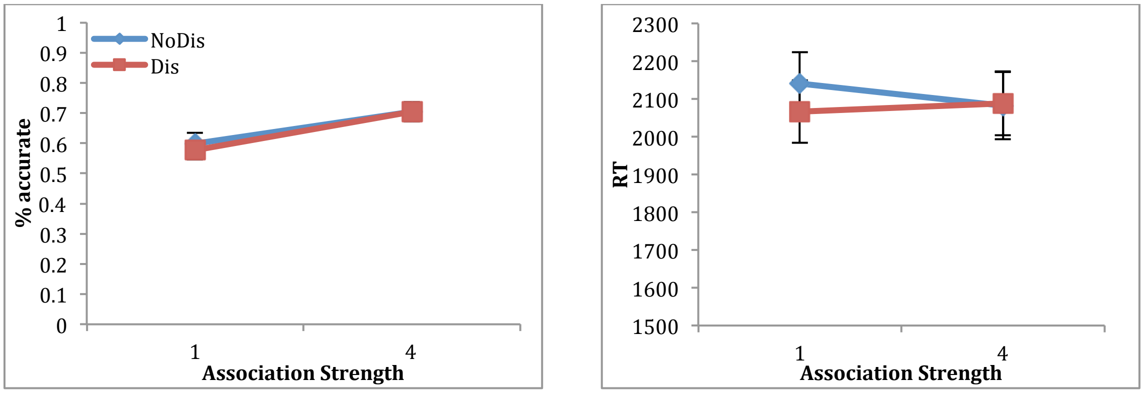

Figure 3-6. Retrieval accuracy (left) and retrieval time (in ms, right) in run 2 of Expt. 2c.

Figure 3-7 left shows the accuracy data for recognition of the distractor images. One sample t-test showed that except for recognition of weak (level 1) association strength items in run 2 (*p* > .70), the images in each of the other three conditions were all recognized above chance level, *p*'s < 0.04. A 2 (runs: 1 vs. 2) x 2 (association strength: level 1 vs. level 4) ANOVA showed a main effect of run, *F*(1, 26) = 15.58, *p* < 0.01, and a main effect of strength, *F*(1, 26) = 14.70, *p* < .001. Paired samples t-test showed a significant difference between run 1 level 1 vs. run 1 level 4 (t(26) = -3.24, p =0.003) and between run 2 level 1 and run 2 level 4 (t(26) = -2.42, p = 0.02). Distraction images from the high association strength condition were more often correctly recognized than those in the low association strength condition in both runs. Figure 3-7 right shows the response time in the recognition task as a function of image condition. A 2 x 2

ANOVA showed no effect of run or association strength, and no significant interaction, all p's > 0.12. Paired samples t-test showed no significant difference between the association strength levels in each run, p > 0.16.

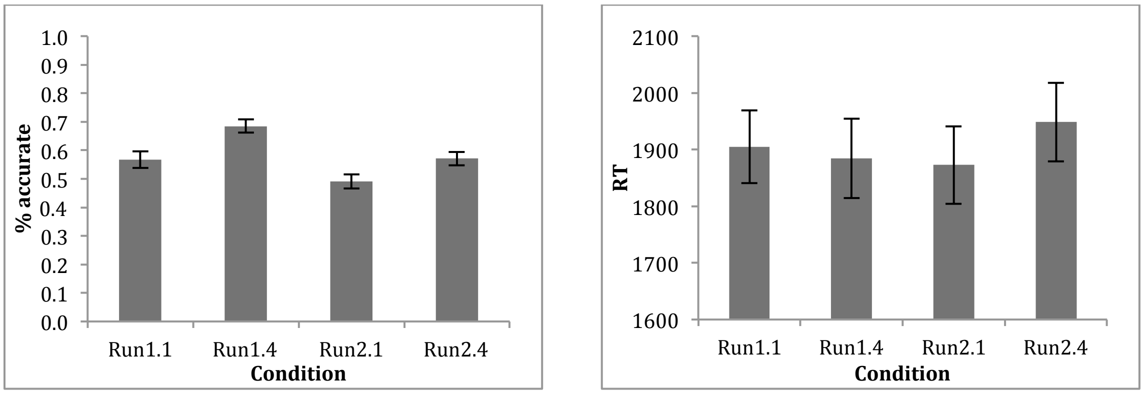

Figure 3-7. Recognition accuracy (left) and response time (in ms, right) in Expt. 2c.

3.5 Discussion

In Experiment 2, association strength was manipulated in an episodic memory task. Participants studied half of the paired associates more times than the other half, resulting in a high association strength and low association strength condition respectively. The results showed that participants respond more accurately and more quickly in the high association strength than in the low association strength condition. The effect of association strength often is studied in semantic memory tasks (e.g., Anderson & Reder, 1999; Badre et al., 2005; Martin & Cheng, 2006) and to a much less extent studied in episodic memory task. Our findings bridged this gap and showed that the association strength effect also applies to episodic memory.

As before, the visual distraction slowed down the response time but had little effect on retrieval accuracy. Also, the interaction between the association strength and visual distraction was not found. Notably, in Experiment 2c, there was no significant distraction effect in retrieval latency. One might think that repeated testing of same items might have messed with the distraction effects. However, even in the first run where the participants were first tested on the items, the distraction effects were not there. Participants studied the mixture of the categorical information and color detail during the encoding phase but were only tested on one aspect in each retrieval run. It is possible that this parsing or required selection of useful information from a combination of information resulted in a different recollection task for participants compared to that in Expt. 2a and 2b. Future studies are needed to see if this null effect is replicable. It is also possible that the absence of a distraction effect on retrieval latency in this experiment represents a Type II error.

Experiment 1 and 2 tested the effects of mnemonic competition and association strength together with visual distraction effects on episodic memory tasks. In eight experiments so far, we found largely consistent effects such that visual distraction disrupts memory performance. However, in reality, we often engage in different types of memory processes such as retrieving information from longer-term conceptual or semantic memory while facing perceptual distraction. To see if the effects we found in the earlier experiments can be generalized to another types of memory, in Experiment 3, we will use a semantic memory task – a verb generation task, for which there is an existing manipulation of both association strength and selection demand. We will again apply the visual distraction paradigm in this task, now to examine the combined effects of internal and external cognitive control requirements on retrieval from semantic memory.

Chapter 4
Experiment 3: The effect of visual distraction on semantic memory retrieval

4.1 Introduction

In Experiments 1 and 2, we looked at the effects of selection demand and association strength together with environmental visual distraction on episodic memory tasks. In order to test if the effects we found on episodic memory also are observed in another form of memory, particularly retrieval from longer-term conceptual memory, we used a verb-generation task. In this series of experiments, we aimed to investigate the effects of selection demand and association strength in a verb generation task under visual distraction vs. no-distraction conditions.

4.2 Experiment 3a

In this sub-experiment, the design was a 2 (competition) x 2 (association strength) x 2 (distraction status) factorial one. Participants were asked to generate a verb for a given noun in different runs. The distraction style in this experiment involved screen-saver-like images in which changing background images of textures appeared on the screen during the verb generation task.

4.2.1 Methods

4.2.1.1 Subjects

Twenty-nine University of Minnesota students (age range 18-23, mean age = 19.14 (SD=1.41), mean years of education = 13.28 (SD=1.34), 8 male) took part in this study for extra course credit. As in the previous experiments, all participants in this and the following experiments were native English speakers with normal or corrected-to-normal vision, and were screened for depressive symptoms that could affect their cognitive and memory performance with the Brief Symptom Inventory (Derogatis & Melisaratos, 1983). Informed consent was obtained from all participants in accordance with the University of Minnesota Institutional Review Board. Five additional students participated in the current experiment but their data were excluded from analyses because one had high a depression score (greater than 11) and the other four did not understand the instructions or didn't follow the instructions well as they either only responded to fewer than half of the verb generation trials or provided adjectives more often than verbs.

4.2.1.2 Stimuli and materials

We requested and obtained the verb generation stimuli used by Snyder et al. (2011). There were 100 nouns with the nouns selected on the basis of two factors, as determined by Latent Semantic Analysis measures and normative data collected by Snyder et al. (2011): association strength (retrieval demand: high vs. low) and competition level (selection demand: high vs. low). Four conditions were created by crossing these two factors (i.e., high competition/high association, high competition/low association, low competition/high association, low competition/low association), with 25 nouns per condition. We used four words as examples in the instructions, resulting in 96 nouns with 24 in each condition in the main task.

The verb generation task was presented in two runs. Each run used the same stimuli but the distraction and non-distraction conditions were flipped for a given noun across the two runs. In this way, every noun was presented twice, once with distraction and once without distraction.

The distraction stimuli for this experiment were comprised of one hundred and twenty texture images (see Figure 4-1), with distraction stimuli presented on one half of the verb generation trials in each run. The distraction stimuli were screen-saver like, in which changing background images of textures were presented behind the nouns. The textures changed every few hundred ms. To pilot and get a sense of how the presentation would work for a possible future fMRI study, we added distraction only trials in this experiment in which only distraction images were presented without noun stimuli. An additional 30 texture images were used in these “distraction only” trials in each run. Each distraction image was repeated 4 times across trials. Distraction images were randomly selected and changed across conditions for different participants. To be able to test recognition memory of the distraction images separately by condition, distracting images could not be used in two different conditions.

