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# Attention Capture By Episodic Long-term Memories: Evidence from Eye Movement Data

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# ATTENTION CAPTURE BY EPISODIC LONG-TERM MEMORIES: EVIDENCE FROM EYE MOVEMENT DATA

by

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Partial Fulfillment of the

Requirements for the Degree of

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at

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# ABSTRACT

## ATTENTION CAPTURE BY EPISODIC LONG-TERM MEMORIES: EVIDENCE FROM EYE MOVEMENT DATA

by

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The University of Wisconsin-Milwaukee, 2020
Under the Supervision of Professor Deborah E. Hannula

Successfully navigating the world on a moment-to-moment basis requires the interaction of multiple cognitive processes. Therefore, studies that examine when and how these fundamental processes interact can provide important insights into how we behave. Many studies indicate that long-term memory can facilitate search for a target object (e.g., contextual cueing), however, the ways in which long-term memory might capture attention and disrupt goal-directed behavior have not been well studied. In five experiments, questions about whether encoded objects might capture attention, even when they are task-irrelevant, were addressed. Each experiment began with an encoding phase, where participants were instructed to commit scene-objects pairs to memory. Then, participants completed a visual search task where they were instructed to make a single eye movement to either the unique shape (Experiments 1, 4, and 5; e.g., a square among circles) or the unique color (Experiments 2 and 3; e.g., the blue shape among other gray shapes) in search displays as quickly and accurately as possible. Occasionally, one of the objects in the search displays was one of the encoded objects, and sometimes one of the encoded scenes was presented prior to the search display. We found, across experiments, that attention was captured by task-irrelevant encoded objects, and that the greatest amount of capture was documented following scene cues. Further, more time was spent fixating encoded objects when they captured attention and scene cues were presented before search displays. Lastly, we found that when saccades were initiated to targets as instructed, saccade latencies were slower when scene cues preceded search displays. Initially, we had interpreted this as an effect of covert capture by the encoded objects, however, the final two experiments suggest that the slowdown is more likely to be the result of presenting complex visual information prior to search displays. Together, the results of these experiments suggest that episodic long-term memories can capture attention and does so in a way that is consistent with the idea that selection history can guide where attention is directed.

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# Chapter 1: Introduction

Successfully navigating the world on a moment-to-moment basis requires the interaction of multiple cognitive processes. Two such processes are memory and attention. Historically, these processes have been studied independently. Therefore, studies that examine when and how these fundamental processes interact can provide important insights into how we behave. A handful of seminal studies have examined the effect of focused (Rock & Gutman, 1981) or divided attention during memory encoding and retrieval (e.g., Baddeley, Lewis, Eldridge, & Thomson, 1984; Craik, Govoni, Naveh-Benjamin, & Anderson, 1996; Uncapher & Rugg, 2009). Rock and Gutman (1981) presented participants with two overlapping line drawings. The lines were different colors and participants were instructed to direct their attention to only one of objects. Subsequent memory for the unattended object was poorer than for the object that was attended. Consistent with these results, completion of a secondary task at encoding impairs subsequent performance on a test of memory (Baddeley et al., 1984). In contrast, divided attention during retrieval has little if any impact on memory performance; instead, secondary task performance is compromised (Craik et al., 1996). Consequently, it has been suggested that retrieval may occur automatically (Baddeley et al., 1984; Craik et al., 1996) or is at least prioritized in the face of competition (Craik et al., 1996; Mulligan & Picklesimer, 2016; Naveh-Benjamin, Craik, Perretta, & Tonev, 2000). If this is the case, then it seems reasonable to suspect that information retrieved from LTM might capture attention.

Other recent investigations have examined how attention and memory can interact such that behavior is facilitated (for review see Hutchinson & Turk-Browne, 2012; Aly & Turk-Browne, 2017; Hannula, 2018). For example, the effects of long-term memory (LTM) on the speed and accuracy with which attention was deployed to targets in a visual search task has been examined (e.g., Chun & Jiang, 1998; Brockmole & Henderson, 2006; Summerfield, Lepsien, Gitelman et al., 2006). In one example, participants searched for a target embedded among several distractors (Chun & Jiang, 1998). Some of these search displays were presented repeatedly, while others were presented only once. The ones that were presented repeatedly provided a consistent spatial context, predictive of target location, which resulted in a decrease in the time it took to locate the target—called "contextual cueing". This suggests that memory for the repeated displays facilitated the allocation of attention to the target – i.e., memory and attention were working cooperatively to enhance goal-directed behavior. The behavioral experiments proposed here have been designed to investigate a qualitatively different question. Here, we are interested in whether encoded content might capture attention even if that information is task-irrelevant and attending to it harms performance of the task.

Traditionally, distinctions have been drawn in the attention literature between bottom-up attention, which is the capturing of attention by a salient stimulus (e.g., something that stands out by virtue of it physical or perceptual characteristics) regardless of an observers' goals, and top-down attention, which is attention that is in line with current goals and objectives (Todd & Van Gelder, 1979; Posner, 1980; Serences & Yantis, 2006). Imagine that you are trying to locate a group of friends at a busy beach in the summer.  One of your friends has told you that the group will meet you near a concession stand. Top-down processes allow you to prioritize the concession stand, which reduces the number of items that must be processed in order for you to find your friends. However, the beach is busy, so as you use your top-down attentional resources to search the environment efficiently, your attention might be captured involuntarily by a volleyball that suddenly lands near your feet or by a man yelling out to his kids. Bottom-up attentional processes are being drawn to these salient distractions, interrupting search for your friends.

Consistent with the proposed dichotomy, laboratory studies have indicated that attention can be captured involuntarily by physically or perceptually salient materials (e.g., Theeuwes, 1994a, 1994b; Yantis & Jonides, 1984, 1990). Historically, research has focused on the effects of presenting an object suddenly in search displays (i.e., an onset - a highly perceptually salient stimulus; Todd & Van Gelder, 1979; Jonides & Yantis, 1988), or including, in a search display, an item that stands out based on its physical properties (i.e., color singleton; Theeuwes, 1992; Theeuwes, De Vries, & Godjin, 2003; for review see Theeuwes & Godjin, 2001). For example, if participants are instructed to locate a green circle in a display of green diamonds, attention is often captured by a red diamond when it is present (Theeuwes, & Godjin, 2001). In this example, the red diamond is an irrelevant singleton – i.e., not part of the instructed task set – and capture by this object slows down or otherwise harms search performance.

There is active debate about whether capture is strictly related to physical/perceptual salience or whether it might be contingent on task demands (i.e., contingent capture) or the strategies participants adopt to comply with instructions (i.e., singleton detection mode). For instance, it was proposed by Folk and colleagues (Folk & Remington, 1998; Folk, Remington, & Johnston, 1992) that when attention is captured, it is because there is a contingency, or match, between features of the attention capturing stimulus and the target stimulus (Carmel & Lamy 2015; Roque, Wright, & Boot, 2016). Consistent with this proposal, it has been reported that in search for a target that is an onset, an irrelevant object in the target display captured attention only when it was also an onset (Folk & Remington, 1998). In contrast, others have suggested that capture is the result of participants having adopted a specific kind of top-down attentional set –

i.e., singleton detection mode (Bacon & Egeth, 1994). In this case, if the target is a unique shape and the distractor is a unique color, participants may adopt a top-down attention set for singletons, which then results in attention sometimes going to the unique shape (correctly) and sometimes going to the uniquely colored, yet irrelevant, distractor.

As discussed above, it has been proposed that capture is contingent on task demands and/or due to use of a singleton search strategy. However, other studies have indicated that capture effects are quick and short-lived (for review see Theeuwes & Godjin, 2001). The delay in the contingent capture work was long and it may be the case that capture might have occurred to both stimulus types – regardless of contingency – but was stuck on the capturing object if it matched the task set (e.g., find onset). More generally, even when distractors are not singletons and do not match goals/objectives, they capture attention (e.g., Anderson, Laurent, & Yantis, 2011a, 2011b, 2012; Anderson & Yantis, 2012; Schmidt, Belopolsky, & Theeuwes, 2015a, 2015b; Hickey, Chelazzi, & Theeuwes, 2010a, 2010b; Hopkins, Helmstetter, & Hannula, 2016). This raises the question, if physical salience or contingency is sufficient, then why doesn't capture occur all the time? An inhibitory mechanism has been proposed that seems to account for the lack of attention capture in some cases (Gaspelin & Luck, 2018). Salient stimuli do tend to capture attention, but capture can be avoided if the information is suppressed using cognitive control. If the information is sufficiently suppressed processing should reduce below baseline. There is some preliminary evidence consistent with these claims (for review see Gaspelin & Luck, 2018).

While controversy over the mechanisms responsible for capture remain unresolved and continue to be investigated, it is also the case that some investigators have argued the standard, and well-accepted, dichotomous model of attention may be too narrow – i.e., factors that influence the allocation of attention have been identified that do not neatly fit into either top-down or bottom-up conceptualizations (Awh, Belopolsky, & Theeuwes, 2012). Awh and colleagues (2012) suggest that in addition to the top-down and bottom-up deployment of attention, attention can be influenced by selection history. Examples of selection history include search history, history of reward, and active maintenance in working memory. In each case, it has been proposed that the standard dichotomous view of attention is inadequate because the attention capturing stimuli in these situations are not perceptually salient and are to be ignored.

One set of empirical observations identified by Awh and colleagues (2012) as problematic for dichotomous models of attention has to do with the effects of recent experience on target detection, or search history. For example, when a search target is defined by a given feature (e.g., the color yellow), search for the same feature is more efficient on subsequent trials (Maljkovic & Nakayama, 1994). More important for our purposes, this feature also attracts attention if the search target has changed, making this feature task-irrelevant (Eimer, Kiss, & Cheung, 2010; Kristjansson & Campana, 2010; Brascamp, Blake, & Kristjansson, 2011; Theeuwes & Van der Burg, 2011). These results indicate that stimuli gain priority by having been experienced recently, and that priority is maintained even when they become task-irrelevant.

Much like task-irrelevant features that attract attention due to search history, materials that have a history of being paired with reward or punishment capture attention disproportionately relative to other equally salient distractors (e.g., Anderson et al., 2011a, 2011b, 2012; Anderson & Yantis, 2012; Schmidt et al., 2015a, 2015b; Hickey et al., 2010a, 2010b; Hopkins et al., 2016). In one recent example, Le Pelley and colleagues (2015) paired high and low monetary reward with a certain color of distractor object. Participants completed a search task where they were to locate a gray diamond among gray circles in a search display and indicate whether the line segment inside the diamond was oriented horizontally or vertically. Sometimes, one of the circles was a color singleton (i.e., either red, blue or green). Participants were not told that one color predicted high reward and the other low reward (the third color was equally likely to be paired with high or low reward). Instead, like all of the other distractors, they were told that these items were irrelevant to the search task (i.e., find the diamond). Furthermore, they were told that payment depended on how quickly they found the target and reported the orientation of the line segment. The results indicated that response times were significantly slower when distractors associated with high value were present in the display. This is notable, because attending to these stimuli actually resulted in the loss of the amount that was supposed to be awarded that trial (i.e., they should be distracted by these items less often as they were missing out on high reward).

In the examples above, selection and attentional priority were affected by search history and associative learning. One other factor that can affect search efficiency is information held active in working memory (e.g., Olivers, Meijer & Theeuwes, 2006; Soto, Heinke, Humphreys, & Blanco, 2005). The basic approach in these experiments combines a working memory task with visual search. In one example, an object characterized by unique color and shape was presented at the start of each trial. Participants were instructed to keep both the shape and color active in memory for a probe at the end of the trial. The probe stimulus was a colored shape, and participants were instructed to indicate if it was the same or different than the object presented at the beginning of the trial (Soto et al., 2005). Prior to the probe stimulus, a search display was presented, and participants were required to locate a target – a tilted line segment – presented within one of two, four or eight shapes and indicate its orientation. When one of the shapes in the search array matched the shape held in working memory, target identification was slower than for trials without matching shapes, despite the shapes being irrelevant to the search task. Importantly, on trials where there was no working memory requirement (i.e., the shape was presented, and the search task completed but there was no test at the end of the trial) there was no evidence of capture. This suggests that the representation may need to be processed and held in an active state for capture to occur. In summary, evidence suggests that search history, history of reward or punishment, and active representation (selection) of stimulus information can have a negative impact on search efficiency. These effects are documented even when the distractors are not physically salient, and therefore do not fit the definition of bottom-up attention. In the current studies, we were interested in whether attention is captured in a similar way by information retrieved from long-term memory.

Response times are traditionally used as a measure of attention capture. However, button press responses are susceptible to decision making processes that can affect the data. In addition to using response times as an index of attention capture, eye movements have been used as an indicator of attentional priority (Deubel & Schneider, 1996; Hoffman & Subramaniam, 1995), Many studies suggest that the misallocation of attention can also be indexed using eye movement behavior (e.g., Hopkins et al., 2016; Theeuwes, Kramer, Hahn, & Irwin, 1998; Theeuwes & Belopolsky, 2012). Eye movements provide a continuous measure of attentional priority; they permit evaluation of both overt (i.e., saccades made in error to non-targets; oculomotor capture) and covert (i.e., increased saccade latencies) attentional deployment, as well as the ease of attentional (dis)engagement when overt capture has occurred (Godijn & Theeuwes, 2002). Eye movements may also be less susceptible to decision making and response selection processes, which take time and can affect button press responses (see Hannula, Althoff, Warren, Riggs, Cohen, & Ryan, 2010; see Hannula, 2018). In the following experiments, eye movements were used to examine capture by information represented in long-term memory.

The idea that attention might be captured by information represented in LTM is based on results from published studies that show eye movements go rapidly to remembered content (Hannula, Ryan, Tranel, & Cohen, 2007; Hannula & Ranganath, 2009), that sometimes eye movements are a better record of past experience than explicit recognition responses (Hannula, Baym, Warren, & Cohen, 2012; Hannula & Ranganath, 2009), and that these memory-based viewing effects persist even when they are counterproductive based on task demands (e.g., to conceal memory; Mahoney, Osmon, Kapur, & Hannula, 2018). In one paradigm that has been used in several experiments to address questions about the time-course and automaticity of memory retrieval, participants learned several scene-face pairs (Hannula et al., 2007; Hannula & Ranganath, 2009). Subsequent to encoding, test trials were initiated with the presentation of a studied scene meant to trigger retrieval of the learned associate, and then three studied faces were superimposed on top of the scene. Sometimes, one of these faces was the studied associate of the scene cue. Analysis of viewing patterns to the 3-face test display consistently indicate that participants view the associate of the scene disproportionately, an effect that emerges early in the test trial (i.e., within 500-750ms following test display onset and approximately 1000ms prior to explicit recognition responses). The interpretation has been that relational memory has a rapid and perhaps automatic or obligatory influence on eye movement behavior (Chua, Hannula, & Ranganath, 2012; Hannula et al., 2007; Hannula & Ranganath, 2009; for review see Hannula et al., 2010), a conclusion that complements findings from studies that have found little consequence of divided attention during retrieval on these eye-movement based effects (Craik et al., 1996; Naveh-Benjamin, Craik, Guez, & Dori, 1998). Consistent with the proposed automaticity of retrieval and the rapid expression of these memory-based viewing effects, it was predicted in the current studies, that information stored in episodic memory might capture attention when this information is task irrelevant, especially in the presence of a memory cue.

Different subtypes of memory are supported by distinct neural regions (Cohen & Squire, 1980; Squire, 2004). Initially, studies differentiated between declarative (consciously accessed, episodic and semantic memory) and non-declarative or procedural memory (changes in performance with practice that need not depend on awareness; Cohen & Squire, 1980; see Squire & Dede, 2015 for review). This early distinction was based on patient studies in which differential impairments in memory were found following brain damage. In the most common example, H.M. underwent a bilateral temporal lobe resection, which included the removal of the hippocampus, in an attempt to control severe seizures (Scoville & Milner, 1957). Following the surgery, H.M was no longer able to form new episodic or semantic memories. He was, however, still able to learn new skills through practice even though he was unaware that he had performed these tasks before, suggesting that his non-declarative or procedural memory remained intact (Corkin, 1968; Milner, 1962; Gabrieli, Corkin, Mickel, & Growdon, 1993). Based on these findings, it has been suggested that the medial temporal lobe (MTL), specifically the hippocampus, is required for the formation of new declarative memories. Specifically, it has been proposed the hippocampus is required for the binding of items and contexts across space and time (Relational Memory Theory; cf. Cohen & Eichenbaum, 1993; Diana, Yonelinas, & Ranganath., 2007; Eichenbaum, Yonelinas, & Ranganath, 2007).

In an especially compelling demonstration of the dependence of relational memory on hippocampal integrity, Konkel & colleagues (2008) reported that memory for spatial, temporal, and associative relationships were disrupted for individuals with amnesia relative to healthy controls, but that memory for the items themselves was intact unless the lesions causing the amnesia extended outside of the hippocampus. This pattern of results suggests that relational memory, but not item memory, depend on the hippocampus and provides support for the relational memory theory.

As indicated above, it has been reported in several experiments that eye movements are sensitive to relational memory retrieval (Hannula et al., 2007; Hannula & Ranganath, 2009; Ryan, Althoff, Whitlow, & Cohen, 2000; for review see Hannula et al., 2010). Consistent with the proposed role of the hippocampus in relational memory encoding and retrieval, when hippocampal amnesics are tested there is no evidence for relational memory in eye movement behavior. Furthermore, when neurologically healthy college-age participants were tested using combined fMRI and eye tracking methods, these eye-movement based relational memory effects were predicted by activity differences in the hippocampus during presentation of memory cues that preceded the test displays (Hannula & Ranganath, 2009). This outcome is consistent with the proposed role of the hippocampus in pattern completion processes - i.e., the spontaneous retrieval of encoded content when partial information is presented (Marr, 1971; Mizumori, McNaughton, Barnes, & Fox, 1989; see Rolls, 2013 for review). In the following experiments, cues were used to trigger retrieval processes that were expected to drive the eyes to encoded associates when they were present in search displays.

We aimed to investigate whether and how information retrieved from long-term memory is prioritized by attention despite being irrelevant to the goal of locating the target in the search display. Similar to other studies conducted in our lab, in all of the experiments, performance of a search task was preceded by an encoding phase. Each participant learned several scene-item associations. Subsequently, an encoded item could be present in a visual search display and sometimes these search displays were preceded by an encoded scene (i.e., the memory cue). When scenes were presented, it was assumed that participants spontaneously retrieved the associate. However, if the associate was present in the search display it was not the search target, and instead was supposed to be ignored. This meant that most of the time episodic memory and attention were working competitively and not cooperatively. We predicted that encoded information presented in search displays would be prioritized in eye-movement behavior following scene cues, despite instructions to ignore these materials, providing evidence for capture by information represented in long-term memory. These effects were expected to be strongest when scene cues were presented prior to search displays that include the encoded associate. This was because scene cues should trigger retrieval and active representation of retrieved content via pattern completion processes.

# Chapter 2: Capture Studies

Five eye-tracking experiments were conducted to examine whether and under what circumstances information represented in episodic memory captures attention. Briefly, participants in these experiments encoded several scenes, each paired with one simple object from a small set of exemplars. Subsequent to encoding, participants performed a directed viewing task when search displays were presented. Sometimes, one of the encoded objects was present in the search display as a task-irrelevant distractor, and occasionally, the scene that was paired with that object during encoding preceded presentation of the search display. As in studies of capture by reward (e.g., Anderson et al., 2011a, 2011b), the search target was a singleton, distinctive from other search display items based on its shape or color (e.g., a colored square among colored circles). Participants were instructed to make a single eye movement to the location occupied by the target, ignoring other information in the search display, and were simply instructed to view the scene if one was presented (i.e., there was no explicit requirement to retrieve the associate, nor was there an immediate memory test following search).

Critically, encoded objects were not singletons – the perceptual characteristics of these objects did not distinguish them from other distractors in the display (i.e., all of the distractors were colored circles). This was important because it mitigates any potential concern that capture (by encoded objects) was due to the use of a singleton detection processing mode (Bacon & Egeth, 1994). As a reminder, this suggests that capture is contingent on participants having adopted a task-specific top-down attentional set (i.e. searching for a singleton). More generally, explicit retrieval was not part of the task set, though we expect that retrieval occurred spontaneously in the presence of a scene cue, consistent with the proposed role of the hippocampus in pattern completion processes (Hannula & Ranganath, 2009; see for review Hannula, 2018). Based on previous work that points to very rapid attraction of the eyes to remembered materials, particularly in the presence of memory cues (e.g., Hannula et al., 2007), it was anticipated that attention would be deployed in error (either overtly or covertly) to encoded distractors more often than other distractors in the search displays, and that these effects would be most pronounced following scene cues.

## Methods

### *Sample Size Calculations*

All of the participants were recruited from the University of Wisconsin-Milwaukee (UWM) and the surrounding community. They were either compensated with course credit or a $10 gift card. Procedures for this experiment were approved by the local Institutional Review Board at UWM (Protocol #15.327).

Sample sizes were estimated with R (Version 3.4.1, The R Foundation for Statistical Computing, Vienna, Austria) based on outcomes reported by Anderson and Yantis (2012); while the manipulation in this study was capture by reward, we adapted the task to study capture by memory using the same search displays. In Anderson and Yantis (2012), the effect size associated with the comparison of oculomotor capture by rewarded distractors versus baseline distractors that were not rewarded was large (Cohen's d = 1.4). Two-tailed sample size estimation, with significance level and power set to .05 and 90%, respectively, indicated that at least 8 participants would be required to detect a capture effect in our work. Here, we doubled that number to bring it in line with standard practice (i.e., a sample size of approximately 15 participants) and to ensure a fully counterbalanced experimental design. It was anticipated that some participants would be dropped from analyses because they failed to follow instructions or because eye movements could not be tracked reliably; participants were replaced to meet the target sample size number of 16 individuals.

In Experiments 2, 3, 4 and 5, hypotheses were more exploratory, and it was anticipated that any observed differences would be harder to detect. Therefore, sample size estimates were more conservative to ensure that there would be adequate power for statistical tests. Sample size for these experiments was estimated, once again, with R (Version 3.4.1, The R Foundation for Statistical Computing, Vienna, Austria). In this case, assuming an effect size equal to .6 (a medium effect), with significance level and power set to .05 and 80%, respectively, the required sample size is 23. This number was rounded up to 24 to ensure a fully counterbalanced experimental design and, as above, participants were tested until we reached this number (given that some participants were eliminated from analyses).

Finally, 32 students completed Experiment 3. More participants were tested in this experiment because a yoking procedure (described below) was used to test the participants. As in the other four experiments, the sample was filled out until we had usable data from 32 participants.

### ***Materials***

Materials were real-world scenes (e.g., a barber shop, Millennium Park) and a small set of simple objects (i.e., colored circles, simple colored objects). The same set of 72 scenes were used in all five experiments and were selected from an existing database (cf. Hannula et al., 2007). In addition to intact scenes, Experiment 4 called for scrambled versions of those scenes. These images were created using the "scramble" filter plugin (Telegraphics, Australia) for Adobe Photoshop. Briefly, each 800 x 600 pixel image was broken up into 5 x 5 pixel squares and randomly reassigned to a new location. Use of this procedure meant that basic perceptual characteristics of the scenes were retained (e.g., color, luminance), but that the pictures themselves were no longer be identifiable.

Objects used in Experiments 1, 4, and 5 – i.e., circle, square, trapezoid, hexagon, and cross – were created in Power Point and edited for color and size with Adobe Photoshop. Every object in this set of five was rendered in six colors: dark blue, cyan, orange, purple, white, and yellow (cf. Anderson et al., 2011). The circle was also rendered in four additional colors: red, light blue, pink, and green. Collectively then, in Experiments 1, 4 and 5, the set consisted of 34 objects (i.e., square, trapezoid, hexagon, and cross in six colors; circles in ten colors; See Table 1).

Table 1. *CIE L*a*b* values for materials used in Experiments 1, 2, 3, 4, and 5.*

| Color | CIE L* | CIE a* | CIE b* |
|---|---|---|---|
| Red | 54 | 81 | 70 |
| Light Blue | 54 | 9 | -73 |
| Pink | 56 | 84 | 6 |
| Green | 88 | -79 | 81 |
| Dark Blue | 30 | 68 | -112 |
| Purple | 39 | 75 | -95 |
| Orange | 68 | 45 | 75 |
| Cyan | 91 | -51 | -15 |
| Yellow | 98 | -16 | 93 |
| White | 100 | 0 | 0 |
| Gray Exp. 2 | 54 | 0 | 0 |
| Gray Exp. 3 | 47 | 0 | 0 |
| Blue Exp. 3 | 47 | 30 | -73 |
| Red Exp. 3 | 46 | 67 | 54 |
| Orange Exp. 3 | 47 | 18 | 55 |
| Green Exp. 3 | 47 | -48 | 49 |

For Experiment 2, the number of objects increased to ten. These objects included four exemplars from the set described above for Experiment 1, 4 and 5 – i.e., square, trapezoid, hexagon, cross – each rendered in gray, and six new objects – i.e., sun, star, diamond, flower, apple, and light bulb. The new objects were either created using the “shapes” tool in Power Point or were taken from the internet and then edited (e.g., for equivalent line thickness) using Adobe Photoshop. New objects were rendered in gray, red, light blue, pink, and green. Collectively then, for Experiment 2, there was a set of 34 objects (i.e., 10 shapes, 6 of these in 5 different colors and 4 in gray alone).

Finally, for Experiment 3, the set of objects increased to 13 exemplars. The objects – a button, nut, leaf, lock, lamp, anchor, cup, bow, moon, heart, ball, star, and mitten – were from the Snodgrass and Vanderwart (1980) set and were modified for this experiment using Adobe Photoshop. Eight objects divided into two sets of four (i.e., button, nut, leaf, lock; lamp, anchor, cup, and bow) were always gray. The remaining objects (i.e., moon, heart, ball, star, and mitten) were gray, red, blue, orange, and green. This means that for Experiment 3 there was a set of 33 objects (i.e., 13 shapes, 8 in gray alone and 5 in 5 different colors).

From a viewing distance of 70 cm, scenes subtended 18.3° of visual angle horizontally and 13.9° vertically; shapes were approximately 2.5° squared and superimposed on a black background.

### *Apparatus*

Eye movements were recorded with an Eyelink 1000 eye tracking system (SR Research LTD, Ontario, Canada). This system operates with a temporal resolution of 1000 Hz and has a head-supported spatial resolution of 0.01°. Saccades were identified using an automated algorithm with minimum velocity and acceleration criteria set to 30°/s and 8000°/$s_2$, respectively. Experiment Builder and Data Viewer (SR Research LTD, Ontario, Canada) were used to program the experiment and to analyze the data. Stimuli were presented on a 22-inch View Sonic monitor with 1680x1050 pixel resolution and a refresh rate of 60 Hz.

### *Eye Movement Analyses*

For analysis, search displays were subdivided into 8 regions of interest (ROIs) – one surrounding central fixation (approximately 5.8° of visual angle), six surrounding locations occupied by individual search display objects, and one that covered the remainder of the screen. The ROIs that encompass search display elements were part of a hexagon (excluding the center location) that subtended approximately 24° of visual angle and was split into 6 equally sized sections.

Trials were eliminated from analyses if the first saccade did not begin in the center ROI, and if saccade initiation was faster than 80ms or slower than 600ms following display onset (e.g., Theeuwes & Belopolsky, 2012). Trials were also eliminated from analyses if participants failed to make an eye movement out of the center ROI while the search display was in view. Only the first saccade that left the center ROI was considered. Saccades were defined as having landed on the target or the encoded distractor if they were within 30° of arc from the center of that object (e.g., Devue, Belopolsky, & Theeuwes, 2012) and were within the associated ROI.

Three dependent measures were used to examine the influence of LTM on the allocation of attention to display elements: 1) the percentage of trials on which initial saccades were directed to ROIs occupied by encoded (or other) distractors instead of the target ROI (i.e., an index of overt capture), 2) the amount of time spent fixating the distractor when overt capture occurred (i.e., dwell time) and 3) saccade latency to targets when they were fixated immediately after display onset as instructed (i.e., a potential index of covert capture). In this last case, a delay in saccade deployment may occur because covert attention was directed, in error, to an encoded distractor rather than the search target. For Experiments 1, 2, 4, and 5 a baseline index of overt capture was obtained by calculating the percentage of baseline trials on which participants directed an initial saccade, in error, to one of the distractors in the search display divided by the total number of these items (i.e., 5 circles). This approach has been used previously (Anderson & Yantis, 2012) and was meant to equate potential for capture across conditions by taking into account the number of opportunities for capture to occur (just one encoded distractor versus five distractors for baseline trials). A built-in baseline comparison object was used in Experiment 3.

### ***Statistical Contrasts***

Mauchly’s test of sphericity were calculated for all of the reported ANOVAs with more than one degree of freedom in the numerator. If sphericity was violated, then Greenhouse-Geisser adjusted degrees of freedom, p-values, and epsilons (*G-Gε*) have been reported. Post-hoc statistical tests were Bonferroni corrected for multiple comparisons based on the number of tests that were performed. Partial eta-squared ($\eta_{p2}$) and Cohen's d were calculated as indices of effect size.

## Experiment 1

This experiment was designed to investigate whether evidence for attention capture by long-term memories can be documented in eye movement behavior.

### *Participants*

Twenty-one students from UWM completed this experiment. Data obtained from five individuals were excluded from reported analyses – three because too few trials remained after the exclusion criteria were applied (i.e., the percentage of trials excluded from the sample was more than 2 times the interquartile range calculated from group data) and two more because explicit recognition performance was less than 2 times the interquartile range calculated from the group data. Therefore, all of the reported analyses were based on data obtained from 16 participants.

### *Design and Procedure*

After written informed consent was obtained and task instructions were provided, participants were seated 70cm from the computer monitor and a chinrest was adjusted to comfortably fix head position. A calibration procedure was performed using a 9-point automated display.

Subsequent to calibration, participants completed a brief practice block meant to familiarize them with task procedures. Practice consisted of 10 encoding trials and 30 directed viewing task trials (see below for more information). In contrast to the experiment proper, encoded distractors were not presented in directed viewing task search displays. Following practice, any questions about the task were addressed and the experiment was initiated.

The experiment consisted of two identical parts, each subdivided into encoding, directed viewing, and recognition blocks (See Figure 1). During encoding, participants were presented with 36 unique scene-object pairs and were instructed to commit each pair to memory. The objects were four colored circles rendered in red, light blue, pink, or green. Each colored circle (e.g., red) was paired with nine different scenes.

Encoding trials were initiated automatically, contingent upon participants fixating a centrally located crosshair (minimum fixation duration = 200ms). When the trial advanced, a scene was presented for two seconds and then an object was superimposed on top of that scene for four seconds. Adjacent trials were separated by an 800ms intertrial interval (ITI) and individual pairs were seen three times in random order. Altogether, participants were presented with 72 unique pairs (36 in each part of the experiment).

Subsequent to encoding, participants completed a directed viewing task. Participants were told that each trial would begin with fixation of a centrally located crosshair and that when a six-object display was presented, they should make a single eye movement to the location occupied by the object that had a unique shape (e.g., the square among circles). It was explained that everything else in the display was to be ignored. Encoded scenes were presented prior to search displays on a subset of trials and participants were told that on these trials the task remains the same; there was no stated requirement to retrieve the associate, they were simply told to view the picture.