Figure 4-1. A sample texture image used as perceptual distraction in Expt. 3a.

4.2.1.3 Procedure

Participants were tested individually. Participants were given written instructions to read and completed example trials with the experimenter before starting the experimental task. In each trial, a noun (e.g., “cat”) appeared in the center of the screen for 3.5 sec. Participants were asked to generate the first verb that came to their mind when they saw a noun. The verb could be either something the noun does (for example, “meow”) or something they do with it (for example, “feed”). Participants were instructed to press the space bar as soon as a verb came to their mind, and at the same time say the word aloud so the experimenter could record their responses. It was emphasized that it was important that they pressed the space bar as soon as they thought of the verb. To anticipate the distraction only trials, participants were told to fixate their eyes on the fixation cross and were instructed not to press any key if they saw a “+” in the middle of the screen. As usual, they were asked not to close their eyes or to look away during this task.

Within each run, the stimuli were grouped into 3-item mini blocks in which the three items were from the same condition. The order of these blocks was randomized and different for each participant. Half of the blocks were accompanied by visual distraction, half were not. The items in all mini-blocks were re-sampled in different runs. During the distraction trials, 10 background screen-saver like images were changed every 350ms, such that each trial was 3.5 sec in duration (see Figure 4-2). The order of the 10 images in each trial was randomized. The ITI was 350ms.

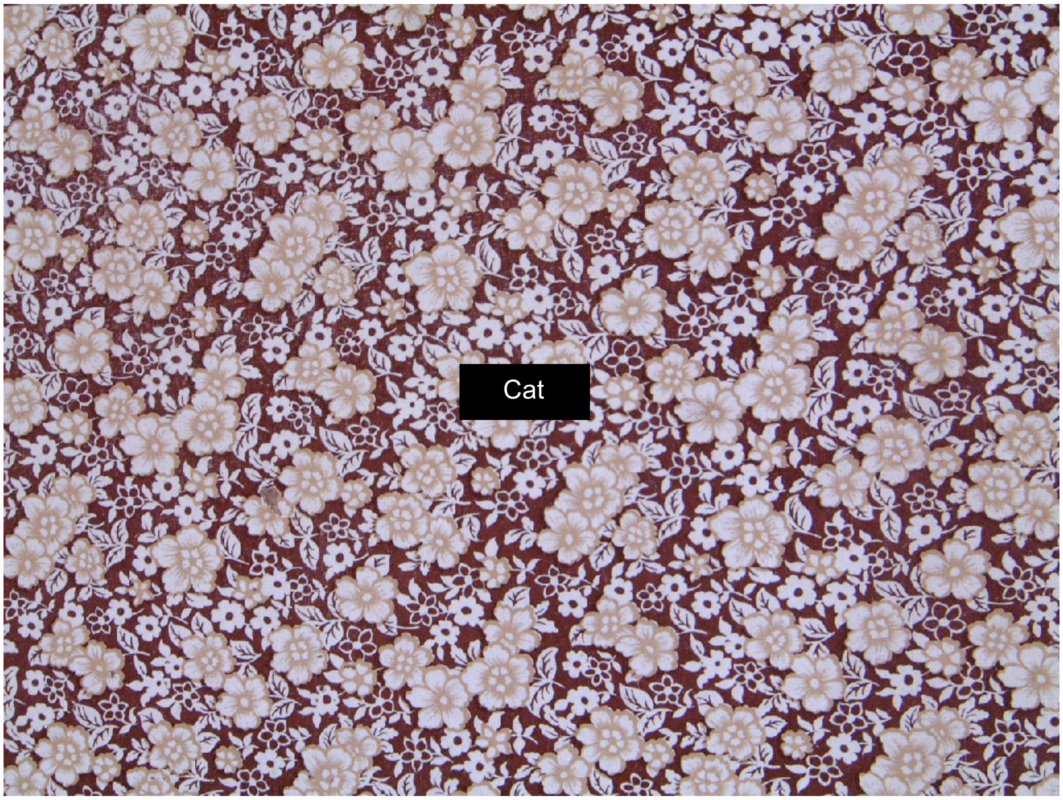

Figure 4-2. A sample trial with distraction in Expt. 3a. The background image changed to a different image every 350ms.

Participants’ memory for the distraction images was tested in a two alternative forced choice task in which 300 trials were presented. In each trial a correct image and a lure were displayed side by side for 1.5 sec. The ITI was 500ms. Participants were asked to decide which image was shown during the previous task, pressing “1” if they believed the left image was shown earlier during the verb generation task, and “2” if the right image was shown.

4.2.2 Results

We looked at the combined data of the two runs. In all verb generation tasks, no-answer trials were excluded and only the RTs that were within 3 SD of each condition mean were used in analyses.

Figure 4-3 shows response time as a function of condition (i.e., high competition/high association, high competition/low association, low competition/high association, low competition/low association) and distraction status when both runs were combined. Overall the distraction slows verb generation times in all four conditions. In addition, the response times are the longest in the most difficult condition (i.e., high competition/low association) and are the shortest in the easiest condition (i.e., low competition/high association). A 2 (high vs. low competition) x 2 (high vs. low association strength) x 2 (distraction status: distraction vs. non-distraction) repeated measures ANOVA showed a main effect of competition, $F(1, 29) = 63.72$, $p < .001$, a main effect of association strength, $F(1, 29) = 130.77$, $p < .001$, and a main effect of distraction, $F(1, 29) = 14.06$, $p < 0.01$. The interactions were not significant, *p's* > .12.

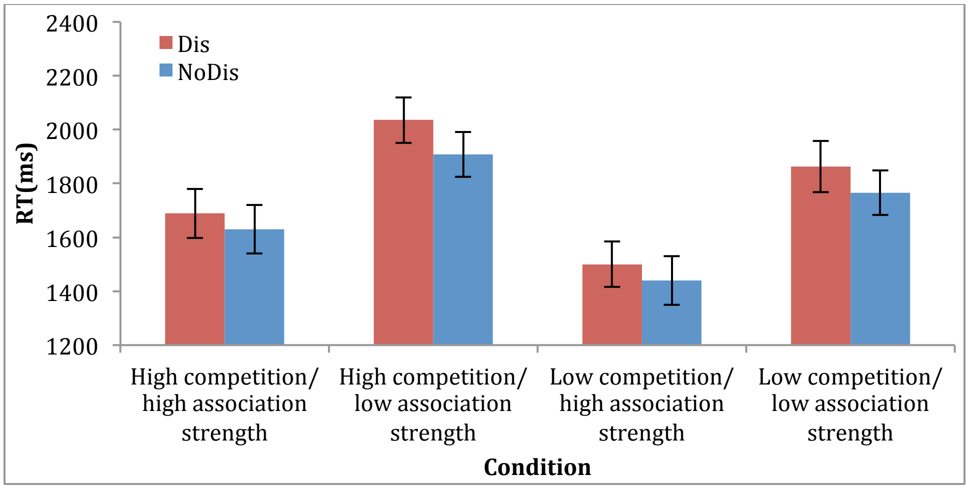

Figure 4-3. Retrieval time (in ms) as a function of word condition and distraction status when run 1 and run 2 data were combined.

Figure 4-4 left shows response time as a function of competition level (high vs. low) and distraction status (distraction vs. non-distraction) in combined runs. The presence of visual distraction slows verb generation times. The high competition condition took longer to respond. A 2 (high competition vs. low competition) x 2 (distraction status: distraction vs. non-distraction) repeated measures ANOVA showed a main effect of competition, $F(1, 28) = 64.00$, $p < .001$ and a main effect of distraction, $F(1, 28) = 27.49$, $p < 0.001$. The interaction between the two factors was not significant, $F < 1$.

Figure 4-4 right shows response time as a function of association strength (high vs. low) and distraction status (distraction vs. non-distraction) in the combined runs. The distraction slows verb generation times overall. And the high strength condition took less time to respond. A 2 (high association strength vs. low association strength) x 2 (distraction status: distraction vs. non-distraction) repeated measures ANOVA showed a main effect of association strength, $F(1, 28) = 130.47$, $p < .001$. The main effect of distraction was significant as before, $F(1, 28) = 27.49$, $p < 0.001$. The interaction between the two factors was not significant, $F(1, 28) = 1.75$, $p = 0.20$.

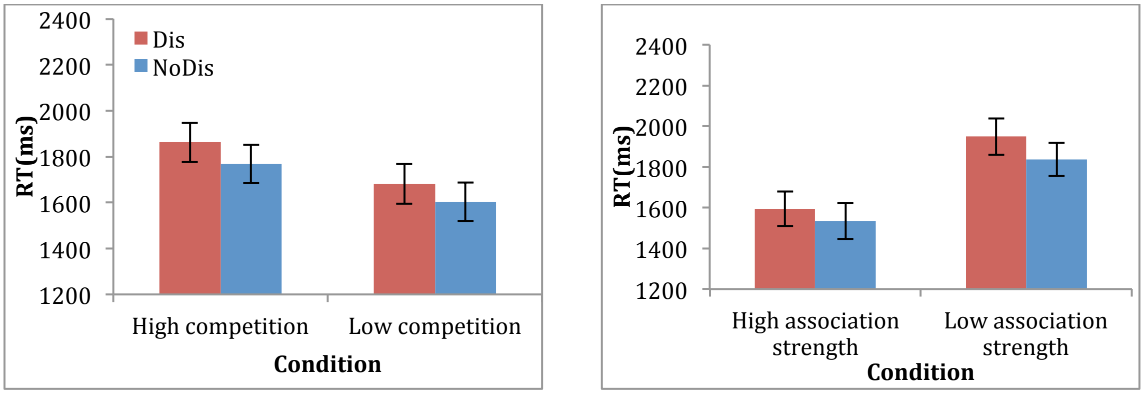

Figure 4-4. Left, retrieval time as a function of competition level and distraction status in combined data; right, retrieval time as a function of association strength level and distraction status in combined data.