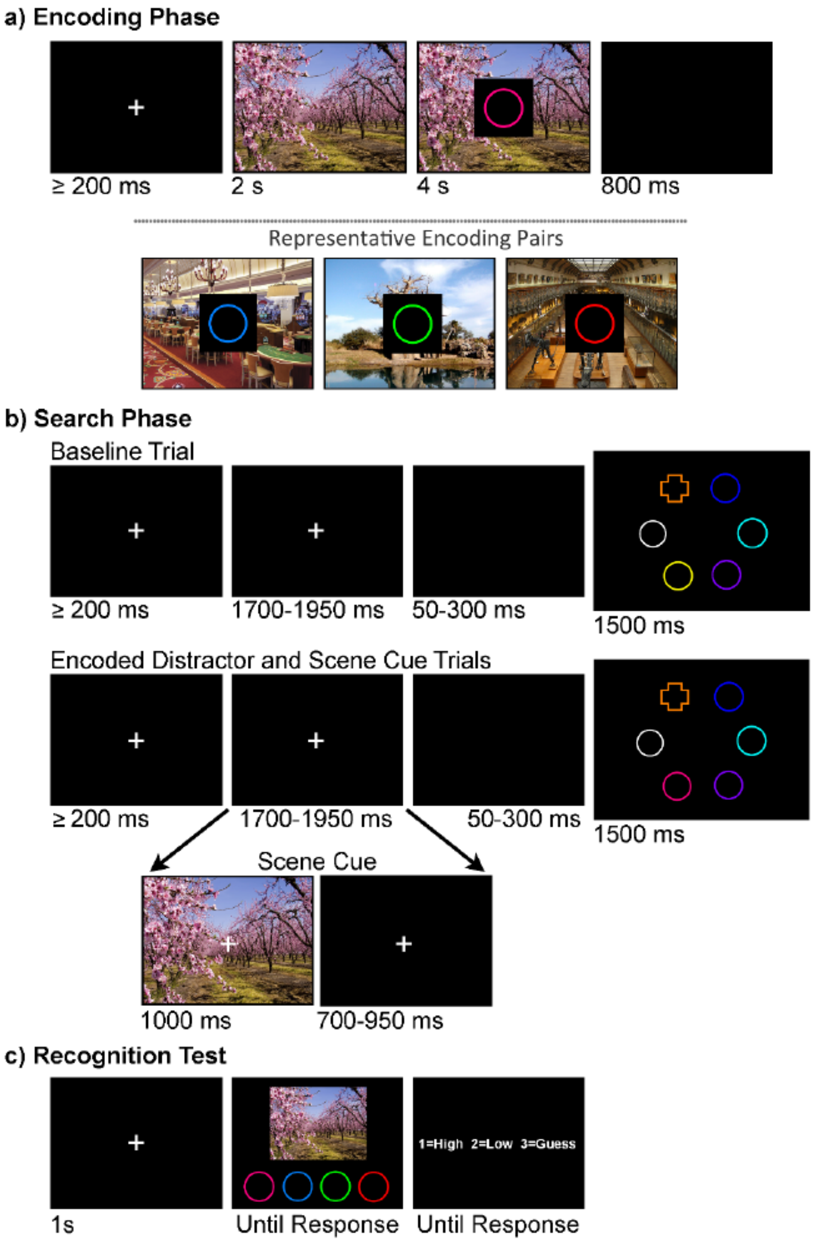

*Figure 1. Methods for Experiment 1.* (a) Event timing for a single encoding trial; representative pairs. (b) Trial structure and event timing for the visual search task. All three conditions are illustrated. An encoded circle was present in a subset of the search displays (here, the pink circle in the bottom search display is the encoded exemplar). Sometimes, the corresponding scene, from encoding, was presented prior to search (Scene Cue trials) and sometimes it was not (Encoded Distractor trials). Encoded circles were not present in Baseline trials. Participants were instructed to make a single saccade to the location of the shape target – here, the cross – and to ignore everything else in the display. (c) Trial structure and event timing for the associative recognition test.

Each trial in the directed viewing task was initiated automatically, contingent upon fixation of a centrally located crosshair (minimum fixation duration = 200ms). Subsequently, depending upon the trial type, the crosshair either remained in view (1700-1950ms) or one of the encoded scenes was presented along with the crosshair for 1000ms. The scene was then removed, but the crosshair remained on the screen for an additional 700-950ms. For all trial types, the crosshair was then removed, and the screen remained blank for 50-300ms. As in past work, this was done to ease attentional disengagement from the center of the screen (Saslow, 1967). Together, events that constituted the start (crosshair, and scene cue, if one was presented) of the trial always had a total duration of 2000ms. Finally, the six-object display was presented for 1500ms. The next trial began after an 800ms ITI and central fixation (minimum fixation duration = 200ms). Objects in the display were located on the circumference of an imaginary circle with a radius of 8° surrounding the center of the screen and were equidistant from their neighbors and from the screen center. Displays always consisted of a single target – either the square, the trapezoid, the hexagon, or the cross – presented among circles, which served as distractors. As outlined below, on a subset of trials, one of the circles was from the set of four presented during the encoding phase (i.e., red, light blue, pink, or green). None of the objects in search display were the same color.

The directed viewing task consisted of 108 trials distinguished by the presence (or absence) of an encoded circle in the search display and by whether or not an encoded scene precedes the display. Baseline search displays were not preceded by an encoded scene and none of the colored circles were seen during encoding. Encoded Distractor search displays were not preceded by an encoded scene, but now one of the circles in the search display was presented during the encoding phase (i.e., was either red, light blue, pink, or green). Finally, search displays on Scene Cue trials were preceded by an encoded scene and one of the colored circles in the display was paired with that scene during encoding. In other words, the encoded distractor was the associative match of the preceding scene. There was never more than one encoded circle in a search display and objects were always be superimposed on a black background (see Figure 1b). Altogether, data was obtained from 72 baseline trials, 72 encoded distractor trials, and 72 scene cue trials across parts 1 and 2 of the experiment (differences between the conditions and trial numbers for each experiment are located in Table 2).

Table 2. *Trial numbers and conditions of interest subdivided by Experiment.*

| | **Baseline** | **Encoded Distractor** | **Scene Cue** | **Scrambled Scene** | **Baseline Scene** | **Total** |
|---|---|---|---|---|---|---|
| **Experiment 1** | 72 | 72 | 72 | -- | -- | 216 |
| **Experiment 2** | 72 | 72 | 72 | -- | -- | 216 |
| **Experiment 3** | 144 | 72 | 72 | -- | -- | 288 |
| **Experiment 4** | 72 | 72 | 72 | 72 | -- | 288 |
| **Experiment 5** | 36 | 36 | 36 | -- | 36 | 144 |

Finally, following encoding and performance of the directed viewing task, memory for all 36 scene-object associations was tested. Prior to test, participants were told that each trial will consist of a scene (top) and four colored circles (bottom). They were told to identify the colored circle that had been paired with the scene during the encoding phase; the display remained in view until a response was made. Following selection of the associate, participants were asked to indicate how confident they were in the accuracy of their choice (i.e., 1= High Confidence, 2= Low Confidence, 3= Guess; see Figure 1c). Individual trials were separated by a 1s ITI. Across parts 1 and 2 of the experiment, memory for 72 pairs was tested.

For counterbalancing purposes, individual scenes were randomly assigned to one of eight lists (9 scenes per list), each with roughly equivalent numbers of indoor and outdoor exemplars. Each encoding phase object was paired with scenes from two lists and lists of scenes were paired equally often with all four of these colored circles across participants. Finally, scene-object pairs presented in the first half of the experiment for one subject were used in the second half of the experiment for another subject.

During the directed viewing task, target objects were equally likely to be the square, the trapezoid, the hexagon, or the cross. Across trials, targets occupied each spatial location and were shown in each of six possible colors equally often. Note that targets were never presented in an encoded color and that color itself was completely irrelevant to performance of the directed viewing task. Colors (from the non-encoded set of six) were randomly assigned to the remaining items in the search displays (all circles) and were all different; sometimes (i.e., encoded distractor and scene cue trials) one of these was replaced with an encoded color. When an encoded distractor was present, it was equally likely to be one-, two-, or three-positions away from the target location.  Like targets, encoded distractors occupied each location in the search display equally often across trials.

### ***Results***

#### *Recognition Performance*

Because scene-object pairs were presented three times during encoding, a choice that was made to ensure strong encoding, it was predicted that performance on explicit tests of recognition would be very good. It was also predicted that participants would have high confidence in the accuracy of their correct responses – again, because the number of pairs to be encoded was relatively few and three opportunities to encode the materials had been provided. Results indicated that scene-object associations were successfully encoded. On average, the correct choice was selected (from among four alternatives) on 93.83% (*SD* = 1.83) of the trials and performance was well above chance, $t(15) = 159.51$, $p < 0.001$, $d = 39.80$. Additionally, when correct responses were made, participants reported high confidence in the accuracy of their choice 91.73% ($SD = 9.29$) of the time. In contrast, when responses were incorrect, reports of high confidence dropped to 25.69% ($SD = 38.51$); four participants did not make any incorrect responses.

### *Viewing Behavior*

It was predicted that when scene cues were presented encoded distractors (red, light blue, pink, or green circles etc.) would draw attention in error more often than baseline distractors. In addition, we also examined whether encoding status alone, absent a retrieval cue, affects attentional deployment. As indicated earlier, three participants were dropped from analyses because too few trials remained after exclusion criteria were applied. For the remaining participants, this procedure resulted in an average loss of 5.15% ($SD = 4.03$) of the trials.

**Overt (Oculomotor) Capture**. We expected that overt capture (i.e. erroneous eye-movements to the encoded object embedded in the search display) would occur disproportionately on trials where scene cues and encoded distractors were present. It could be the case that encoded content, in the absence of a scene cue, captured attention disproportionately relative to baseline trials. To test this prediction, a repeated-measures ANOVA with the factor experimental condition (Baseline, Encoded Distractor, Scene Cue) was calculated. As predicted, the percentage of trials in which the first saccade was directed towards a non-target object was affected by our experimental manipulation, $F(1.13, 16.91) = 39.52$, $p < 0.001$, $G\text{-}G\ \varepsilon = 0.56$, $\eta_{p2} = 0.73$. Bonferroni corrected post-hoc comparisons were also calculated. These tests indicated that saccades were made more often in error to encoded objects in the absence of a scene cue as compared to objects in Baseline trials (Encoded Distractor vs. Baseline: $t(15) = 4.22$, $p = 0.002$, $d = 1.06$). In addition, encoded objects in the presence of scene cues captured attention the most often relative to other encoded objects and objects in baseline trials (Scene Cue vs. Encoded Distractor: $t(15) = 6.17$, $p < 0.001$, $d = 1.54$; Scene Cue vs. Baseline: $t(15) = 6.54$, $p < 0.001$, $d = 1.64$; See Figure 2.).

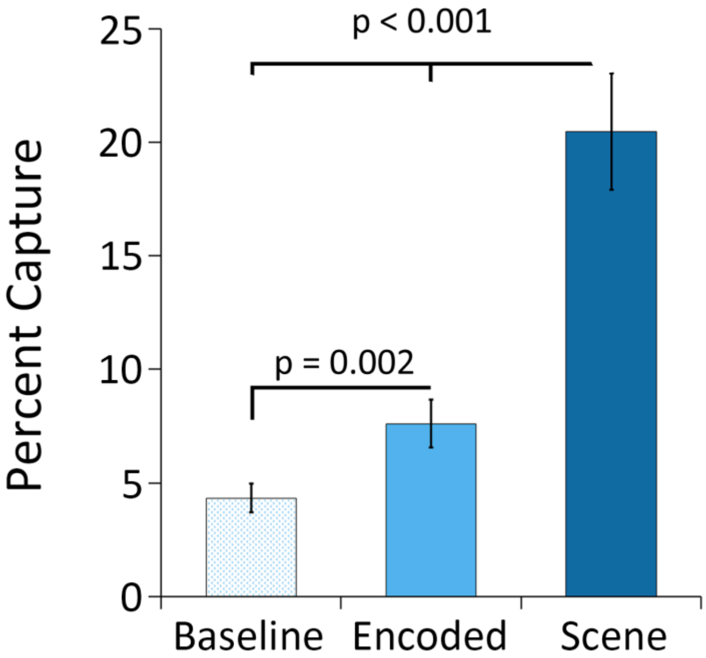

*Figure 2. Oculomotor capture Experiment 1.* The percentage of trials on which participants made an initial, erroneous saccade to a distractor in the search display for Experiment 1.

**Dwell Time**. It was expected that dwell times (i.e. amount of time spent at the distractor location when overt capture occurred) would be longest for trials where scene cues and encoded distractors were present. Similarly, dwell times would be longer for encoded objects in the absence of scene cues relative to baseline trials. To test this prediction, a repeated-measures ANOVA with the factor experimental condition (Baseline, Encoded Distractor, Scene Cue) was calculated. As predicted, dwell times were affected by our experimental manipulations, $F(1.48, 22.20) = 11.75$, $p = 0.001$, $G\text{-}G\ \varepsilon = 0.74$, $\eta_{p2} = 0.44$. Bonferroni corrected post-hoc comparisons indicated that it was more difficult for participants to disengage attention from encoded circles, but only when the search display was preceded by the scene associate (Scene Cue vs. Baseline: $t(15) = 4.98$, $p < 0.001$, $d = 1.24$; Scene Cue vs. Encoded Distractor: $t(15) = 2.85$, $p = 0.04$, $d =$

0.71). The small numerical difference in disengagement time that distinguished Encoded Distractor from Baseline trials was not significant (Encoded Distractor vs. Baseline: *t*(15) = 1.40, $p > 0.05$, $d = 0.35$; See Figure 3).

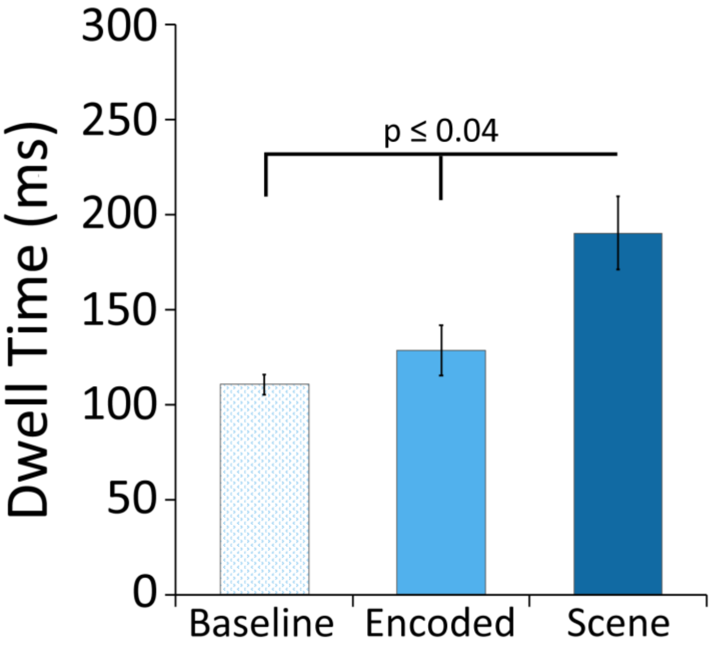

*Figure 3. Dwell time Experiment 1.* The amount of time, in milliseconds, that was spent fixating the ROI occupied by a distractor when overt, oculomotor capture had occurred.

**Covert Capture**. It was expected that saccade latencies (i.e. time required to initiate first saccade) would be longest for trials where scene cues and encoded items are present. Similarly, saccade latencies would be longer for encoded objects in the absence of scene cues relative to Baseline trials. To test this prediction, a repeated-measures ANOVA with the factor experimental condition (Baseline, Encoded Distractor, Scene Cue) was calculated to determine whether there are differences in saccade latencies, across conditions. Results indicate that saccade latencies were affected by our experimental manipulation, $F(1.15, 17.03) = 35.45$, $p < 0.001$, *G-G* $\varepsilon = 0.58$, $\eta_{p2} = 0.70$. Bonferroni corrected post-hoc comparisons indicated that saccade latencies were longer when scene cues preceded search displays (Scene Cue vs. Baseline: t(15) = 5.93, $p < 0.001$, $d = 1.48$; Scene Cue vs. Encoded Distractor: $t(15) = 6.28$, $p < 0.001$, $d = 1.57$). The small numerical difference between Encoded Distractor and Baseline trials was not significant (Encoded Distractor vs Baseline: *t*(15) = 0.28, *p* > 0.05, *d* = 0.07; See Figure 4).

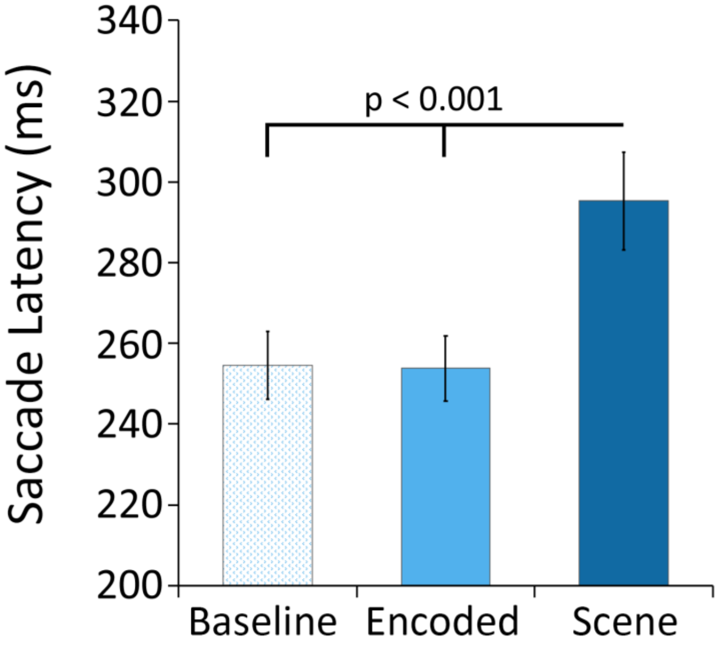

*Figure 4. Saccade latency Experiment 1.* Time, in milliseconds, required to initiate saccades to targets, as instructed, for Experiment 1.

### *Discussion*

Results from Experiment 1 suggest that attention was being deployed in error to encoded distractors even though participants were instructed to make a single eye movement to the location of a unique shape in the search displays. The effects were particularly robust when scene cues, meant to trigger retrieval of the associate, were presented prior to search displays. Further, when no scene cue was presented, there were no differences relative to baseline trials for either dwell time or saccade latency measures.

The items used for encoding in Experiment 1, like the other distractors, were defined by color. Therefore, they should not be any more physically salient than any of the other task-irrelevant items in displays (cf. Anderson & Halpern, 2017). However, they still captured attention disproportionately. In the next experiment, questions about the relative ease of processing different elements of the distractors and targets were addressed. In this experiment, the distractor and target feature values were swapped such that encoded objects were defined by shape and the target objects by color. This made the search target a singleton, defined by a proposed guiding attribute of attention (Wolfe & Horowitz, 2004, 2017), which should make it unlikely or impossible to document evidence for attention capture by long-term memory.

## Experiment 2

Encoded objects were defined by shape and targets by color. Because the search target was a singleton and color is a guiding attribute of attention (Wolfe & Horowitz, 2004, 2017), it was thought that this change might make it difficult to document, and may completely obviate, any evidence for memory-based capture.

### *Participants*

Twenty-five students from UWM completed this experiment. Data obtained from one individual was excluded from reported analyses because explicit recognition performance was less than 2 times the interquartile range calculated from the group data. Therefore, all of the reported analyses were based on data obtained from 24 participants.

### *Design and Procedure*

With the exception of two critical differences, design and procedure were identical to Experiment 1. In contrast to what was described above, encoded objects were distinguished by shape (i.e., square, trapezoid, hexagon, cross) rather than color (i.e., all gray), and targets in search displays were defined by color (i.e., red, pink, light blue, or green) rather than shape. All of the search distractors in the search display were gray and none of the objects in a given display had the same shape (see Figure 5).

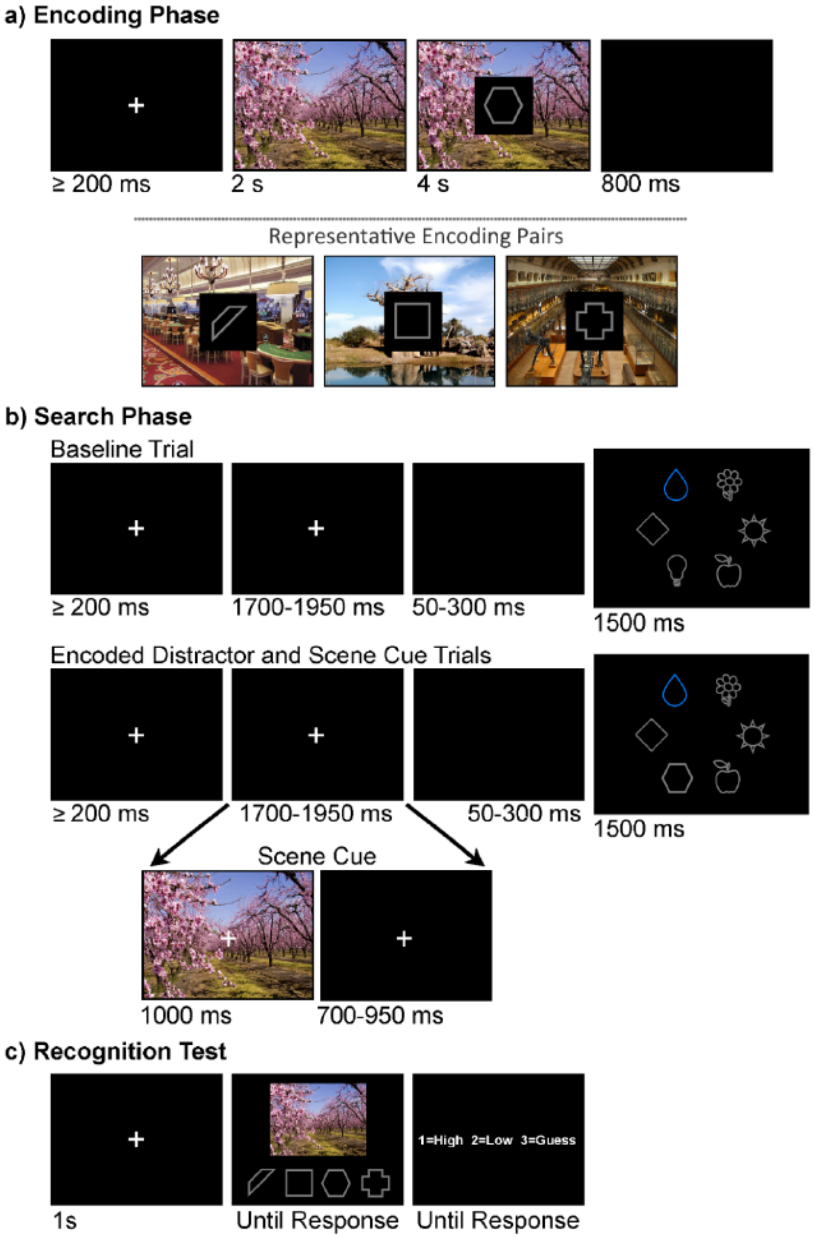

*Figure 5. Methods for Experiment 2.* (a) Event timing for a single encoding trial along with a set of representative scene-object pairs. (b) Trial structure and event timing for the visual search task. All three conditions are illustrated here. An encoded shape was present in a subset of the search displays (here, the hexagon in the bottom search display). Sometimes, the corresponding scene from encoding was presented prior to search (Scene Cue trials) and sometimes it was not (Encoded Distractor trials). Encoded shapes were not present in Baseline trials. Participants were instructed to make a single saccade to the location of the color target – here, the blue tear drop – and to ignore everything else in the display. (c) Trial structure and event timing for the associative recognition test.

Counterbalancing was as described for Experiment 1 with the following exceptions: target objects were equally likely to be a flower, tear, sun, diamond, apple, or light bulb and were distinctive by virtue of their color, which was red, light blue, green, or pink equally often across trials. As above, encoded distractors (i.e., square, trapezoid, hexagon, cross) were 1-, 2-, or 3-steps from the target when they were present and occupied every spatial location in the search display equally often across trials; encoded distractors were never search targets.

## ***Results***

### *Recognition Performance*

Similar to Experiment 1, it was predicted that performance on explicit tests of recognition would be very good and that participants would have high confidence in the accuracy of their correct responses. Results indicated that scene-object associations were successfully encoded. On average, the correct choice was selected (from among four alternatives) on 90.51% (*SD* = 11.59) of the trials and performance was well above chance, $t(23) = 27.69$, $p < 0.001$, $d = 5.65$. Additionally, when correct responses were made, participants reported high confidence in the accuracy of their choice 81.18% (*SD* = 22.21) of the time. In contrast, when responses were incorrect, reports of high confidence dropped to 27.84% (*SD* = 37.20); five participants did not make any incorrect responses.

### *Viewing Behavior*

The application of exclusion criteria in this experiment resulted in an average loss of 5.67% (*SD* = 4.39) of the trials across participants.

**Overt (Oculomotor) Capture**. We expected that the pattern of results for Experiment 2 would be similar to Experiment 1, however the magnitude of the effect would be reduced relative to Experiment 1. To test these predictions, two repeated-measures ANOVAs were calculated.

One with the factor experimental condition (Baseline, Encoded Distractor, Scene Cue) and one with the between subjects factor, experiment (1 or 2), and within subjects' factor, condition (Baseline, Encoded Distractor, Scene Cue). As predicted, we found a significant effect of condition that was similar to the pattern of results as in Experiment 1, $F(1.21, 27.77) = 7.57$, $p = 0.007$, $G\text{-}G\ \varepsilon = 0.60$, $\eta_{p2} = 0.25$. Bonferroni corrected post-hoc comparisons indicated that encoded objects in the presence of scene cues captured attention the most often relative to objects in Baseline trials (Scene Cue vs. Baseline: $t(23) = 3.10$, $p = 0.02$, $d = 0.63$). In addition, saccades were made more often in error to encoded objects in the absence of a scene cue as compared to objects in baseline trials (Encoded Distractor vs. Baseline: $t(23) = 3.64$, $p = 0.004$, $d = 0.74$). The small numerical difference between trials with encoded distractors present was not significant (Scene Cue vs. Encoded Distractor: $t(23) = 1.98$, $p > 0.05$, $d = 0.41$). Between experiments comparisons suggested that the magnitude of our effects in Experiment 2 were reduced relative to Experiment 1 (Experiment: $F(1, 38) = 22.49$, $p < 0.001$, $\eta_{p2} = 0.46$; Condition: $F(1.16, 44.01) = 55.15$, $p < 0.001$, $G\text{-}G\ \varepsilon = 0.58$, $\eta_{p2} = 0.59$; Interaction: $F(2, 76) = 22.49$, $p < 0.001$, $\eta_{p2} = 0.37$; See Figure 6).

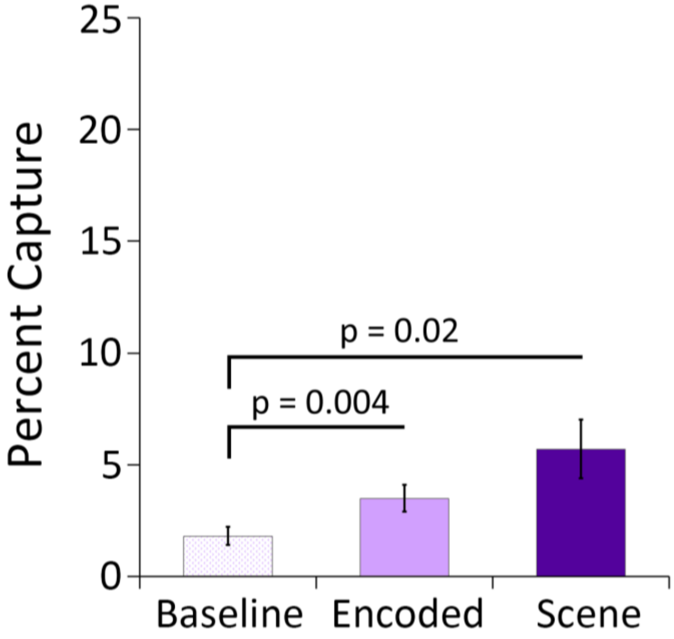

*Figure 6. Oculomotor capture Experiment 2.* The percentage of trials on which participants made an initial, erroneous saccade to a distractor in the search display for Experiment 2.

**Dwell Time**. It was predicted that dwell times would be longest for scene cue trials and shortest for baseline trials. To test these predictions, a repeated-measures ANOVA was calculated with the factor experimental condition (Baseline, Encoded Distractor, Scene Cue). Results indicated that there was an effect of our experimental manipulation, $F(1.13, 19.29) = 6.97$, $p = 0.01$, $G\text{-}G\ \varepsilon = 0.57$, $\eta_{p2} = 0.29$. Bonferroni corrected post-hoc comparisons were also calculated. These results suggested that dwell times were longest for Scene Sue trials, though the difference between Scene Cue and Encoded Distractor trials was marginal after correcting for multiple comparisons (Scene Cue vs. Baseline: $t(23) = 2.94$, $p = 0.03$, $d = 0.69$; Scene Cue vs. Encoded Distractor: $t(23) = 2.34$, $p = 0.09$, $d = 0.55$). The difference between Encoded Distractor and Baseline trials was not significant **(**Encoded Distractor vs. Baseline: $t(23) = 2.09$, $p > 0.05$, $d = 0.49$; See Figure 7).

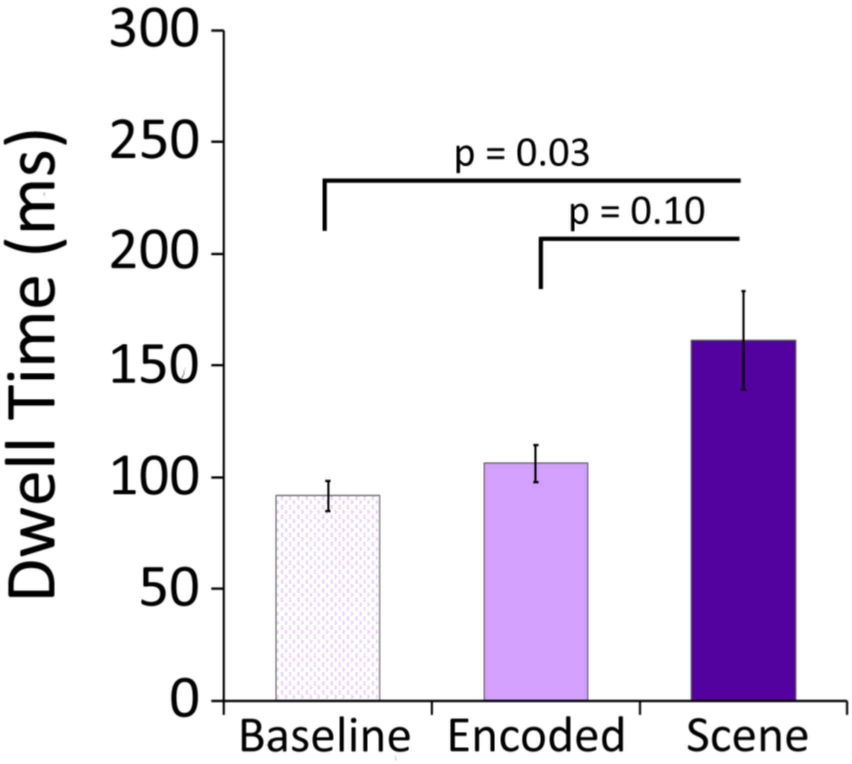

*Figure 7. Dwell time Experiment 2.* The amount of time, in milliseconds, that was spent fixating the ROI occupied by a distractor when overt, oculomotor capture had occurred.

**Covert Capture.** It was expected that saccade latencies would be longest for trials where scene cues and encoded items are present. Similarly, saccade latencies could be longer for encoded objects in the absence of scene cues relative to baseline trials. To test this prediction, a repeated-measures ANOVA with the factor experimental condition (Baseline, Encoded Distractor, Scene Cue) was calculated to determine whether there are differences in dwell times, following overt oculomotor capture, across conditions. Results indicated that there was an effect of our experimental manipulation, $F(1.36, 31.23) = 38.17$, $p < 0.001$, $G\text{-}G\ \varepsilon = 0.68$, $\eta_{p2} = 0.62$. Bonferroni corrected post-hoc comparisons suggested that saccade latencies were longest for scene cue trials (Scene Cue vs. Baseline: $t(23) = 7.08$, $p < 0.001$, $d = 1.45$; Scene Cue vs. Encoded: $t(23) = 6.15$, $p < 0.001$, $d = 1.26$). There were no differences between encoded distractor and baseline trials (Encoded Distractor vs. Baseline: $t(23) = 0.05$, $p > 0.05$, $d = 0.01$;

See Figure 8). It was predicted that saccade latencies to targets would be shorter for Experiment 2 than Experiment 1. To test this prediction a repeated measures ANOVA with the between subjects' factor, experiment (1 or 2), and within subjects' factor, condition (Baseline, Encoded Distractor, Scene Cue) was calculated. Results indicated that saccades were made more quickly in Experiment 2 relative to Experiment 1 (Experiment: $F(1, 38) = 18.93$, $p < 0.001$, $\eta_{p2} = 0.33$; Condition: $F(1.24, 47.10) = 78.97$, $p < 0.001$, $G\text{-}G\ \varepsilon = 0.62$, $\eta_{p2} = 0.68$; Interaction: $F(2, 76) = 8.33$, $p = 0.001$, $\eta_{p2} = 0.18$).

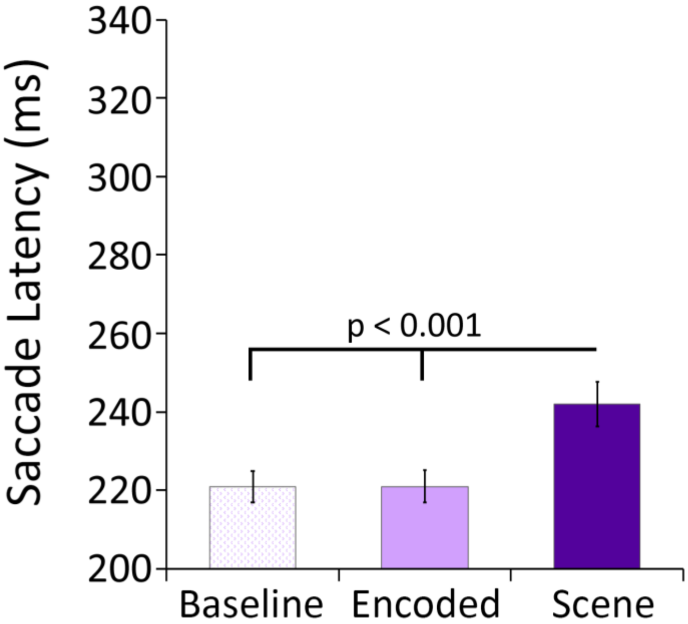

*Figure 8. Saccade latency Experiment 2.* Time, in milliseconds, required to initiate saccades to targets, as instructed, for Experiment 2.