The mean 2AFC recognition task accuracy is 0.50. Figure 4-5 left shows the accuracy data as a function of the verb generation condition during which the distraction images had appeared. A one-way ANOVA showed no significant difference between conditions, $F(3, 63) = 2.00$, $p = 0.12$. Figure 4-5 right shows the response times in the recognition task as a function of the verb generation condition during which the distraction images had appeared. No significant difference was found between any conditions, $F < 1$.

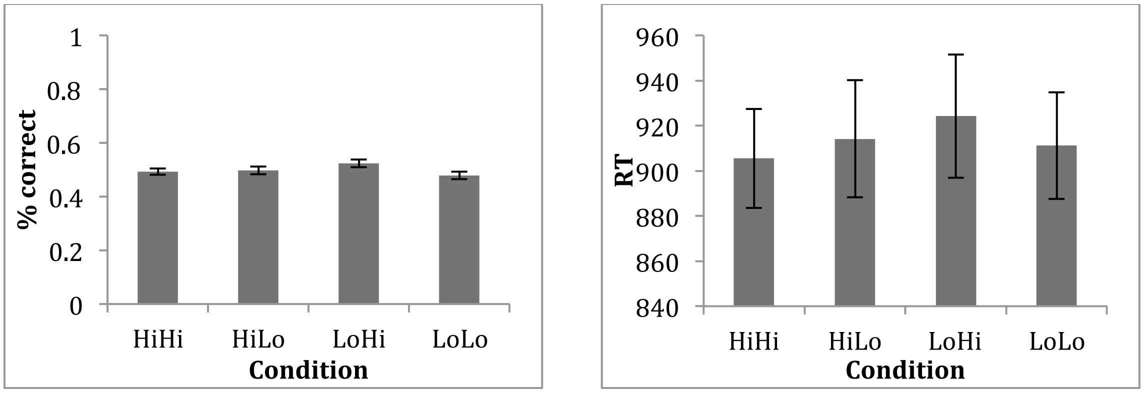

Figure 4-5. Recognition accuracy (left) and response time (in ms, right) in Expt. 3a. HiHi: high competition/high association, HiLo: high competition/low association, LoHi: low competition/high association, LoLo: low competition/low association.

4.3 Experiment 3b

The design was the same as in Experiment 3a except that we presented each stimulus 4 times in 4 runs, in order to get more trials and more power the in analyses. We also wanted to see if the visual distraction effect changes when participants became more familiar with the stimuli and potentially use fewer cognitive resources and less top-down cognitive control to perform the verb generation task over runs. According to the load theory, it is possible that as the primary task becomes easier (in the verb generation task, participants might spend less effort to give a verb after they see the item multiple times), the distraction may have a larger effect (according to perceptual load theory) or, rather, a smaller effect (according to cognitive load theory).

4.3.1 Methods

4.3.1.1 Subjects

Twenty-eight University of Minnesota students (age range 18-25, mean age = 19.04 (SD=1.52), mean years of education = 13.46 (SD=1.30), 8 male) took part in this study for extra course credit. One additional student participated but the data were excluded from analyses because the subject was not a native English speaker.

4.3.1.2 Stimuli and materials

We used the same stimuli as in the previous experiment. In Expt. 3a, each noun was used twice across 2 runs and each distraction image was repeated 4 times across the full verb generation task. In the current study, the task was expanded to 4 runs with the same 96 stimuli in each run. Across the entire verb generation session, each distraction image was repeated 8 times.

4.3.1.3 Procedure

With the exceptions just noted, the procedure was the same as in Expt. 3a.

4.3.2 Results

We looked at the data combined across all four runs.

Figure 4-6 shows response time as a function of condition (i.e., high competition/high association, high competition/low association, low competition/high association, low competition/low association) and distraction status when all four runs were combined. The same pattern as in Expt. 3a appears. Overall the distraction slows the generation time in all four conditions. In addition, the response times are the longest in the most difficult condition (i.e., high competition/low association) and are the shortest in the easiest condition (low competition/high association). A 2 (high vs. low competition) x 2 (high vs. low association strength) x 2 (distraction status: distraction vs. non-distraction) repeated measures ANOVA showed a main effect of competition, $F(1, 27) = 84.79$, $p < .001$, a main effect of association strength, $F(1, 27) = 175.29$, $p < .001$, and a main effect of distraction, $F(1, 27) = 21.92$, $p < 0.001$. The interactions were not significant, *p's* > .29.

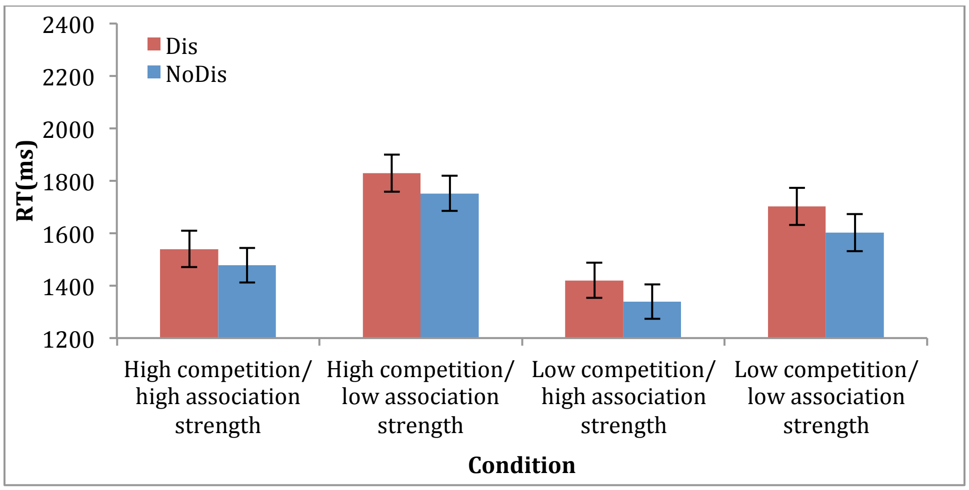

Figure 4-6. Retrieval time as a function of word condition and distraction status when all runs were combined.

Figure 4-7 left shows response time as a function of competition level (high vs. low) and distraction status (distraction vs. non-distraction) in combined runs. The distraction slows the generation time. The high competition condition took longer to respond. A 2 (high competition vs. low competition) x 2 (distraction vs. non-distraction) repeated measures ANOVA showed a main effect of competition, $F(1, 27) = 84.79$, $p < .001$ and a main effect of distraction, $F(1, 27) =$

21.91, $p < 0.001$. The interaction between the two factors was not significant, $F(1, 27) = 1.15$, $p = 0.30$.

Figure 4-7 right shows response time as a function of association strength (high vs. low) and distraction status (distraction vs. non-distraction). The distraction slows the generation time overall. And the high strength condition took less time to respond. A 2 (high association strength vs. low association strength) x 2 (distraction status: distraction vs. non-distraction) repeated measures ANOVA showed a main effect of association strength, $F(1, 27) = 175.29$, $p < .001$. The main effect of distraction was significant as before, $F(1, 27) = 21.91$, $p < .001$. The interaction between the two factors was not significant, $F < 1$.

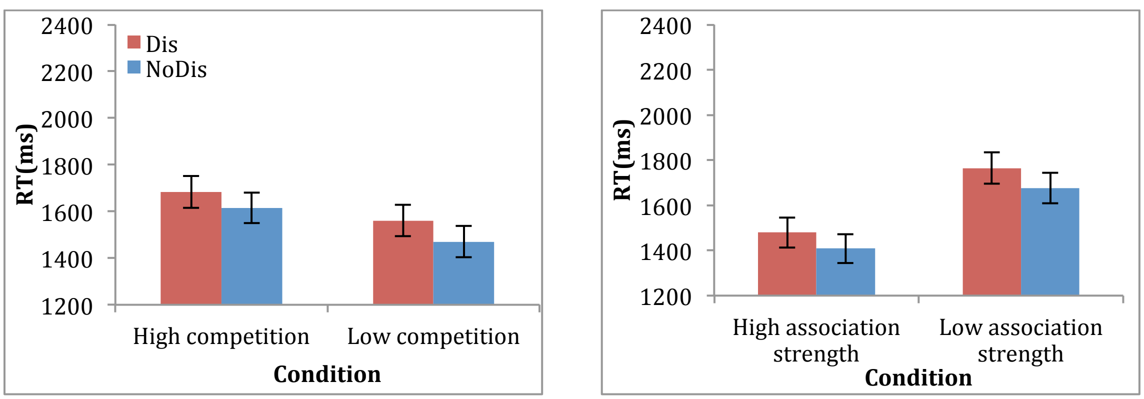

Figure 4-7. Left, retrieval time as a function of competition level and distraction status when all data were combined; right, retrieval time as a function of association strength level and distraction status in the combined data.