### *Discussion*

The results from Experiment 2 replicated results from Experiment 1, however differences between Scene Cue and Encoded trials did not survive corrections for multiple comparisons in overt capture and dwell time measures. The difference between Experiment 1 and 2 was a change in feature mapping of encoded distractors and search targets. Specifically, in Experiment

2 search targets were defined by color and encoded distractors by shape. We hypothesized that color would be an especially strong attractor of attention and may reduce capture by long term memory. Consistent with this hypothesis, a direct comparison of Experiment 1 and 2 showed that overt capture was reduced, and saccades were initiated more quickly to targets in Experiment 2. This is supports evidence that suggests that color, but not shape, is an especially strong attractor of attention (Wolfe & Horowitz, 2004, 2017). Together, Experiments 1 and 2 suggest that episodic long-term memories can capture attention and disrupt goal-directed behavior and that this effect is most likely to occur following scene cues.

Experiment 3 was an attempted replication of Experiment 2 with a few changes: 1) we better equated the luminance of encoded and target colors. This is important because it helps rule out the possible influence of relative brightness of distractors on attention. 2) we implemented a stricter practice phase, with feedback about whether participants were making eye movements to the correct locations. Finally, 3) A yoking procedure was used calculate baseline levels of capture. As in Experiment 1 and 2, we hypothesized that capture effects would most likely be documented when scene cues were presented prior to search displays that contained encoded distractors, however, the changes implemented might make it impossible to document evidence of capture.

## Experiment 3

This was a replication of Experiment 2; however, efforts were made to better equate luminance of target colors and to ensure that luminance was better controlled within search displays (colored target and gray distractors). Greater efforts were made to further emphasize in instructions and practice that participants were to make a single eye movement to the location of the target stimulus, avoiding any other information in the display, and that these saccades should be made as quickly as possible without sacrificing accuracy. Finally, a yoking procedure was used to establish a different baseline comparison condition for contrasts of interest.

### ***Participants***

Forty-two students from UWM completed this experiment. Data obtained from ten individuals were excluded from reported analyses – six because too few trials remained after the exclusion criteria were applied (i.e., the percentage of trials excluded from the sample was more than 2 times the interquartile range calculated from group data), one because explicit recognition performance was less than 2 times the interquartile range calculated from the group data, and three more due to experimenter error. Therefore, all of the reported analyses were based on data obtained from 32 participants.

### ***Design and Procedure***

Three critical differences were made relative to Experiments 1 and 2. The first change was in instruction and practice trial feedback. In contrast to the other experiments, an error screen was used when participants practice the directed viewing task. Specifically, when saccades were not directed to the target, as instructed, the trial ended abruptly and a message that read, “ERROR! Look at the uniquely colored object”, was presented. The second change concerns luminance of search display objects. Specifically, colors were selected to minimize any potential confounding effect of this factor on search. CIE L*a*b* color values were selected so that L* values, a proxy for brightness, were matched (gray = 47, 0, 0; red = 46, 67, 54; blue = 47, 30, -73; orange = 47, 18, 55; green = 47, -48, 49; See Table 1); furthermore, a foot candle light meter (Extech Instruments Corporation, Boston, MA) was used to measure brightness objectively on the monitor (i.e., each stimulus has a recorded brightness of 53.82 lux). Finally, a new baseline comparison procedure was developed. For this experiment, eight objects (i.e., button, nut, leaf, lock, lamp, anchor, cup, and bow) from the set of 13 were never used as targets in search displays. Instead, these objects were subdivided into two sets of four (Set 1: button, nut, lock, and leaf; Set 2: lamp, anchor, cup, and bow) and were either encoded or used as critical distractors in baseline trials. For half of the participants, objects from Set 1 were encoded and used as encoded distractors during the directed viewing task, while objects from Set 2 were critical distractors in baseline search displays. For the remaining participants, this mapping was swapped. Individual participants from each group were yoked so that all of the other search display characteristics (i.e., the position, color, and identity of the target object; the identities of other distractors in a given search display) were the same. This design feature meant that we could compare overt capture by encoded distractors (1 per display in Scene Cue and Encoded Distractor conditions) directly with overt capture by critical baseline distractors (1 per display in the Baseline condition). More generally, this meant that like encoded elements, critical baseline distractors were relatively rare – they were not present in all of the search displays – and were never seen as targets. As such, for purposes of evaluating overt capture, comparisons were based on percentage of capture by encoded distractors (Scene Cue and Encoded Distractor conditions) and by critical baseline distractors (Baseline condition) (See Figure 9).

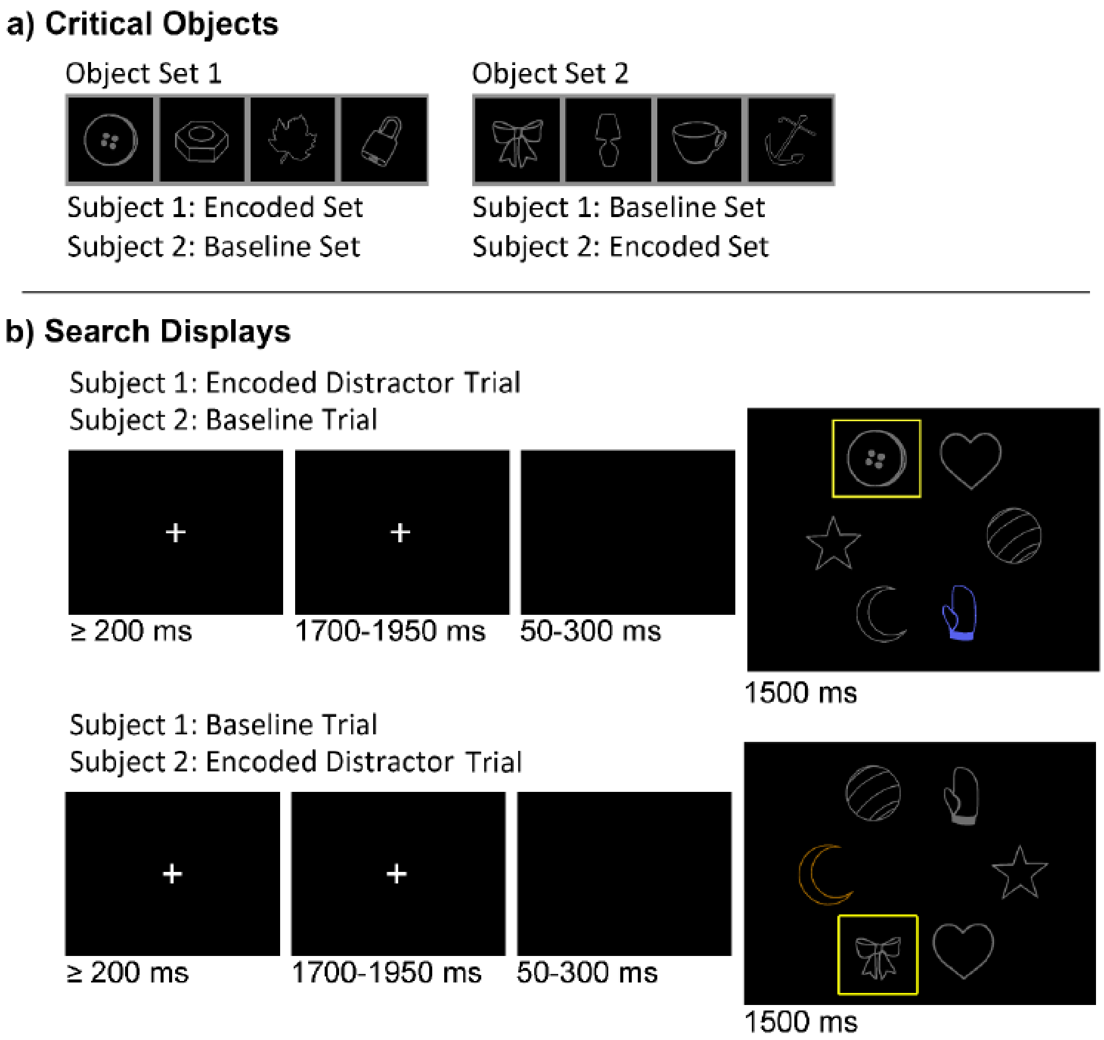

*Figure 9. Experiment 3 critical objects and search display details.* (a) Sets of objects that were either used as encoded distractors or critical baseline distractors; these sets were counterbalanced across subjects. For example, the button, nut, leaf and lock would have been encoded by subject 1, with scenes. The same objects would have been used as baseline distractors in search displays for subject 2. (b) Examples of yoked search displays for subjects 1 and 2. For subject 1, the button is an encoded distractor; for subject 2, the button is a baseline distractor; the mappings revers in the bottom search display where the bow is the critical item. Yellow boxes are for illustration only and Scene Cue trials are not shown in this figure but, in scene cue trials, scenes would have been presented in advance of search displays that included the encoded associate.

Counterbalancing was as described for Experiments 1 and 2 with the following exceptions: target objects were equally likely to be a moon, heart, ball, star, and mitten and were distinctive by virtue of their color which was red, blue, orange, or green equally often across trials. Here, not only encoded distractors, but also critical baseline objects were 1-, 2-, or 3-steps from the target and occupied every spatial location in the search display equally often across trials.

### ***Results***

#### *Recognition Performance*

Similar to Experiments 1 and 2, it was predicted that performance on explicit tests of recognition would be very good and that participants would have high confidence in the accuracy of their correct responses. Results indicated that scene-object associations were successfully encoded. On average, the correct choice was selected (from among four alternatives) on 94.31% ($SD = 6.83$) of the trials and performance was well above chance, $t(31) = 57.42$, $p < 0.001$, $d = 10.15$. Additionally, when correct responses were made, participants reported high confidence in the accuracy of their choice 84.12% ($SD = 15.82$) of the time. In contrast, when responses were incorrect, reports of high confidence dropped to 22.41% ($SD = 35.09$); ten participants did not make any incorrect responses.

#### *Viewing Behavior*

The application of exclusion criteria in this experiment resulted in an average loss of 4.25% ($SD = 2.77$) of the trials across participants.

**Overt (Oculomotor) Capture.** Similar to Experiments 1 and 2, we expected that overt capture would occur disproportionately on trials where scene cues and encoded distractors were present. In addition, encoded content, in the absence of a scene cue, would capture attention disproportionately relative to baseline trials. To test this prediction a repeated measure ANOVA with the factor experimental condition (Baseline, Encoded Distractor, Scene Cue) was calculated. Unlike Experiments 1 and 2, our experimental manipulation did not affect overt capture, $F(1.31, 40.73) = 1.38$, $p > 0.05$, $G\text{-}G\ \varepsilon = 0.66$, $\eta_{p2} = 0.04$ (See Figure 10).

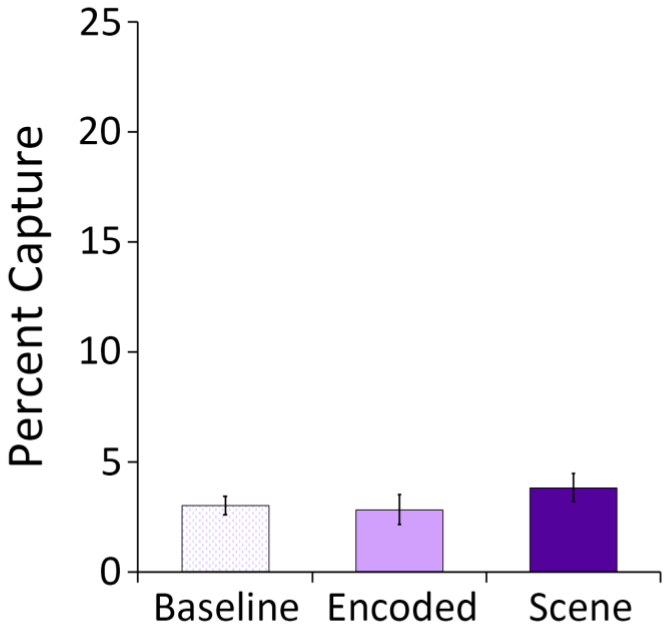

*Figure 10. Oculomotor capture Experiment 3.* The percentage of trials on which participants made an initial, erroneous saccade to a distractor in the search display for Experiment 3.

We were also interested in the potential differences between Experiments 2 and 3. To do this, we calculated a repeated-measures ANOVA with the factors experiment (2 or 3) and experimental condition (Baseline, Encoded Distractor, Scene Cue). Results indicated that there was an effect of experimental condition, $F(1.45, 78.44) = 8.92$, $p = 0.001$, *G-G* $\varepsilon = 0.73$, $\eta_{p2} = 0.14$. There was no main effect of experiment, $F(1, 54) = 0.35$, $p > 0.05$, $\eta_{p2} = 0.01$. The interaction between factors was significant, $F(2, 108) = 3.75$, $p = 0.03$, $\eta_{p2} = 0.07$. Bonferroni corrected post hoc comparisons indicated that there were no differences between conditions across experiments ($t(54)$'s $< 2.04$, $p$'s $> 0.05$, $d$'s $< 0.55$), though differences between Baseline trials between experiments were significant before correcting.

**Dwell Time.** 15 participants did not have data for one or more conditions (no trials with overt capture, therefore we could not calculate dwell times), resulting in excluding almost half our sample, so we did not calculate ANOVAs for this measure.

**Covert Capture.** Similar to Experiments 1 and 2, we expected that saccade latencies would be longest when scene cues and encoded distractors were present. In addition, encoded content, in the absence of a scene cue, might result in longer latencies relative to baseline trials. To test this prediction a repeated measures ANOVA with the factor experimental condition (Baseline, Encoded Foil, Scene Cue) was calculated. Results indicated that there was a significant influence of our experimental manipulation, $F(1.26, 38.99) = 29.34$, $p < 0.001$, $G\text{-}G\ \varepsilon = 0.63$, $\eta_{p2} = 0.49$ (See Figure 11). Bonferroni corrected post-hoc comparisons suggested that saccade latencies were longest when scene cues were presented (Scene Cue vs. Baseline: $t(31) = 5.41$, $p < 0.001$, $d = 0.96$; Scene Cue vs. Encoded: $t(31) = 5.92$, $p < 0.001$, $d = 1.05$). There were no differences between encoded distractor and baseline trials (Encoded vs Baseline: $t(31) = 0.16$, $p > 0.05$, $d = 0.03$).

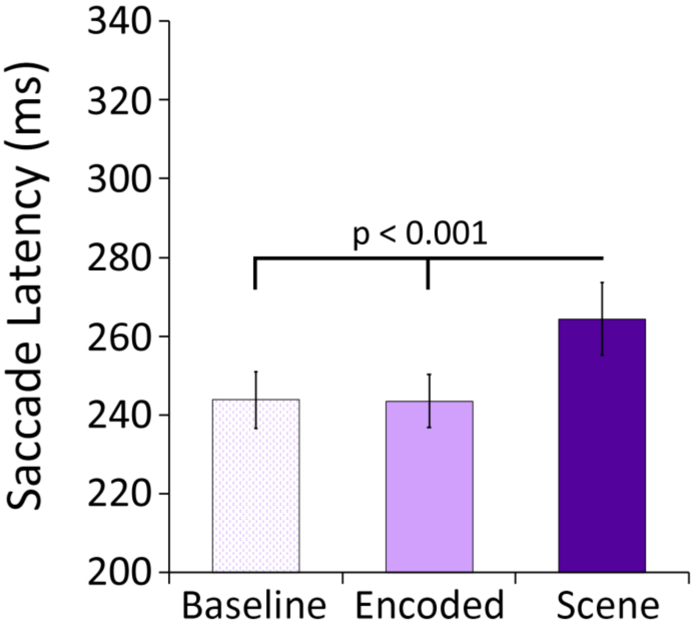

*Figure 11. Saccade latency Experiment 3.* Time, in milliseconds, required to initiate saccades to targets, as instructed, for Experiment 3.

We were also interested in between experiment comparisons. A repeated measures ANOVA with the factors experiment (2 or 3) and experimental condition (Baseline, Encoded

Distractor, Scene Cue) was conducted. Results indicated that there was an effect of experimental condition, $F(1.31, 70.65) = 61.66$, $p < 0.001$, $G\text{-}G\ \varepsilon = 0.65$, $\eta_{p2} = 0.53$. There also a main effect of experiment, $F(1, 54) = 5.56$, $p = 0.02$, $\eta_{p2} = 0.09$, with slower latencies for Experiment 3. The interaction between factors was not significant, $F(2, 108) = 0.01$, $p > 0.05$, $\eta_{p2} = 0.00$.

### ***Discussion***

Experiment 3 was a replication of Experiment 2 with three changes: 1) We attempted to better equate the luminance of the objects used; 2) We used a strict practice procedure; 3) We used an alternative procedure to calculate baseline levels of capture. Following these changes, differences in overt oculomotor capture were no longer significant.

Results from Experiment 2 and 3 were compared to examine the differences in the pattern of results across studies. Here, we found that there was a non-significant increase in overt capture in Baseline trials and a non-significant decrease overt capture in Scene Cue and Encoded Distractor trials in Experiment 3. This pattern of results would explain the experiment by condition interaction when we compared Experiment 2 and 3, and the non-significant effects when looking only at Experiment 3.

This Experiment used an alternative procedure to calculate the percentage of capture that occurred on Baseline trials. Specifically, we were interested in whether the correction procedure used in Experiment 1 and 2 was underestimating the percentage of overt capture in Baseline trials. Patterns of results indicated that the percentage of baseline no different between Experiment 2 and 3.

While patterns of overt capture did not match those of Experiment 1 and 2, the saccade latency results were replicated. Saccade latencies were slowest when scene cues were presented prior to search displays containing encoded distractors. When Experiment 2 and 3 were compared, latencies were slower for Experiment 3. It is likely that attempts to equate the luminance of the distractors and targets meant that targets were not brighter than other objects in the search display, and this led to slower latencies. In other words, the targets blended in better and may have been more difficult to locate.

In the final two experiments we return to the methods from Experiment 1 in an attempt to replicate the effects from Experiment 1. We were also interested in possible alternative interpretations for differences in saccade latencies. We had initially interpreted this as an effect of covert capture (following scene cues, attention is drawn covertly to encoded distractors before saccades are initiated to targets). An alternative interpretation is that a visual stimulus prior to the search display is distracting or disruptive and this is the cause of the increase in saccade latencies seen in Experiments 1-3. In Experiment 4, we presented scrambled scenes prior to baseline search displays. If visual information is the only cause, there will be no differences in saccade latencies comparing Scene Cue and Scrambled Scene trials.

## Experiment 4

Experiment 4 included an additional condition where, instead of scene cues, scrambled scenes were presented prior to the search display on a subset of trials.

### *Participants*

Twenty-six students from UWM completed this experiment. Data obtained from two individuals were excluded from reported analyses because explicit recognition performance was less than 2 times the interquartile range calculated from the group data. Therefore, all of the reported analyses were based on data obtained from 24 participants.

***Design and Procedure***

With the exception of one critical difference, design and procedure were identical to Experiment 1. In addition to scene cue, encoded distractor, and baseline trials, there were also baseline search displays preceded by scrambled scenes. In this case, event timing was matched to scene cue trials, but scene cues were replaced with scrambled scenes and encoded objects were not present in corresponding search displays (see Figure 12). This meant that we could examine whether differences in saccade latencies to targets following scene cues are due to covert capture by encoded associates of scene cues or to the mere presence of visual information prior to search.

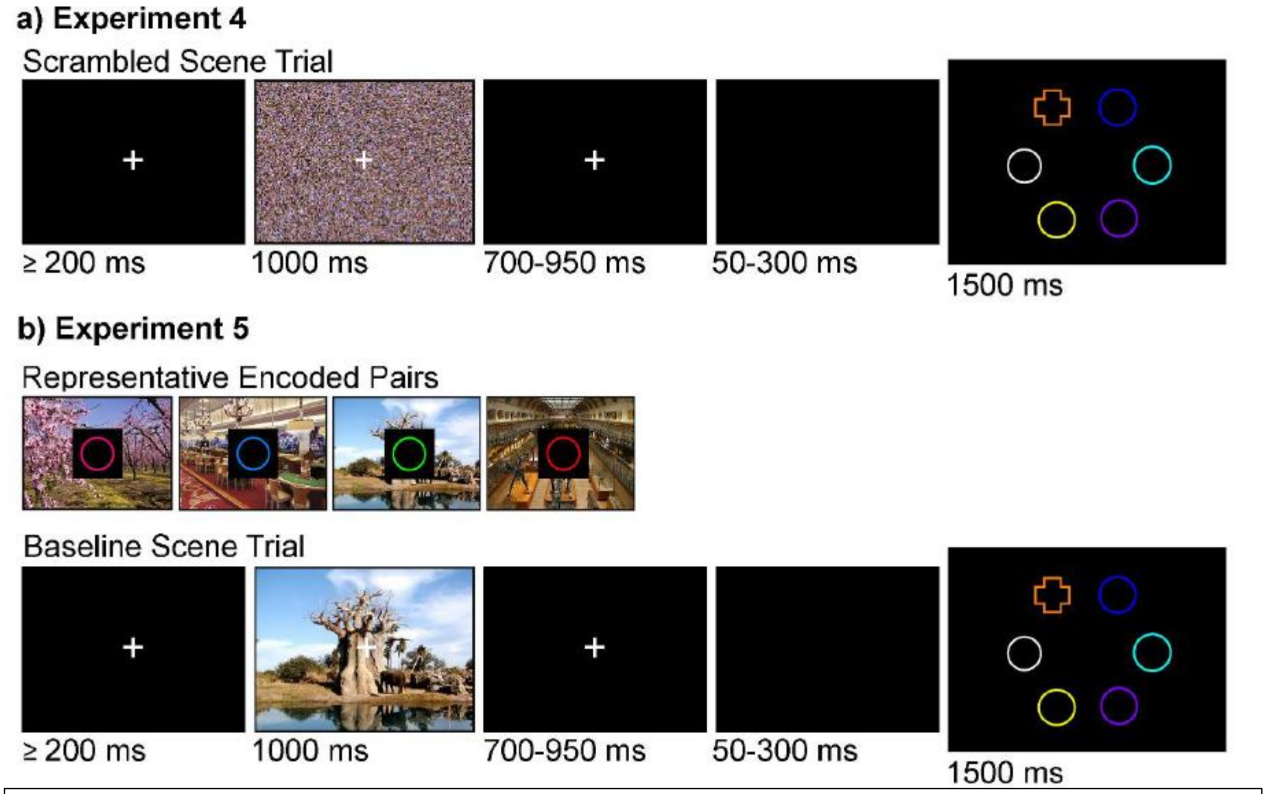

*Figure 12. New, control trials used in Experiments 4 and 5.* (a) Event timing for Scrambled Scene trials. None of the distractors in the search display were encoded. (b) Representative examples of pairs seen during the encoding phase along with a corresponding Baseline Scene trial. Here, the scene was encoded but distractors in the search display were not.

Counterbalancing was as described for Experiment 1, but now 36 scrambled scene trials were included in each directed viewing block (i.e., 72 trials collapsed across blocks). As above, targets and encoded distractors were presented equally often in every search display location across trials, and encoded distractors were 1-, 2-, or 3-steps from the target with equal frequency.

### ***Results***

#### *Recognition Performance*

Similar to Experiments 1 - 3, it was predicted that performance on explicit tests of recognition would be very good and that participants would have high confidence in the accuracy of their correct responses. Results indicated that scene-object associations were successfully encoded. On average, the correct choice was selected (from among four alternatives) on 91.90% ($SD$ = 8.61) of the trials and performance was well above chance, $t(23) = 38.08$, $p < 0.001$, $d$ = 7.77. Additionally, when correct responses were made, participants reported high confidence in the accuracy of their choice 88.67% ($SD$ = 12.69) of the time. In contrast, when responses were incorrect, reports of high confidence dropped to 38.10% ($SD$ = 34.53); four participants did not make any incorrect responses.

#### *Viewing Behavior*

The application of exclusion criteria in this experiment resulted in an average loss of 12.90% ($SD$ = 10.10) of the trials across participants.

**Overt (Oculomotor) Capture.** Similar to Experiments 1-3, we expected that overt capture would occur disproportionately on trials where scene cues and encoded distractors were present. In addition, encoded content, in the absence of a scene cue, would capture attention disproportionately relative to baseline trials. To test this prediction, a repeated-measures ANOVA with the factors Scene Cue (Present or absent) and Encoding Status (Encoded or not) was calculated. Results showed that capture was affected by the presence of a visual information prior to the search display, $F(1, 23) = 15.21$, $p = 0.001$, $\eta_{p2} = 0.40$, and the presence of an encoded distractor in the display, $F(1, 23) = 59.42$, $p < 0.001$, $\eta_{p2} = 0.72$. There was also a significant interaction between these factors, $F(1, 23) = 13.97$, $p = 0.001$, $\eta_{p2} = 0.38$ (See Figure 13).

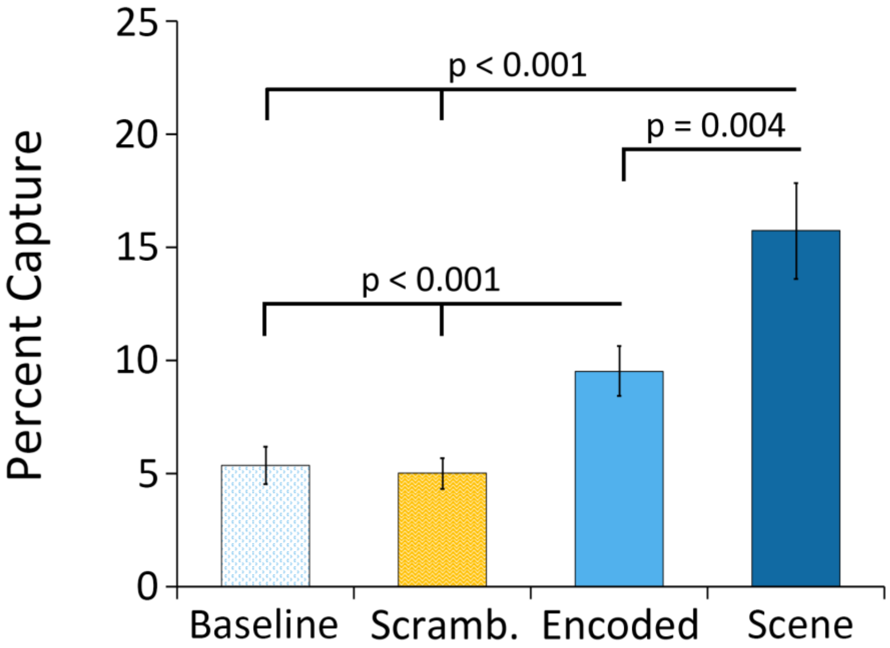

*Figure 13. Oculomotor capture Experiment 4.* The percentage of trials on which participants made an initial, erroneous saccade to a distractor in the search display for Experiment 4.

Bonferroni corrected post-hoc comparisons were also calculated. This allowed us to determine whether visual information or memory retrieval are influencing our measurements. Capture occurred most often on scene cue trials relative to all other conditions (Scene Cue vs. Scrambled: $t(23) = 6.43$, $p < 0.001$, $d = 1.31$; Scene Cue vs. Encoded: $t(23) = 3.94$, $p = 0.004$, $d = 0.80$; Scene Cue vs. Baseline: $t(23) = 7.08$, $p < 0.001$, $d = 1.44$). In addition, encoded items in the absence of a scene cue captured attention as compared to the other conditions (Encoded vs. Baseline: $t(23) = 5.29$, $p < 0.001$, $d = 1.08$; Encoded vs Scrambled: $t(23) = 4.93$, $p < 0.001$, $d = 1.01$). There were no differences between scrambled scene and baseline trials (Scrambled vs Baseline: $t(23) = 0.83$, $p > 0.05$, $d = 0.17$).

**Dwell Time.** Like Experiments 1-3, it was expected that dwell times would be longest for trials where scene cues and encoded distractors were present. Similarly, dwell times would be longer for encoded objects in the absence of scene cues relative to baseline trials. To test this prediction, a repeated-measures ANOVA with the factors Scene Cue (Present or absent) and Encoding Status (Encoded or not) was calculated. Results suggested that, like for overt oculomotor capture, there was a significant effect of visual information prior to search, $F(1, 20) = 16.59$, $p = 0.001$, $\eta_{p2} = 0.45$, and the presence of an encoded object, $F(1, 20) = 17.77$, $p < 0.001$, $\eta_{p2} = 0.47$. There was also a significant interaction between these factors, $F(1, 20) = 13.80$, $p = 0.001$, $\eta_{p2} = 0.41$ (See Figure 14).

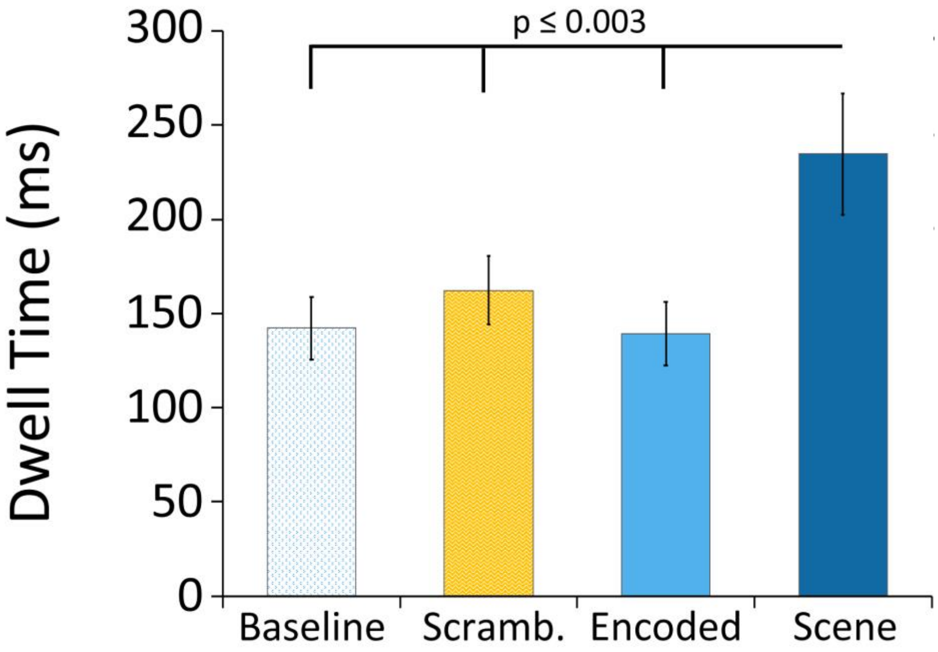

*Figure 14. Dwell time Experiment 4.* The amount of time, in milliseconds, that was spent fixating the ROI occupied by a distractor when overt, oculomotor capture had occurred.

Bonferroni corrected post-hoc comparisons were also calculated. This allowed us to determine whether visual information or memory retrieval are influencing our measurements. Dwell times were longest when scene cues preceded search displays with encoded objects (Scene Cue vs. Scrambled Scene: $t(20) = 4.31$, $p = 0.002$, $d = 0.94$; Scene Cue vs. Encoded Distractor:

*t*(20) = 4.14, *p* = 0.003, *d* = 0.90; Scene Cue vs. Baseline: *t*(20) = 4.86, *p* < 0.001, *d* = 1.06). There were no other significant differences (Scrambled Scene vs Baseline: *t*(20) = 2.29, *p* > 0.05, *d* = 0.50; Encoded Distractor vs. Baseline: *t*(20) = 0.37, *p* > 0.05, *d* = 0.08; Encoded Distractor vs. Scrambled: *t*(20) = 1.74, *p* > 0.05, *d* = 0.38).

**Covert Capture.** As in Experiments 1-3, we expected that saccade latencies would be longest for trials where scene cues and encoded items were present. Here, we were specifically interested in whether visual information presented prior to search displays without encoded distractors would drive saccade latencies up. To test this prediction, a repeated-measures ANOVA with the factors Scene Cue (Present or absent) and Encoding Status (Encoded or not) was calculated. Results showed at there was an effect of presenting visual information prior to search displays, *F*(1, 23) = 30.53, *p* < 0.001, $\eta_{p2}$ = 0.57, and the presence of an encoded distractor in the display, *F*(1, 23) = 7.02, *p* = 0.01, $\eta_{p2}$ = 0.23. There was also a significant interaction between these factors, *F*(1, 23) = 4.22, *p* = 0.05, $\eta_{p2}$ = 0.16 (See Figure 15).