The mean 2AFC recognition task accuracy is 0.50. Figure 4-8 left shows the accuracy data as a function of the verb generation condition during which the distraction images had appeared. A one-way ANOVA revealed no significant difference between conditions, $F(3, 75) = 1.14$, $p = 0.34$. Figure 4-8 right shows the response times for the recognition task as a function of image condition. No significant difference between conditions was found, $F < 1$.

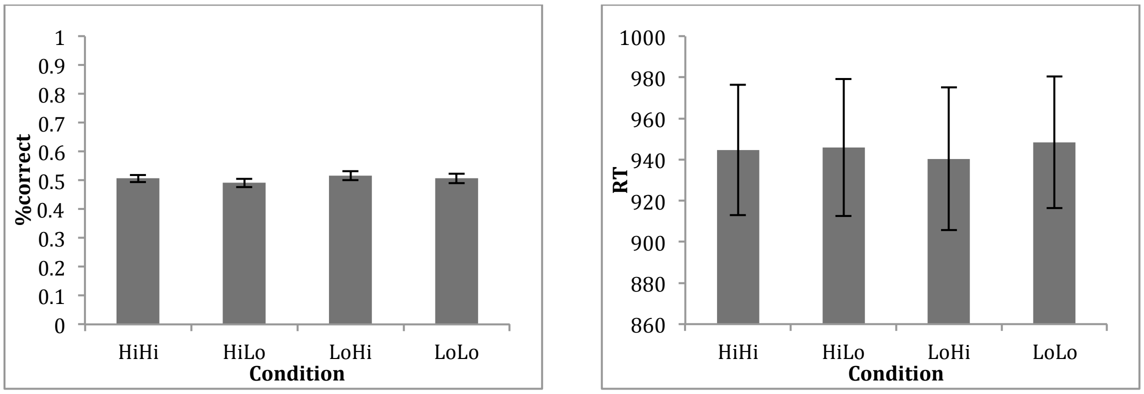

Figure 4-8. Recognition accuracy (left) and response time (in ms, right) in Expt. 3b. HiHi: high competition/high association, HiLo: high competition/low association, LoHi: low competition/high association, LoLo: low competition/low association.

4.4 Discussion

Using a well-established verb generation task, we replicated the findings of Snyder et al. 2011, such that participants responded more slowly in high competition and low association strength conditions. In addition, generation reaction time was the fastest in the low competition/high association strength condition, which confirms the successful manipulation of selection demand and association strength. Interestingly, when participants became more fluent (this fluency was confirmed by the fact that the response time became faster in all conditions over runs when we looked at the data in individual runs) in generating the same stimuli, the distraction effect became smaller in magnitude (the distraction effect is 85.86ms in Expt. 3a where the stimuli have been encountered 2 times; and the distraction effect is 79.69ms in Expt. 3b where the stimuli were shown 4 times). This finding can be seen as consistent with cognitive load theory (Lavie, 2005) as the theory states that as the primary task becomes easier, the distractor receives less processing (i.e., the distractor exerts less effect).

The irrelevant visual information during verb generation slowed response time in all conditions. The interaction between visual distraction and selection demand or association strength was not evident, even in later runs. This finding is not surprising since we did not find an interaction of internal (mnemonic) and external (perceptual) cognitive control demands in the episodic memory task either. This consistency suggests that internal and external attentional control systems may be in action independently.

Chapter 5
Conclusion

When trying to remember detailed information about previously experienced events, we use internal selection processes to select and focus on the relevant memory trace from alternative competitors (James, 1890; Mandler, 1980). At the same time, environmentally distracting information is constantly present and competes for limited attentional resources. This situation places demands on us to use cognitive control processes to filter out both internal and external goal-unrelated information.

In the current study we addressed some questions and limitations in previous research on the topic of the effects of internal interference (selection demand and retrieval demand) and external perceptual distraction on long-term memory retrieval. First, we examined the joint effects of internal and external interference on cognitive performance. For episodic memory, we used a systematic manipulation of association strength and a parametric manipulation of selection demand together with perceptual distraction; for semantic memory, we used an independent manipulation of both association strength and retrieval competition together with perceptual distraction. Second, we examined both memory accuracy and memory retrieval time. Third, to test the generality of the effects of visual distraction, we explored both episodic memory, probing memory for both specific perceptual detail and categorical information of specific spatiotemporal events, and a semantic memory task, involving retrieval of longer-term conceptual knowledge. Moreover, in separate experiments we explored the effects of both static and dynamic visual distraction, and employ both abstract and semantically meaningful scenes as distraction images. Fourth, to overcome the reinstatement and other confounds introduced by eye closure, we compared a distraction condition with a neutral gray screen in all experiments.

We found that as internal mnemonic competition increased, retrieval accuracy decreased and retrieval time increased, and, as the association strength between a given retrieval cue and a target memory increased, retrieval accuracy increased and retrieval time decreased. In addition, visual distraction resulted in small effects on memory accuracy (average effect size *d* of .25), whereas it resulted in large effects on memory retrieval time (average effect size *d* of .99, average response cost of 135ms). Notably, there was little evidence that visual distraction exerted differentially greater effects on retrieval latency under either high selection or high retrieval demands. That is, external perceptual distraction imposed no greater costs when there were many internal target memory contenders (high selection demand) or when the target memory was weak (high retrieval demand).

These results are in general consistent with a number of previous studies (e.g., Badre & Wagner, 2007; Martin & Cheng, 2006; Snyder et al., 2011; Snyder & Munakata, 2008). In particular, the fan effect indicates that the more facts a concept associates with, the more time is needed to retrieve/select any one fact and lower accuracy results (Anderson & Reder, 1999). Our results are similar to this fan effect such that as the number of associates of a name increases, the accuracy decreases and retrieval time increases linearly.

As noted in the introduction, many research studies used a dual task paradigm and found disruption of a secondary task on cognitive processes (Fernandes & Moscovitch, 2000; Fernandes et al., 2006; Jacoby, 1991; Troyer et al., 1999); our current findings and the findings from some previous research (e.g., Wais et al., 2010, 2011, 2012) revealed that entirely irrelevant information can also interfere with long-term memory. Table 5-1 summarizes the distraction effect on memory accuracy and RT across experiments, using Cohen's *d* effect size measures, and the average distraction effect in ms. Specifically, we found that irrelevant visual distraction resulted in slower retrieval of the target memory in both episodic and semantic memory tasks. But, in our experiments, there was no consistent effect of visual distraction on memory accuracy. A meta-analysis of the effects of visual distraction on accuracy across studies showed that the 95% confidence interval of the mean effect size is 0.10-0.38. And a homogeneity analysis failed to reject the null hypothesis of homogeneity (that is, we found similar effects of visual distraction across different modes of distraction and across different memory tasks). Thus, across studies, there is only a slight effect of visual distraction on memory accuracy.

A meta-analysis on the effect of visual distraction on RT across studies showed that the 95% confidence interval of the mean effect size for retrieval latency is 0.88-1.13. And a homogeneity analysis rejected the null hypothesis of homogeneity (that is, the effects of visual distraction are likely different across different modes of distraction and across different memory tasks). This may be due to the fact that the effect sizes on RT varied dramatically across experiments. As we can see from Table 5-1, the effect sizes for semantic memory experiments (Experiment 3) are relatively larger than other experiments, although when we look at the mean visual distraction effect in ms, this does not emerge strongly. The relatively larger effect size in semantic memory experiments may be due to several reasons. First, the semantic task is very different from the episodic memory tasks we used in Experiment 1 and 2. It is testing a longer-term conceptual knowledge, which might be easier than the just learned episodic events. Second, there may be less variability across participants in the RTs for the semantic memory task than for the episodic memory ones. This is indeed the case when we look at the average standard deviation (SD) of RTs for the 3 Experiments. The average SDs of RTs were 787.13, 630.19, and 417.93 in Experiment 1, 2, and 3, respectively. Third, the visual distraction used in semantic memory tasks is screen-saver like images, which is different than those in the other experiments. Nevertheless, despite the varied effect sizes on RT across experiments, (with just one exception) the effect sizes for the visual distraction effects on retrieval latency are large for all the sub-experiments.

Table 5-1. Summary of the effects of visual distraction across all experiments. Column two and three show the distraction effect using Cohen's *d* measures for memory retrieval accuracy and memory retrieval time (RT) in each experiment, respectively. The last column shows the mean effect of distraction on retrieval latency (in ms) in each experiment.