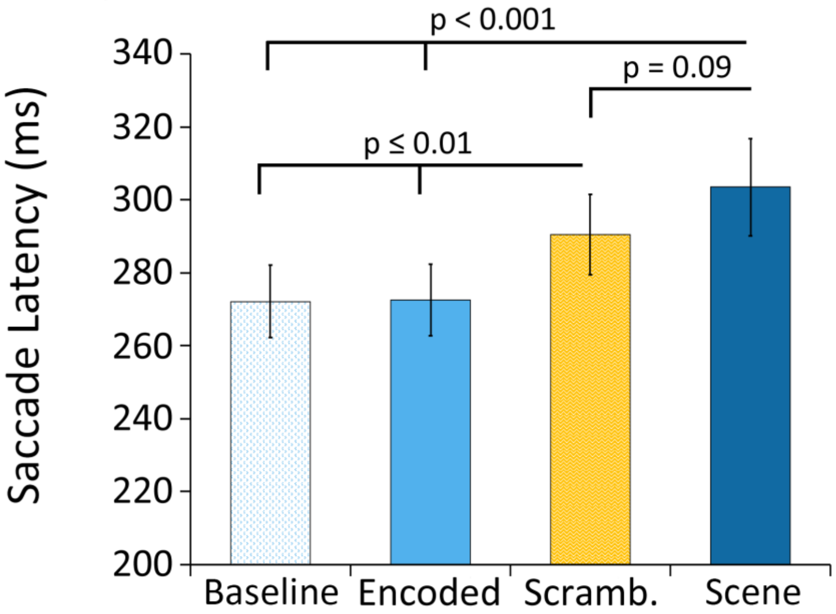

*Figure 15. Saccade latency Experiment 4.* Time, in milliseconds, required to initiate saccades to targets, as instructed, for Experiment 4.

Bonferroni corrected post-hoc comparisons were also calculated. This allowed us to determine whether visual information or memory retrieval are influencing our measurements. Like in the previous experiments, when scenes cues preceded search displays that contained encoded distractors saccade latencies were longest (Scene Cue vs. Baseline: $t(23) = 6.12$, $p < 0.001$, $d = 1.25$; Scene Cue vs. Encoded Distractor: $t(23) = 5.42$, $p < 0.001$, $d = 1.11$). The difference between Scene Cue trials and Scrambled Scene trials was marginal following corrections for multiple comparisons (Scene Cue vs. Scrambled Scene: $t(23) = 2.62$, $p = 0.09$, $d = 0.53$). Saccades were made more slowly when scrambled scenes were presented prior to search displays (Encoded Distractor vs. Scrambled Scene: $t(23) = 3.50$, $p = 0.01$, $d = 0.71$; Scrambled Scene vs Baseline: $t(23) = 3.58$, $p = 0.009$, $d = 0.73$). As in previous work, there were no differences between Encoded Distractor trials and Baseline trials (Encoded Distractor vs. Baseline: $t(23) = 0.13$, $p > 0.05$, $d = 0.03$).

### ***Discussion***

Experiment 4 was an attempted replication of Experiment 1. In addition, we aimed to examine whether the saccade latency effects documented in Experiments 1-3 were due to covert capture by encoded distractors or were the effect of presenting a visual stimulus before the search displays. Results from overt capture and dwell time replicated previous work. Encoded distractors captured and held attention to a greater extent when scene cues were presented prior to displays. Also consistent with the previous studies, saccade latencies were slowest when scene cues were presented, and encoded distractors were in search displays. Our critical contrast in this study, a comparison between Scene Cue and Scrambled trials, suggested that saccades were initiated more slowly in Scene Cue trials, however this difference was marginal after correcting for multiple comparisons. So, it seems that visual information prior to search accounts for some of the slowdown in saccade latencies. It is possible that the remaining slowdown could be attributed to the retrieval of the associate, but not covert capture by the encoded object in the display. Experiment 5 was designed to test this possibility. In this experiment we presented encoded scenes prior to baseline search displays. If retrieval is playing a part, then saccades latencies to targets should be the same following scene cues, regardless of whether the encoded distractor is in the search display. This new condition also allowed us to determine whether our capture effects could be documented when scene cues were not 100% predictive of the presence of the encoded distractor.

## Experiment 5

Experiment 5 included an additional condition, where scene cues were presented prior to search displays that did not contain encoded distractors.

### *Participants*

Twenty-seven students from UWM completed this experiment. Data obtained from three individuals were excluded from reported analyses – one because too few trials remained after the exclusion criteria were applied (i.e., the percentage of trials excluded from the sample was more than 2 times the interquartile range calculated from group data) and two more because explicit recognition performance was less than 2 times the interquartile range calculated from the group data. Therefore, all of the reported analyses were based on data obtained from 24 participants.

### *Design and Procedure*

With the exception of one critical difference, the design and procedure were identical to Experiments 1 and 4. In addition to scene cue, encoded distractor, and baseline trials, there were also baseline trials that were preceded by studied scenes where encoded distractors were not present in the display. This meant that we could examine whether differences in saccade latencies to targets following scene cue requires the presence of an encoded object in the search displays (See Figure 12).

Counterbalancing was as described for Experiment 1, but now half of the 36 encoded scenes were presented prior to baseline search display (i.e., there were now 36 trials per condition collapsed across blocks). As above, targets and encoded distractors were presented equally often in every search display location across trials, and encoded distractors were 1-, 2-, or 3-steps from the target with equal frequency.

## ***Results***

### *Recognition Performance*

Similar to Experiments 1 - 4, it was predicted that performance on explicit tests of recognition would be very good and that participants would have high confidence in the accuracy of their correct responses. Results indicated that scene-object associations were successfully encoded. On average, the correct choice was selected (from among four alternatives) on 95.02% (*SD* = 6.45) of the trials and performance was well above chance, $t(23) = 59.20$, $p < 0.001$, $d = 10.86$. Additionally, when correct responses were made, participants reported high confidence in the accuracy of their choice 88.07% (*SD* = 18.40) of the time. In contrast, when responses were incorrect, reports of high confidence dropped to 29.36% (*SD* = 30.70); seven participants did not make any incorrect responses.

### *Viewing Behavior*

The application of exclusion criteria in this experiment resulted in an average loss of 4.92% (*SD* = 4.01) of the trials across participants.

**Overt (Oculomotor) Capture.** Effects from previous experiments were replicated once again. A repeated-measures ANOVA with the factors Scene Cue (Present or absent) and

Encoding Status (Encoded or not) was calculated. Results indicated that capture was more likely to occur when scene cues were presented prior to search displays, *F*(1, 23) = 34.46, $p < 0.001$, $\eta_{p2} = 0.60$, and when encoded distractors were present in the displays, *F*(1, 23) = 51.19, $p < 0.001$, $\eta_{p2} = 0.69$. There was also a significant interaction between these factors, *F*(1, 23) = 23.14, $p < 0.001$, $\eta_{p2} = 0.50$ (See Figure 16).

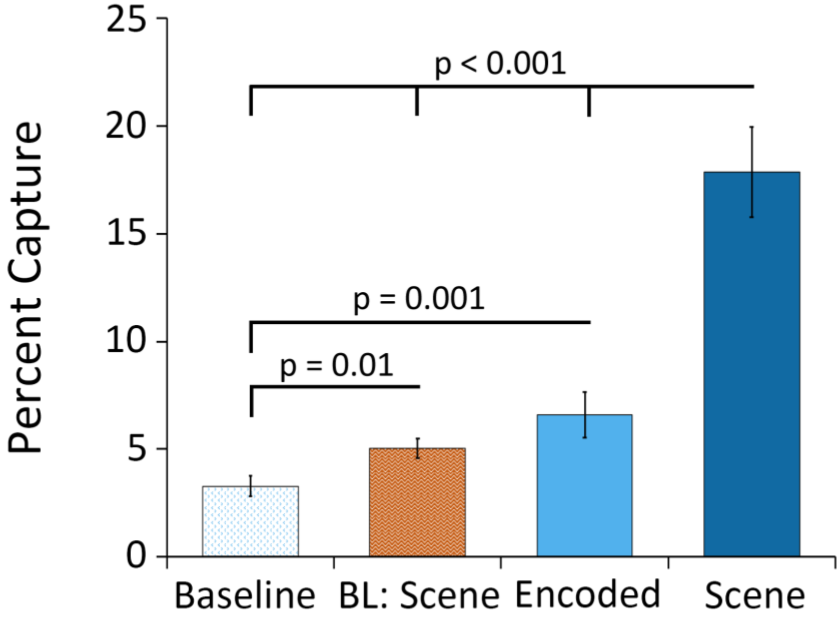

*Figure 16. Oculomotor capture Experiment 5.* The percentage of trials on which participants made an initial, erroneous saccade to a distractor in the search display for Experiment 5.

Bonferroni corrected post-hoc comparisons were also calculated. These tests indicated that capture was more likely to occur when scene cues were presented and encoded distractors were present (Scene Cue vs. Baseline Scene: *t*(23) = 6.74, $p < 0.001$, *d* = 1.38; Scene Cue vs. Encoded Distractor: *t*(23) = 5.45, $p < 0.001$, *d* = 1.11; Scene Cue vs. Baseline: *t*(23) = 7.33, $p < 0.001$, *d* = 1.50). Capture was more likely to occur in Baseline Scene and Encoded Distractor trials as compared to Baseline trials (Baseline Scene vs Baseline: *t*(23) = 4.52, $p = 0.001$, *d* = 0.92; Encoded Distractor vs. Baseline: *t*(23) = 3.51, $p = 0.01$, *d* = 0.72). There were no differences between Encoded Distractor and Baseline Scene trials (Encoded Distractor vs Baseline Scene: $t(23) = 1.53$, $p > 0.05$, $d = 0.31$).

**Dwell Time.** A repeated-measures ANOVA with the factors Scene Cue (Present or absent) and Encoding Status (Encoded or not) was calculated. Results indicated that there was an effect of presenting a scene cue prior to the search displays, $F(1, 18) = 20.78$, $p < 0.001$, $\eta_{p2} = 0.54$, and the presence of an encoded object in the search display, $F(1, 18) = 13.02$, $p = 0.002$, $\eta_{p2} = 0.42$. The interaction between these factors was not significant, $F(1, 18) = 1.28$, $p > 0.05$, $\eta_{p2} = 0.07$ (See Figure 17).

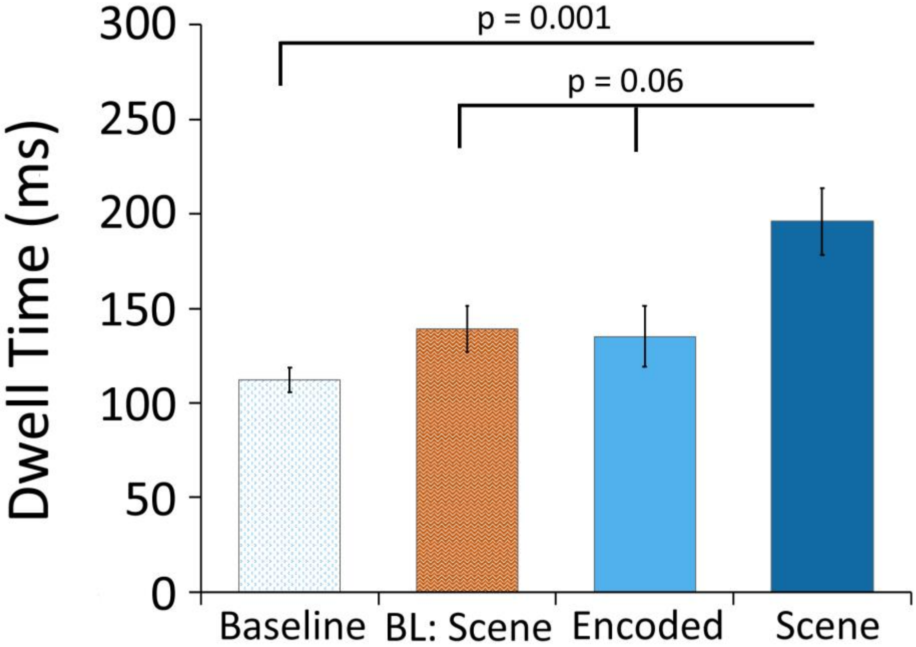

*Figure 17. Dwell time Experiment 5.* The amount of time, in milliseconds, that was spent fixating the ROI occupied by a distractor when overt, oculomotor capture had occurred.

Bonferroni corrected post-hoc comparisons were also calculated. It was discovered that, in general, dwell times were longest when scene cues preceded search displays, however, the differences between Scene Cue and Baseline Scene and Scene Cue and Encoded Distractor were marginal after correcting for multiple comparisons (Scene Cue vs. Baseline Scene: $t(18) = 2.89$, $p = 0.06$, $d = 0.66$; Scene Cue vs. Encoded Distractor: $t(18) = 2.87$, $p = 0.06$, $d = 0.66$; Scene Cue vs. Baseline: $t(18) = 4.64$, $p = 0.001$, $d = 1.06$). None of the other differences were significant (Baseline Scene vs Baseline: $t(18) = 2.22$, $p > 0.05$, $d = 0.51$; Encoded Distractor vs. Baseline: $t(18) = 1.41$, $p > 0.05$, $d = 0.32$; Encoded Distractor vs. Baseline Scene: $t(18) = 0.39$, $p > 0.05$, $d = 0.09$).

**Covert Capture.** In the previous experiments, saccades were made more slowly to targets when encoded distractors were present in search displays when scene cues were presented. Results from Experiment 4 suggest that visual information presented prior to search displays contributes to some of this slowdown. In this experiment, we were interested in whether the remaining influence on saccade latency is due to covert capture or to retrieval processes that are initiated when scene cues presented. To test this, a repeated-measures ANOVA with the factors Scene Cue (Present or absent) and Encoding Status (Encoded or not) was calculated. Results indicated that there was an effect of presenting a scene cue prior to the search displays, $F(1, 23) = 29.13$, $p < 0.001$, $\eta_{p2} = 0.56$, and a marginal effect of the presence of an encoded object in the search display, $F(1, 23) = 3.16$, $p = 0.09$, $\eta_{p2} = 0.12$. The interaction between these factors was not significant, $F(1, 23) = 0.18$, $p > 0.05$, $\eta_{p2} = 0.01$ (See Figure 18).

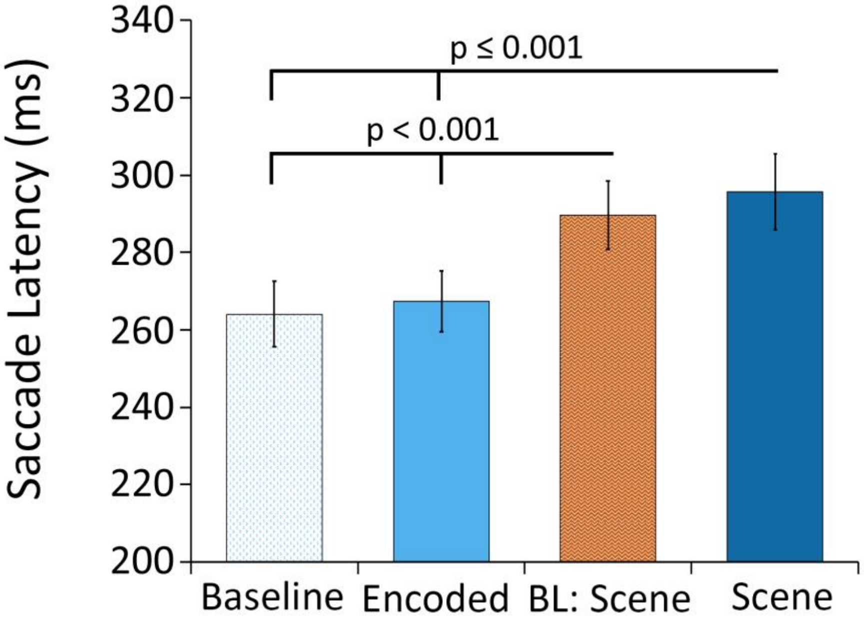

*Figure 18. Saccade latency Experiment 5.* Time, in milliseconds, required to initiate saccades to targets, as instructed, for Experiment 5.

Bonferroni corrected post-hoc comparisons were also calculated. In general, saccade latencies were longest when scene cues were presented prior to search displays that contained encoded distractors (Scene Cue vs. Encoded: t(23) = 4.47, p = 0.001, d = 0.91; Scene Cue vs. Baseline: t(23) = 5.03, p < 0.001, d = 1.03), however, the difference between Scene Cue and Baseline Scene trials was not significant (Scene Cue vs. Baseline Scene: t(23) = 1.15, p > 0.05, d = 0.23). Saccade latencies were longer for Baseline Scene trials as compared to Encoded Distractor and Baseline trials (Encoded vs Baseline Scene: t(23) = 4.54, p < 0.001, d = 0.93; Baseline Scene vs Baseline: t(23) = 4.53, p < 0.001, d = 0.92). There were no differences between Encoded Distractor and Baseline trials (Encoded vs. Baseline: t(23) = 1.15, p > 0.05, d = 0.23).