Experiment	Accuracy (Cohen's *d*)	RT (Cohen's *d*)	Mean effect in RT (ms)
Expt. 1a	0.40	0.60	94.23
Expt. 1b	0.28	0.80	145.19
Expt. 1c	0.52	1.41	203.23
Expt. 1d	-0.27	0.58	72.09
Expt. 1e	0.13	0.88	322.41
Expt. 2a	0.34	1.12	253.39
Expt. 2b	0.41	0.92	261.24
Expt. 2c	0.15	-0.23	-17.67
Expt. 3a	-	1.98	85.86
Expt. 3b	-	1.80	79.69
Mean	0.25	0.99	134.73

On the one hand, our results are consistent with the results of Wais et al. regarding the detrimental effect of visual distraction. However, they found decreased accuracy in the distraction condition compared to the no-distraction condition. This discrepancy might be due to the different condition manipulation in our experiments, as we did not have an eyes-closed condition. The gray background condition in our experiments might not be sufficiently neutral as a comparison condition, as there is still sensory stimulation present. However, an eye-closure condition, which was used in many studies, may not be ideal as it may allow more room for spontaneous mental context reinstatement (Vredeveldt & Penrod, 2013), resulting in less experimental control in comparing the eyes-closed condition and eyes-open condition. Thus, the gray background condition may provide fuller and tighter control for factors such as spontaneous mental context reinstatement and thereby be better equated to the visual distraction condition. In future studies, researchers might include more than two levels of distraction to see if it produces different effects on memory retrieval accuracy.

On the other hand, our findings of little effect of visual distraction on memory retrieval accuracy seems consistent with the claim by Baddeley et al. (1984) that memory retrieval does not demand much attention (thus it is automatic) as the effect of a secondary task on retrieval (in terms of accuracy) is none to very small, but there is an effect of secondary task load on retrieval time. However, on the contrary of Baddeley's claim, some studies did find that retrieval is attentionally demanding (e.g., Johnston et al., 1970; Martin, 1970; Trumbo & Milone, 1971) such that errors in concurrent task performance increased more and response time slowed during memory recall. Furthermore, our findings of little effect of visual distraction on memory retrieval accuracy are also consistent with Rae and Perfect (2014). However, these authors used word lists in free recall tasks, which is different from the episodic memory task and verb generation task that we used here.

The inconsistent findings of visual distraction effect on memory accuracy may be due to paradigm differences and variations in task sensitivity and require more exploration in future studies. One thing to keep in mind is that although we did not find much effect of visual distraction on memory accuracy, it does not mean that visual distraction has no influence on retrieval accuracy. It is possible that under perceptual distraction conditions, memory retrieval processes are undermined but this detrimental effect is not potent enough to appear as a cost in recall accuracy when memory is tested following a short retention interval. It might be the case that if we tested memory after a longer retention interval, we would have seen effects on memory accuracy. In addition, in all of our experiments, it is essentially a single association that must be retrieved. However, in more complex everyday contexts, several forms of interrelated information might need to be retrieved. It is possible that in those contexts, visual distraction will be more detrimental to retrieval accuracy or to retrieval success.

Previous research on the cognitive control of memory retrieval when facing internal mnemonic competition found interference resolution in left VLPFC, but predominantly with semantic memory and working memory tasks. Although there is an implication for the involvement of left VLPFC in episodic memory, the evidence is less clear. We started to explore the effect of competition on episodic memory here and hoped to provide the foundations for a future imaging study. In addition, in terms of mnemonic competition, most of the previous studies used only two levels of selection demand (i.e., selection vs. non-selection), little has been explored as to how the different levels of competition influence the memory retrieval performance and cognitive control. We introduced a three-level manipulation of selection demand in the current research. The manipulation was successful and the results across experiments were consistent. Using the manipulation of three levels of selection revealed that the memory performance changed linearly as the selection demand change continuously from low to high.

Also, the three-level manipulation provided more fine-grained control and better represented the real situation, as the selection demands are more likely to have more than two extremes (i.e., high vs. low) in everyday life. Furthermore, while previous studies mostly used semantic tasks in investigating the effects of memory association strength, we explored these effects on both semantic (Experiment 3) and episodic memory tasks (Experiment 2).

Across our experiments, we used both static and dynamic visual distraction. Although there were many across-experiment differences and distracting image content differences (abstract images vs. scenes) for the static distraction vs. dynamic distraction, we found that both types of distraction disrupted memory retrieval performance to a similar extent. Specifically, the average distraction effect when using static distraction (Expt. 1a-1c) was 147.55ms, and the average distraction effect when using dynamic distraction (Expt. 1d-1e, 2a-2c, 3a-3b) was 129.92ms. This finding is in contrast to what Rae and Perfect (2014) found. They found no effect of dynamic visual noise on retrieval. One possible reason for this, as postulated by Craik (2014), is that, in their study, the information to be retrieved was qualitatively very different from the distracting material as in the experiments (Rae & Perfect, 2014) participants attempted to recall individual words while looking at a dynamic visual noise screen. However, we are conservative with such a claim (e.g., Craik, 2014; Fernandes & Moscovitch, 2000), because in our experiments, what participants needed to retrieve was always very different from the distracting images. Thus, we think that the effects of visual distraction we found are unlikely to be attributable to semantic or conceptual overlap between the distracting content and the target memory. Future research with a more analytically incisive design is needed to study in depth what factors determine the magnitude of the distraction effect, on both long-term memory retrieval accuracy and response latency.

There were no consistent results in participants' recognition performance for the distracting images. In Expt. 1a-1d, we used a single-probe old/new recognition paradigm; because the participants were strongly biased toward calling items "new", the results were not clear in those experiments. In Expt. 1e with a 2AFC paradigm, we found that distractor images from easy trials (competition 1 and 2) were correctly recognized more often than were images from difficult trials (competition 3). In Expt. 2c, we found that distraction images from the easy condition (high association strength) were recognized more often than those from the difficult condition (low association strength). These effects were not found in Expt. 2a and 2b. In Expt. 3a, images from a relatively easy (low competition/high association) condition were recognized more often than those from a relatively difficult (low competition/low association) condition. In Expt. 3b, again distractor images from a relatively easy (low competition/high association) condition were slightly more often recognized than those from a relatively difficult (high competition/low association) condition. Our findings from the memory test for the distractors are partially consistent with the load theory (Lavie, 2005). The load theory has two sides. Perceptual load theory states that high perceptual load (i.e., in the primary task) results in less distractor processing whereas cognitive load theory states that high cognitive load increases distractor processing. Our findings in the experiments outlined above seem to be consistent with perceptual load theory. However, it should be noted that the primary tasks in our experiments are cognitive tasks. The reason why the findings are consistent with perceptual load rather than cognitive load theory is unclear.

A central and consistent finding in our current research is that our manipulation of mnemonic interference did not interact with visual distraction. According to the load theory of attention (Lavie, 1995; Lavie et al., 2004), high perceptual load reduces distractor interference whereas high cognitive load increases distractor interference. Our research did not find evidence for this given that the visual distraction effect did not differentiate in the high cognitive load condition (e.g., high competition or low association strength) versus the low cognitive load conditions (e.g., low competition or high association strength). We next consider several possible reasons for the lack of interaction.

First, we may have a very large pool of cognitive resources, such that even at our highest competition level or lowest association strength, there were still enough resources left to monitor the environment, so there is no additional cost at the highest competition level or lowest association strength while facing visual distraction. This account is not very likely as we can see that retrieval accuracy across all of the experiments is usually at 50%-60%. In addition, based on anecdotal casual feedback from participants, the memory tasks were very difficult. To test this account there needs to be more systematic manipulation of competition demand and association strength in future studies to see a possible interaction.

Second, it might be that despite our efforts to make the visual distraction more diverse and more distracting, it was still not effective enough, precluding the observation of the interaction effect. On the one hand, our distraction manipulation was subjectively deemed very distracting and the RT data also attested to that (surprisingly, previous studies on visual distraction rarely looked at response time, so there is no clear way to compare our retrieval latency RT effects with those found in other studies). On the other hand, this account cannot be totally excluded since we do not have independent objective measures of the effectiveness of the distraction. This may be a question for future investigations that use tools to measure brain activity or physiological responses in order to quantify how effective the distraction is.

Third, a combination of the first account and the second account might apply. Again, the current research cannot determine for sure whether it is a plausible explanation of no interaction.

Fourth, it might be the case that it is impossible to monitor the external environment and to retrieve memory at the same time. There may be a processing bottleneck such that the cognitive control systems need to do one task first (e.g., perceptual processing) and then the other task (e.g., memory retrieval) in a serial processing fashion. If this is true, the findings that internal and external interference exert separate and independent (non-interactive) effects on memory accuracy and retrieval time could point to a type of serial gating effect in which cognitive control is focused successively on either the internal or external sources of interference. This account is plausible as it is consistent with studies of the psychological refractory period effect (e.g., Pashler, 1994) using dual-task paradigms. These studies have shown that there is a stubborn bottleneck to carrying out processes such as memory retrieval concurrently with other cognitive operations. However, it is unknown whether the perceptual distraction and memory retrieval are serially processed or alternatively processed (e.g., in an interleaved manner) or in some other method. This could be an important avenue for future studies.

Regarding the neural basis of the visual distraction effect, Wais et al. (2010) suggested two hypotheses regarding the mechanisms underlying the visual distraction effect on memory. First, bottom-up visual processing of external information may diminish the quality of internal representations generated via visual imagery during memory retrieval, because both types of representations rely on overlapping regions of visual cortices. Second, because attentional resources are limited (Pashler & Shiu, 1999), top-down effort required to retrieve memories may be disrupted when incidental attention to the irrelevant visual information diverts some resources away from memory retrieval goals. The two hypotheses are not mutually exclusive but are complementary. Their research supports these hypotheses and provides evidence that there is a capacity-limited frontal control mechanism, which exerts top-down controls for the selection of episodic details, and bottom-up influences from irrelevant visual information that interfere with and impair internal selection through diverting away this limited resource. Our behavioral data also seem compatible with these suggested hypotheses.

Our research has both theoretical and practical implications. The results reported here indicate that no matter if we are seeing static or moving, or abstract vs. concrete visual stimulation, environmental monitoring and memory retrieval compete for cognitive resources. Perceptual distraction in our environment slows memory retrieval. This slowing was found regardless of whether the to-be-retrieved memory was strong or weak, and regardless of whether it was prompted by a retrieval cue with only one or several associated memories. Slowing occurred both when the memory content concerned individual spatiotemporal events that were recently learned (episodic memory) or, instead, involved more cross-situational long-known conceptual information (semantic memory). This has very important implications in educational settings where irrelevant visual distraction could affect how well teachers and students learn and remember and in legal settings where irrelevant visual distraction could affect how well witnesses remember and report criminal events. In addition, in situations (e.g., emergency events, executive meetings) where decisions and actions need to be taken quickly, visual distraction can affect important outcomes. Studying the effects of irrelevant visual distraction on memory retrieval can thus help us to understand the underlying mechanisms and discover useful methods to improve cognitive performance in different settings.

In future research, we will continue to study the interaction between internal attention and external attention. Although there was no clear interaction effect between visual distraction and selection demand and association strength in the current behavioral research, it is still possible that once we look at the neural level of these effects, we could discover some clues about how internally demanding processes interact with sensory processing of environmental information. Nevertheless, both non-interactive and interactive effects of internal and external attention are important to see as either can shed light on the process whereby the top-down control system exerts effects on perception and cognition. In addition, we could investigate the difference between proactive control versus reactive control (e.g., Braver, 2012) and how this could affect the perceptual distraction effect. In our experiments, participants were using reactive control as they were directly prompted by a specific cue to recall the relevant memory and did not know beforehand what type of information they would need. Proactive control may be in use when people know beforehand that some information has a higher probability to be needed. For example, in our Experiment 2, since there were easy vs. difficult memories to retrieve, we could have cued participants as to the type of upcoming trial (e.g., presenting “studied often” before an easy trial and “studied seldom” before a difficult trial). Participants might have used proactive control in this situation, intentionally bringing more resources to bear on the difficult than the easy trials. Furthermore, it might also be worth exploring how normal ageing contribute to the cognitive control of memory retrieval in the face of external distraction since it has been suggested that older adults may have reduced distraction regulation (e.g., Kim et al., 2007; Thomas & Hasher, 2012) and may rely more on reactive than proactive control.

Bibliography

Anderson, J. R., & Reder, L. M. (1999). The fan effect: New results and new theories. *Journal of Experimental Psychology-General, 128*(2), 186-197. doi: Doi 10.1037//0096-3445.128.2.186

Anderson, M. C., Ochsner, K. N., Kuhl, B., Cooper, J., Robertson, E., Gabrieli, S. W., Gabrieli, J. D. E. (2004). Neural systems underlying the suppression of unwanted memories. *Science, 303*(5655), 232-235. doi: Doi 10.1126/Science.1089504

Arnell, K. M., & Jolicoeur, P. (1999). The attentional blink across stimulus modalities: Evidence for central processing limitations. *Journal of Experimental Psychology-Human Perception and Performance, 25*(3), 630-648. doi: Doi 10.1037/0096-1523.25.3.630

Baddeley, A., Lewis, V., Eldridge, M., & Thomson, N. (1984). Attention and retrieval from long-term-memory. *Journal of Experimental Psychology-General, 113*(4), 518-540. doi: Doi 10.1037//0096-3445.113.4.518

Badre, D., Poldrack, R. A., Pare-Blagoev, E. J., Insler, R. Z., & Wagner, A. D. (2005). Dissociable controlled retrieval and generalized selection mechanisms in ventrolateral prefrontal cortex. *Neuron, 47*(6), 907-918. doi: Doi 10.1016/J.Neuron.2005.07.023

Badre, D., & Wagner, A. D. (2002). Prefrontal and medial temporal contributions to controlled semantic retrieval in cognitive aging. *Journal of Cognitive Neuroscience*, 34-34.

Badre, D., & Wagner, A. D. (2007). Left ventrolateral prefrontal cortex and the cognitive control of memory. *Neuropsychologia, 45*(13), 2883-2901. doi: Doi 10.1016/J.Neuropsychologia.2007.06.015

Braver, T. S. (2012). The variable nature of cognitive control: a dual mechanisms framework. *Trends in Cognitive Sciences, 16*(2), 106-113. doi: 10.1016/j.tics.2011.12.010

Carrier, L. M., & Pashler, H. (1995). Attentional limits in lemory retrieval. *Journal of Experimental Psychology-Learning Memory and Cognition, 21*(5), 1339-1348. doi: Doi 10.1037//0278-7393.21.5.1339

Chun, M. M., Golomb, J. D., & Turk-Browne, N. B. (2011). A taxonomy of external and internal attention. *Annual Review of Psychology, Vol 62, 62*, 73-101. doi: Doi 10.1146/Annurev.Psych.093008.100427

Chun, M. M., & Turk-Browne, N. B. (2007). Interactions between attention and memory. *Current Opinion in Neurobiology, 17*(2), 177-184. doi: Doi 10.1016/J.Conb.2007.03.005

Corbetta, M., & Shulman, G. L. (2002). Control of goal-directed and stimulus-driven attention in the brain. *Nature Reviews Neuroscience, 3*(3), 201-215. doi: Doi 10.1038/Nrn755

Correa, A., & Nobre, A. C. (2008). Spatial and temporal acuity of visual perception can be enhanced selectively by attentional set. *Experimental Brain Research, 189*(3), 339-344. doi: Doi 10.1007/S00221-008-1429-2

Craik, F. I. M. (2014). Effects of distraction on memory and cognition: a commentary. *Frontiers in Psychology, 5*. doi: Artn 841 Doi 10.3389/Fpsyg.2014.00841
Craik, F. I. M., Govoni, R., NavehBenjamin, M., & Anderson, N. D. (1996). The effects of divided attention on encoding and retrieval processes in human memory. *Journal of Experimental Psychology-General, 125*(2), 159-180. doi: Doi 10.1037/0096-3445.125.2.159
de Fockert, J. W., Rees, G., Frith, C. D., & Lavie, N. (2001). The role of working memory in visual selective attention. *Science, 291*(5509), 1803-1806. doi: Doi 10.1126/Science.1056496
Dell'Acqua, R., Sessa, P., Jolicoeur, P., & Robitaille, N. (2006). Spatial attention freezes during the attention blink. *Psychophysiology, 43*(4), 394-400. doi: Doi 10.1111/J.1469-8986.2006.00411.X
Doherty, J. R., Rao, A. L., Mesulam, M. M., & Nobre, A. C. (2005). Synergistic effect of combined temporal and spatial expectations on visual attention. *Journal of Neuroscience, 25*(36), 8259-8266. doi: Doi 10.1523/Jneurosci.1821-05.2005
Doherty-Sneddon, G., Bonner, L., & Bruce, V. (2001). Cognitive demands of face monitoring: Evidence for visuospatial overload. *Memory & Cognition, 29*(7), 909-919. doi: Doi 10.3758/Bf03195753
Doherty-Sneddon, G., Bruce, V., Bonner, L., Longbotham, S., & Doyle, C. (2002). Development of gaze aversion as disengagement from visual information. *Developmental Psychology, 38*(3), 438-445. doi: Doi 10.1037//0012-1649.38.3.438
Doherty-Sneddon, G., & Phelps, F. G. (2005). Gaze aversion: A response to cognitive or social difficulty? *Memory & Cognition, 33*(4), 727-733. doi: Doi 10.3758/Bf03195338
Driver, J., & Spence, C. (1998). Attention and the crossmodal construction of space. *Trends in Cognitive Sciences, 2*(7), 254-262. doi: Doi 10.1016/S1364-6613(98)01188-7
Duncan, J., Martens, S., & Ward, R. (1997). Restricted attentional capacity within but not between sensory modalities. *Nature, 387*(6635), 808-810. doi: Doi 10.1038/42947
Egeth, H. E., & Yantis, S. (1997). Visual attention: Control, representation, and time course. *Annual Review of Psychology, 48*, 269-297. doi: Doi 10.1146/Annurev.Psych.48.1.269
Eriksen, B. A., & Eriksen, C. W. (1974). Effects of noise letters upon identification of a target letter in a nonsearch task. *Perception & Psychophysics, 16*(1), 143-149. doi: Doi 10.3758/Bf03203267
Fernandes, M. A., & Moscovitch, M. (2000). Divided attention and memory: Evidence of substantial interference effects at retrieval and encoding. *Journal of Experimental Psychology-General, 129*(2), 155-176. doi: Doi 10.1037/0096-3445.129.2.155
Fernandes, M. A., Pacurar, A., Moscovitch, M., & Grady, C. (2006). Neural correlates of auditory recognition under full and divided attention in

younger and older adults. *Neuropsychologia, 44*(12), 2452-2464. doi: Doi 10.1016/J.Neuropsychologia.2006.04.020
Fletcher, P. C., Shallice, T., & Dolan, R. J. (2000). "Sculpting the response space" - An account of left prefrontal activation at encoding. *Neuroimage, 12*(4), 404-417. doi: Doi 10.1006/Nimg.2000.0633
Fuster, J. M. (1997). The prefrontal cortex: Anatomy, physiology and neuropsychology of the frontal lobe (3rd ed.). Philadelphia, PA: Lippincott-Raven Publishers.
Glenberg, A. M., Schroeder, J. L., & Robertson, D. A. (1998). Averting the gaze disengages the environment and facilitates remembering. *Memory & Cognition, 26*(4), 651-658. doi: Doi 10.3758/Bf03211385
Gold, B. T., Balota, D. A., Jones, S. J., Powell, D. K., Smith, C. D., & Andersen, A. H. (2006). Dissociation of automatic and strategic lexical-semantics: Functional magnetic resonance imaging evidence for differing roles of multiple frontotemporal regions. *Journal of Neuroscience, 26*(24), 6523-6532. doi: Doi 10.1523/Jneurosci.0808-06.2006
Griffiths, T. L., Steyvers, M., & Tenenbaum, J. B. (2007). Topics in semantic representation. *Psychological Review, 114*(2), 211-244. doi: Doi 10.1037/0033-295x.114.2.211
Han, S. H., & Kim, M. S. (2004). Visual search does not remain efficient when executive working memory is working. *Psychological Science, 15*(9), 623-628. doi: Doi 10.1111/J.0956-7976.2004.00730.X
Hollingworth, A., Richard, A. M., & Luck, S. J. (2008). Understanding the function of visual short-term memory: Transsaccadic memory, object correspondence, and gaze correction. *Journal of Experimental Psychology-General, 137*(1), 163-181. doi: Doi 10.1037/0096-3445.137.1.163
Jacoby, L. L. (1991). A process dissociation framework - Separating automatic from intentional uses of memory. *Journal of Memory and Language, 30*(5), 513-541. doi: Doi 10.1016/0749-596x(91)90025-F
James, W. (1890). *The principles of psychology*. New York: Holt.
Johansen-Berg, H., & Lloyd, D. M. (2000). The physiology and psychology of selective attention to touch. *Frontiers in Bioscience, 5*, D894-D904. doi: Doi 10.2741/Berg
Johnston, W. A., Greenber.Sn, Fisher, R. P., & Martin, D. W. (1970). Divided attention - a vehicle for monitoring memory processes. *Journal of Experimental Psychology, 83*(1), 164-&. doi: Doi 10.1037/H0028554
Jolicoeur, P. (1998). Modulation of the attentional blink by on-line response selection: Evidence from speeded and unspeeded Task(1) decisions. *Memory & Cognition, 26*(5), 1014-1032. doi: Doi 10.3758/Bf03201180
Jost, K., Khader, P. H., Dusel, P., Richter, F. R., Rohde, K. B., Bien, S., & Rosler, F. (2012). Controlling conflict from interfering long-term memory representations. *Journal of Cognitive Neuroscience, 24*(5), 1173-1190.

Kim, S., Hasher, L., & Zacks, R. T. (2007). Aging and a benefit of distractibility. *Psychonomic Bulletin & Review, 14*(2), 301-305. doi: Doi 10.3758/Bf03194068

Koutstaal, W., Schacter, D. L., Verfaellie, M., Brenner, C., & Jackson, E. M. (1999). Perceptually based false recognition of novel objects in amnesia: Effects of category size and similarity to category prototypes. *Cognitive Neuropsychology, 16*(3-5), 317-341.

Kuhl, B. A., Dudukovic, N. M., Kahn, I., & Wagner, A. D. (2007). Decreased demands on cognitive control reveal the neural processing benefits of forgetting. *Nature Neuroscience, 10*(7), 908-914. doi: Doi 10.1038/Nn1918

Landauer, T. K., Foltz, P. W., & Laham, D. (1998). An introduction to latent semantic analysis. *Discourse Processes*, *25*, 259–284.

Lavie, N. (1995). Perceptual load as a necessary condition for selective attention. *Journal of Experimental Psychology-Human Perception and Performance, 21*(3), 451-468. doi: Doi 10.1037/0096-1523.21.3.451

Lavie, N. (2005). Distracted and confused?: Selective attention under load. *Trends in Cognitive Sciences, 9*(2), 75-82. doi: Doi 10.1016/J.Tics.2004.12.004

Lavie, N., Hirst, A., de Fockert, J. W., & Viding, E. (2004). Load theory of selective attention and cognitive control. *Journal of Experimental Psychology-General, 133*(3), 339-354. doi: Doi 10.1037/0096-3445.133.3.339

Mandler, G. (1980). Recognizing - the judgment of previous occurrence. *Psychological Review, 87*(3), 252-271. doi: Doi 10.1037//0033-295x.87.3.252

Markson, L., & Paterson, K. B. (2009). Effects of gaze-aversion on visual-spatial imagination. *British Journal of Psychology, 100*, 553-563. doi: Doi 10.1348/000712608x371762

Martin, D. W. (1970). Residual processing capacity during verbal organization in memory. *Journal of Verbal Learning and Verbal Behavior, 9*(4), 391-&. doi: Doi 10.1016/S0022-5371(70)80078-0

Martin, R. C., & Cheng, T. (2006). Selection demands versus association strength in the verb generation task. *Psychonomic Bulletin & Review, 13*(3), 396-401. doi: Doi 10.3758/Bf03193859

Mastroberardino, S., Natali, V., & Candel, I. (2010). The effect of eye closure on children's eyewitness testimonies. *Psychology, Crime & Law*. Advance online publication. doi:10.1080/10683161003801100

Mastroberardino, S., & Vredeveldt, A. (2014). Eye-closure increases children's memory accuracy for visual material. *Frontiers in Psychology, 5*. doi: Artn 241
Doi 10.3389/Fpsyg.2014.00241

Mcleod, P. D. (1973). Interference of attend to and learn tasks with tracking. *Journal of Experimental Psychology, 99*(3), 330-333. doi: Doi 10.1037/H0035249

Minear, M. & Park, D.C. (2004). A lifespan database of adult facial stimuli. *Behavior Research Methods, Instruments, & Computers*, *36*, 630-633. doi: 10.3758/BF03206543

Moss, H. E., Abdallah, S., Fletcher, P., Bright, P., Pilgrim, L., Acres, K., & Tyler, L. K. (2005). Selecting among competing alternatives: Selection and retrieval in the left inferior frontal gyrus. *Cerebral Cortex, 15*(11), 1723-1735. doi: Doi 10.1093/Cercor/Bhi049

Nathaniel-James, D. A., & Frith, C. D. (2002). The role of the dorsolateral prefrontal cortex: Evidence from the effects of contextual constraint in a sentence completion task. *Neuroimage, 16*(4), 1094-1102. doi: Doi 10.1006/Nimg.2002.1167

Noble, M., Trumbo, D., & Fowler, F. (1967). Further evidence on secondary task interference in tracking. *Journal of Experimental Psychology, 73*(1), 146-&. doi: Doi 10.1037/H0024092

Norman, D. A., & Bobrow, D. G. (1979). Descriptions - Intermediate stage in memory retrieval. *Cognitive Psychology, 11*(1), 107-123. doi: Doi 10.1016/0010-0285(79)90006-9

Parasuraman R. 1998. The attentive brain: issues and prospects. In *The Attentive Brain*, ed. R Parasuraman, pp. 3–15. Cambridge, MA: MIT Press

Pashler, H. E. 1998. *The Psychology of Attention*. Cambridge, MA: MIT Press

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

Pashler, H., & Shiu, L. P. (1999). Do images involuntarily trigger search? A test of Pillsbury's hypothesis. *Psychonomic Bulletin & Review, 6*(3), 445-448. doi: Doi 10.3758/Bf03210833

Perfect, T. J., Andrade, J., & Eagan, I. (2011). Eye closure reduces the cross-modal memory impairment caused by auditory distraction. *Journal of Experimental Psychology-Learning Memory and Cognition, 37*(4), 1008-1013. doi: Doi 10.1037/A0022930

Perfect, T. J., Wagstaff, G. F., Moore, D., Andrews, B., Cleveland, V., Newcombe, S., Brown, L. (2008). How can we help witnesses to remember more? It's an (eyes) open and shut case. *Law and Human Behavior, 32*(4), 314-324. doi: Doi 10.1007/S10979-007-9109-5

Persson, J., Sylvester, C. Y. C., Nelson, J. K., Welsh, K. M., Jonides, J., & Reuter-Lorenz, P. A. (2004). Selection requirements during verb generation: Differential recruitment in older and younger adults. *Neuroimage, 23*, 1382–1390. doi:10.1016/j.neuroimage.2004.08.004

Phelps, F. G., Doherty-Sneddon, G., & Warnock, H. (2006). Helping children think: Gaze aversion and teaching. *British Journal of Developmental Psychology, 24*, 577-588. doi: Doi 10.1348/026151005x49872

Posner, M. I., Snyder, C. R. R., & Davidson, B. J. (1980). Attention and the detection of signals. *Journal of Experimental Psychology-General, 109*(2), 160-174. doi: Doi 10.1037//0096-3445.109.2.160

Potter, M. C., Chun, M. M., Banks, B. S., & Muckenhoupt, M. (1998). Two attentional deficits in serial target search: The visual attentional blink and an amodal task-switch deficit. *Journal of Experimental Psychology-Learning Memory and Cognition, 24*(4), 979-992. doi: Doi 10.1037//0278-7393.24.4.979

Raaijmakers, J. G. W., & Shiffrin, R. M. (1981). Search of Associative Memory. *Psychological Review, 88*(2), 93-134. doi: Doi 10.1037/0033-295x.88.2.93

Radvansky, G. A. (1999). The fan effect: A tale of two theories. *Journal of Experimental Psychology-General, 128*(2), 198-206. doi: Doi 10.1037/0096-3445.128.2.198

Rae, P. J. L., & Perfect, T. J. (2014). Visual distraction during word-list retrieval does not consistently disrupt memory. *Frontiers in Psychology, 5*. doi: Artn 362
Doi 10.3389/Fpsyg.2014.00362

Ranganath, C., Johnson, M. K., & D'Esposito, M. (2000). Left anterior prefrontal activation increases with demands to recall specific perceptual information. *Journal of Neuroscience, 20*(22), art. no.-RC108.

Schacter, D. L. (1987). Memory, amnesia, and frontal-Lobe dysfunction. *Psychobiology, 15*(1), 21-36.

Scholl, B. J. (2001). Objects and attention: the state of the art. *Cognition, 80*(1-2), 1-46. doi: Doi 10.1016/S0010-0277(00)00152-9

Shimamura, A. P., Jurica, P. J., Mangels, J. A., Gershberg, F. B., & Knight, R. T. (1995). Susceptibility to memory Iiterference effects following frontal-lobe damage - Findings from tests of paired-associate learning. *Journal of Cognitive Neuroscience, 7*(2), 144-152. doi: Doi 10.1162/Jocn.1995.7.2.144

Snyder, H. R., Banich, M. T., & Munakata, Y. (2011). Choosing our words: Retrieval and selection processes recruit shared neural substrates in seft ventrolateral prefrontal cortex. *Journal of Cognitive Neuroscience, 23*(11), 3470-3482.

Snyder, H. R., & Munakata, Y. (2008). So many options, so little time: The roles of association and competition in underdetermined responding. *Psychonomic Bulletin & Review, 15*(6), 1083-1088. doi: Doi 10.3758/Pbr.15.6.1083

Sohn, M. H., Goode, A., Stenger, V. A., Carter, C. S., & Anderson, J. R. (2003). Competition and representation during memory retrieval: Roles of the prefrontal cortex and the posterior parietal cortex. *Proceedings of the National Academy of Sciences of the United States of America, 100*(12), 7412-7417. doi: Doi 10.1073/Pnas.0832374100

Thomas, R. C., & Hasher, L. (2012). Reflections of distraction in memory: Transfer of previous distraction improves recall in younger and older adults. *Journal of Experimental Psychology-Learning Memory and Cognition, 38*(1), 30-39. doi: Doi 10.1037/A0024882

Thompson-Schill, S. L., D'Esposito, M., Aguirre, G. K., & Farah, M. J. (1997). Role of left inferior prefrontal cortex in retrieval of semantic knowledge: A

reevaluation. *Proceedings of the National Academy of Sciences of the United States of America, 94*(26), 14792-14797. doi: Doi 10.1073/Pnas.94.26.14792
Tootell, R. B. H., Hadjikhani, N., Hall, E. K., Marrett, S., Vanduffel, W., Vaughan, J. T., & Dale, A. M. (1998). The retinotopy of visual spatial attention. *Neuron, 21*(6), 1409-1422. doi: Doi 10.1016/S0896-6273(00)80659-5
Troyer, A. K., Winocur, G., Craik, F. I. M., & Moscovitch, M. (1999). Source memory and divided attention: Reciprocal costs to primary and secondary tasks. *Neuropsychology, 13*(4), 467-474. doi: Doi 10.1037//0894-4105.13.4.467
Trumbo, D., & Milone, F. (1971). Primary task performance as a function of encoding, retention, and recall in a secondary task. *Journal of Experimental Psychology, 91*, 273-279.
Veldhuizen, M. G., Bender, G., Constable, R. T., & Small, D. M. (2007). Trying to detect taste in a tasteless solution: Modulation of early gustatory cortex by attention to taste. *Chemical Senses, 32*(6), 569-581. doi: Doi 10.1093/Chemse/Bjm025
Vredeveldt, A., Hitch, G. J., & Baddeley, A. D. (2011). Eyeclosure helps memory by reducing cognitive load and enhancing visualisation. *Memory & Cognition, 39*(7), 1253-1263. doi: Doi 10.3758/S13421-011-0098-8
Vredeveldt, A., & Penrod, S. D. (2013). Eye-closure improves memory for a witnessed event under naturalistic conditions. *Psychology Crime & Law, 19*(10), 893-905. doi: Doi 10.1080/1068316x.2012.700313
Wagner, A. D. (2002). Cognitive control and episodic memory: Contributions from prefrontal cortex. In L. R. Squire & D. L. Schacter (Eds.), *Neuropsychology of memory* (3rd ed., pp. 174-192). New York: Guilford.
Wager, T. D., Rilling, J. K., Smith, E. E., Sokolik, A., Casey, K. L., Davidson, R. J., . . . Cohen, J. D. (2004). Placebo-induced changes in fMRI in the anticipation and experience of pain. *Science, 303*(5661), 1162-1167. doi: Doi 10.1126/Science.1093065
Wagner, A. D., Pare-Blagoev, E. J., Clark, J., & Poldrack, R. A. (2001). Recovering meaning: Left prefrontal cortex guides controlled semantic retrieval. *Neuron, 31*(2), 329-338. doi: Doi 10.1016/S0896-6273(01)00359-2
Wagner, A. D., Shannon, B. J., Kahn, I., & Buckner, R. L. (2005). Parietal lobe contributions to episodic memory retrieval. *Trends in Cognitive Sciences, 9*(9), 445-453. doi: Doi 10.1016/J.Tics.2005.07.001
Wagstaff, G. F., Brunas-Wagstaff, J., Cole, J., Knapton, L., Winterbottom, J., Crean, V., & Wheatcroft, J. (2004). Facilitating memory with hypnosis, focused meditation, and eye closure. *International Journal of Clinical and Experimental Hypnosis, 52*(4), 434-455. doi: Doi 10.1080/00207140490889062
Wais, P. E., Kim, O. Y., & Gazzaley, A. (2012). Distractibility during episodic retrieval is exacerbated by perturbation of left ventrolateral prefrontal cortex. *Cerebral Cortex, 22*, 717-724. doi: 10.1093/cercor/bhr160

Wais, P. E., & Gazzaley, A. (2011). The impact of auditory distraction on retrieval of visual memories. *Psychonomic Bulletin & Review, 18*(6), 1090-1097. doi: Doi 10.3758/S13423-011-0169-7

Wais, P. E., Martin, G. M., & Gazzaley, A. (2012). The impact of visual distraction on episodic retrieval in older adults. *Brain Research, 1430*, 78-85. doi: Doi 10.1016/J.Brainres.2011.10.048

Wais, P. E., Rubens, M. T., Boccanfuso, J., & Gazzaley, A. (2010). Neural mechanisms underlying the impact of visual distraction on retrieval of long-term memory. *Journal of Neuroscience, 30*(25), 8541-8550. doi: Doi 10.1523/Jneurosci.1478-10.2010

Woldorff, M. G., Gallen, C. C., Hampson, S. A., Hillyard, S. A., Pantev, C., Sobel, D., & Bloom, F. E. (1993). Modulation of early sensory processing in human auditory-cortex during auditory selective attention. *Proceedings of the National Academy of Sciences of the United States of America, 90*(18), 8722-8726. doi: Doi 10.1073/Pnas.90.18.8722

Wolfe, J. M., & Horowitz, T. S. (2004). What attributes guide the deployment of visual attention and how do they do it? *Nature Reviews Neuroscience, 5*(6), 495-501. doi: Doi 10.1038/Nrn1411

Yi, D. J., & Chun, M. M. (2005). Attentional modulation of learning-related repetition attenuation effects in human parahippocampal cortex. *Journal of Neuroscience, 25*(14), 3593-3600. doi: Doi 10.1523/Jneurosci.4677-04.2005

Zelano, C., Bensafi, M., Porter, J., Mainland, J., Johnson, B., Bremner, E., . . . Sobel, N. (2005). Attentional modulation in human primary olfactory cortex. *Nature Neuroscience, 8*(1), 114-120. doi: Doi 10.1038/Nn1368

Zhang, J. X., Feng, C. M., Fox, P. T., Gao, J. H., & Tan, L. H. (2004). Is left inferior frontal gyrus a general mechanism for selection? *Neuroimage, 23*(2), 596-603. doi: Doi 10.1016/J.Neuroimage.2004.06.006