### *Discussion*

Results from Experiment 5 suggest, in line with the previous experiments, that overt capture is documented most often when scene cues are presented prior to search displays containing encoded distractors. In contrast to the other experiments, encoded scenes were not a reliable predictor of the presence of encoded distractors in search displays. In this experiment, half of the encoded scenes were followed by baseline search displays. There was no change in the strength of overt capture effects for Scene Cue trials relative to Experiments 1 and 4, so it is not necessary for encoded distractors to be present following scene cues to document this effect.

The dwell time effects from the other experiments was replicated once again. Participants spent more time looking at distractors when capture occurred in Scene Cue trials. We hypothesize that this effect is the result of difficulty disengaging attention from the encoded distractors and that participants may need time to reorient to the instructed goal when these encoded distractors match representations retrieved following scene cues.

This experiment suggests that differences in saccade latencies across conditions are not the consequence of covert capture by encoded distractors. The small differences between Scene Cue trials and Baseline Scene trials was not significant. What we were interpreting as an effect covert capture is likely an effect of visual information processing and possible retrieval processes triggered by the scene cue, which are time consuming.

# Chapter 3: Discussion and Conclusions

Several experiments were conducted that were designed to address novel questions about how long-term episodic memory and attention might come together to influence behavior. By using eye tracking methodology, we uncovered behavior that suggests that information retrieved from long-term memory is prioritized by the attentional system even when it should be ignored. Specifically, our results showed that encoded objects capture attention even though they are task-irrelevant, and that this occurs most often following a memory cue. However, our results varied depending on which features distinguished distractors from targets. In addition, our results suggested that saccade initiated to targets were generated more slowly following scene cues. We had initially interpreted this as an effect of covert capture to encoded distractors, however the results from Experiment 4 and 5 suggest that this effect is related to visual information presented just before search displays and the time-consuming retrieval processes triggered by the scene cue. Overall, our overt capture results were replicated in several experiments and do not line up well with the standard dichotomous view of attention.

As discussed in the introduction, there is considerable debate about the factors that influence when and where attention is deployed. The dichotomous view of attention suggest that attention is either deployed in a top-down, goal-directed manner, or it is captured by perceptually salient materials. Recently, is had been proposed that this view does not capture all of the possible influences on attention. Specifically, selection history has been proposed as a potential third category. Here, attention is captured by task-irrelevant materials that are not perceptually salient. It is likely that episodic memories would fall into this category, at least in the context of our work, because attention is being captured by encoded objects that were not task-relevant or perceptually salient.

In line with this hypothesis, our results indicated that overt capture occurred most often when search displays containing encoded objects were preceded by scene cues. This is consistent with the results of many studies that show that eye movements are drawn rapidly to associates of scene cues when participants are instructed to identify the associate (e.g., Baym et al., 2014; Chua et al., 2012; Hannula & Ranganath, 2009; Hannula et al., 2007). In contrast to these experiments, in the ones summarized here participants were not instructed to retrieve associates when scene cues were presented. This is consistent with the proposal that scene cues trigger retrieval and active representation of the associate and that eye movements might be automatically directed to the location of these retrieved associates.

For Experiment 1, 4, and 5, overt capture was documented on 15-20% of the trials in the Scene Cue condition. Other work needs to be conducted to determine why capture is avoided for the remaining trials. It may be the case that the scene-object pair was not well encoded, causing the retrieved representation to be weak or degraded. As proposed by Gaspelin & Luck (2018), it may also be the case that the representation was successfully retrieved but actively inhibited before the search display was presented. Other studies would need to be conducted to determine how overt capture is avoided when scene cues precede search displays with encoded distractors.

As far as we know, capture by episodic LTMs has been reported in only one other study, however, this study used response time as their dependent variable and the task required feature binding (Fan & Turk-Browne, 2016). In addition, the cued features served as both targets and distractors. Because of this, it may have been the case that participants prioritized the cued feature to make search more efficient when that feature happened to be the target. It was also the case that there was no baseline condition, and therefore effects may really have been driven by a facilitation effect when cued features were targets rather than a slowdown when cued features were distractors. In contrast to this study, we used eye movements, which provide a direct index of attention capture, and encoded objects were never targets nor did they share features with targets. This last point meant that it was unlikely that participants were voluntarily prioritizing the encoded objects. That said, one potential problem in Experiments 1-4 was that scene cues predicted with 100% certainty that encoded distractors would be in the search displays, and that this was driving our overt capture effects. The results from Experiment 5, where scene cues predicted the presence of encoded distractors only 50% of the time, suggested that this was not the case.

While Experiment 5 showed that the associate need not be present following scene cues to document our effects, Experiments 2 and 3 indicated that there were differences in the robustness and reliability of our effects depending on the feature mapping to targets and distractors. The majority of studies that use displays like ours did/do not define targets by features known to be guiding attributes of attention (i.e., color; cf. Wolfe & Horowitz, 2004, 2017). For example, shape targets and color distractors are used in many studies of capture by reward, similar to Experiment 1, 4 and 5. When color targets were used, they were onsets (i.e., something appeared suddenly in the displays), which are known to capture attention. By reversing the feature mapping in our studies and not using onsets, we have shown that memory has an influence on behavior even when search targets are defined by a guiding feature of attention.

The results of Experiments 2 and 3 showed that the percentage of overt capture to encoded distractors was reduced relative to Experiments 1, 4, and 5. The numerical pattern of results for Experiments 2 and 3 are as hypothesized, however, results do not survive corrections for multiple comparisons or were non-significant. These patterns of results are consistent with another study where the target/distractor feature mapping was swapped (Theeuwes et al., 2003). In this example, both targets and distractors were singletons. Results indicated that when targets were defined by shape and distractors by color, capture was documented 38% of the time. However, when targets were defined by color and distractors by shape no capture was documented. These researchers suggested that shape does not compete very well with color. We did find some evidence for capture when distractors were shapes, thought these effects were small or non-significant. More work needs to be done to determine the ways in which feature mappings of targets and distractors influences attention capture.

Results from Experiments 1-3 showed that saccade latencies were slower to targets when scene cues were presented prior to search displays that contained encoded distractors. Initially, we interpreted this as an effect of the covert capture of attention by the encoded distractor (i.e., despite the lack of an eye movement, attention was drawn to the location of the encoded distractor). However, the results from Experiment 4 indicated that the presentation of visual information (i.e., scrambled scenes) prior to search displays also resulted in slower saccade latencies. Further, in Experiment 5, saccades latencies were slowest when scene cues preceded search displays, regardless of whether an encoded object was present in the search displays. The results of Experiment 4 and 5 suggest that the slowdown in saccade latencies following scene cues is not the result of covert capture by encoded associates. It may be the case, in Experiment 4 and 5, that latencies were longest following scene cues because the scenes were familiar and triggered retrieval of the associate. Other work needs to be done to test this possibility.

When overt capture was documented following scene cues, we found that dwell times were longest. This suggests, it was more difficult to disengage attention from encoded distractors when scene cues were presented prior to search displays. Therefore, it may be the case that when retrieved content matches the object that captured attention, additional processes are required to redirect attention to the search target. The neural mechanisms of how this might occur will be described in the next few paragraphs.

It has been proposed that where eye movements are directed is determined by the relative activation of features in a priority map, and that the FEF is a site of this priority map (Thompson & Bichot, 2005; Bichot, Heard, DeGennaro, & Desimone, 2015). Briefly, the idea is that a topographic map of objects in space is represented in the FEF. Activation of spatial locations in this map is driven by the relative match between objects in the outside world and task-relevant features. A spatial location with the highest activation, or closest match wins, and draws the eyes.

As mentioned in the introduction, activity differences in the hippocampus during presentation of a cue predict preferential memory-based viewing of associates when test displays are presented (Hannula & Ranganath, 2009). How this happens remains a mystery, as there are no direct anatomical connections between the hippocampus and structures containing the hypothesized priority maps (e.g., the frontal eye fields; FEF; Shen, Bezgin, Selvam, McIntosh, & Ryan, 2016). However, recent work using the CoCoMac database, which combines data from studies of anatomical tract tracing in macaques, has shown that there are several short, indirect routes that link these structures (Shen et al., 2016). One of these pathways is of particular interest, as it seems to connect hippocampus to FEF via area 46 in the primate, which seems to be part of a proposed site in the ventral prearcuate (VPA) region of PFC that stores the "attentional template" (Bichot et al., 2015). The proposed human homologue of VPA is the inferior frontal junction (IFJ), which has been implicated in the gating of object-based attention (Baldauf & Desimone, 2014). In the study conducted by Bichot et al. (2015), with nonhuman primates, when VPA was inactivated, FEF cells could trigger saccades and spatial selectivity was intact, but feature selectivity - i.e., saccades dictated by the features of a target object - was impaired.

Based on observations summarized above, a novel neural model accounting attention capture by long-term episodic memory was proposed by Hannula (2018). According to the model, when pattern completion processes in the hippocampus are successful, a template representation of retrieved content becomes available in IFJ. The strength or fidelity of retrieved memory representations determines whether and to what extent this information can influence saccades. If this attentional template in IFJ is strong, it is possible that the information will be selected for attention and an eye movement by the FEF priority map.

When capture is avoided it may either be the result of poor encoding and weak representation of the associate in response to a scene cue (i.e., incomplete or failed pattern completion processes) or the engagement of inhibitory signals meant to keep participants on task. This is consistent with the recent proposal by Gaspelin & Luck (2018) that physically salient objects are not constantly capturing our attention because inhibitory processes keep capture in check. Several studies have examined the regions associated with the inhibition of memory retrieval (for review see Anderson, Bunce, & Barbas, 2016). Many of these studies have used a Think/No-Think task. In this task, participants study arbitrary associations between, for example, words and scenes. During the Think/No-Think task, participants are alerted at the beginning of a trial whether they are to retrieve the word associated with a subsequently presented scene ("think" condition) or to try and avoid retrieving the word ("no-think" condition). In No-Think trials, retrieval suppression is associated with activity in the right anterior dorsolateral prefrontal cortex (rDLPFC). It has been suggested that this region is the source of top-down inhibitory control signals that suppress the retrieval processes in the hippocampus (Anderson et al., 2016). Results from the same study also show that the anterior cingulate cortex (ACC) is more active during memory suppression. Anderson and colleagues (2016) suggest that the ACC detects conflict between information retrieved from memory and the need to stay on task. In addition, the authors suggest that the ACC might also be a key player in top-down control of memory retrieval (Anderson et al., 2016). While there are no direct connections between the DLPFC and the hippocampus, the anterior cingulate cortex is anatomically well positioned to enable the DLPFC to suppress information flow into and out of the hippocampus (Barbas, Ghashghaei, Dombrowski, & Rempel-Clower, 1999; Anderson et al., 2016). There are two main pathways hypothesized to support the ability of the ACC to exhibit inhibitory control over the hippocampus. According to the entorhinal gating hypothesis, ACC might influence information flow into and out of the hippocampus by way of the entorhinal cortex. According to the thalamo-hippocampal modulation hypothesis ACC may directly influence the hippocampus. This pathway, through the thalamic reuniens nucleus, is thought to play a role in modulating excitability of hippocampal neurons but may also suppress hippocampal processing in some cases. It is possible then that activity differences in the DLPFC and/or the ACC will be upregulated when capture by episodic memory is avoided.

A neuroimaging experiment is currently being conducted that was designed to complement the eye tracking studies to provide novel insights into capture by long-term memory and the neural substrates of these effects. A recently proposed neural model of attention capture by episodic memory (Hannula, 2018) is being tested. This model is based on findings from behavioral work along with what we know about hippocampus and memory-based viewing effects, anatomical connections, the proposed role of the inferior frontal junction as a site of the attentional template, and the FEF priority map/driving the eyes.

Lastly, we must address two potential limitations of the work summarized in this dissertation. First, as has been done in studies of capture by reward or aversive materials (e.g., Anderson et al., 2011a, 2011b; Anderson & Yantis, 2012; Anderson & Kim, 2019; Hopkins et al., 2016; Schmidt et al., 2015a, 2015b), we selected a subset of colors to serve as critical items in our search displays (i.e., only 4 of the 10 colors in Experiments 1, 4, and 5 were used for encoded items). We could have counterbalanced or randomized this for each participant to better account for any potential differences across stimuli (i.e., all 10 colors would serve as encoded distractors at some point, rather than just 4). Second, participants were told at the beginning of the experiment that their memory would be tested. Therefore, there is a possibility that participants were using scene cues during the search task to purposefully retrieve and test their memory against the encoded object presented in the subsequent search display. However, in Experiment 5, when scene cues predicted encoded distractors only 50% of the time, we documented more overt capture only when encoded distractors were actually present in search displays.

In conclusion, the work summarized in this dissertation suggests that attention can be captured involuntarily by episodic LTMs when a search display is presented following a scene cue. We argue that this is another potential example of attention capture that does not fit well with the standard dichotomous view of attention and that in our case selection history is having an influence on attention.  More work needs to be conducted to determine how the feature mappings and display properties might influence attention capture. However, this work provides important new insights into when and how we may be distracted and has potential implications for psychiatric conditions, like post-traumatic stress disorder, that are characterized by rumination about traumatic experiences that have happened in the past. One possibility is that retrieval of this experience is triggered by a cue in the environment (or one that is internally generated), and that this then captures attention and has a negative impact on behavior.

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Wolfe, J. M., & Horowitz, T. S. (2017). Five factors that guide attention in visual search. *Nature Human Behaviour*, *1*(3), 0058.

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# ALLISON E. NICKEL, M.S.

## Academic History

| | |
|---|---|
| 2011-present | Candidate in the Doctoral Program in Experimental Psychology - Neuroscience, University of Wisconsin-Milwaukee, Milwaukee, WI, Advisor: Deborah Hannula |
| 2011-2014 | Master of Science in Experimental Psychology - Neuroscience, University of Wisconsin-Milwaukee, Milwaukee, WI, Advisor: Deborah Hannula |
| 2006-2011 | Bachelor of Science Liberal Arts in Chemistry & Psychology, University of Wisconsin-River Falls, River Falls, Wisconsin, Advisor: Lisa Kroutil |

## Honors, Awards and Fellowships

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|---|---|
| 2019-2020 | R1 Advanced Opportunity Program Fellowship Recipient, University of Wisconsin-Milwaukee, Milwaukee, WI |
| 2015 | Department of Psychology Summer Research Fellowship Recipient, University of Wisconsin-Milwaukee, Milwaukee, WI |
| 2014-2017 | Advanced Opportunity Program Fellowship Recipient, University of Wisconsin-Milwaukee, Milwaukee, WI |
| 2014 | Annual Meeting of the Psychonomics Society, Early Career Award Finalist**,** Executive Board of APA's Division 3 Long Beach, CA |

## Publications

**Nickel, Allison E.**, Minor, Greta N., Hopkins, Lauren S., Hannula, Deborah E. (in prep). Influence of Category Membership and Encoding History on Attention Capture.

**Nickel, Allison E.**, Minor, Greta N., Hopkins, Lauren S., Hannula, Deborah E. (Submitted). Episodic Long-Term Memories Capture Attention Disproportionately in the Presence of Retrieval Cues. *Cognition.*

**Nickel, Allison E.**, Henke, Katharina, & Hannula, Deborah E. (2015). Relational memory is evident in eye movement behavior despite use of subliminal testing methods. *PLoS One, 10*(10), e0141677.

Hannula, Deborah E., Tranel, Daniel, Allen, John S., Kirchhoff, Brenda A., **Nickel, Allison E.**, & Cohen, Neal J. (2015). Memory for items and for relationships among items embedded in realistic scenes: Disproportionate relational memory impairments in amnesia. *Neuropsychology, 29*(1), 126-138.

Mahoney, Elaine J.*, **Nickel, Allison E.***, Hannula, Deborah E. (2015). Recognition. In: James D. Wright (Eds.), *International Encyclopedia of the Social & Behavioral Sciences* (2nd ed., Vol. 20, pp. 37–43). Oxford: Elsevier. * denotes equal contribution.

## Presentations (Poster and Oral)

Miskimen, Tessa L., Hopkins, Lauren S., **Nickel, Allison E.**, Helmstetter, Fred J., & Hannula, Deborah E. (2019). *Materials Associated with Aversive Value Capture Attention.* Poster presented at 11th Annual UWM Undergraduate Research Symposium, 2019, Milwaukee, WI

**Nickel, Allison E.**, Minor, Greta N., Hannula, Deborah E. (2019). *Behavioral and Neural Mechanisms of Attention Capture by Episodic Long-Term Memory*. Oral presentation at annual AGSIP symposium, 2019, Milwaukee, WI

**Nickel, Allison E.**, Minor, Greta N., Hannula, Deborah E. (2018). *Saccade Latency as an Index of Covert Capture by Episodic Memory.* Poster presented at Psychonomic Society Meeting 2018, New Orleans, LA

Miskimen, Tessa L., Hopkins, Lauren S., **Nickel, Allison E.**, Blujus, Jenna K., Helmstetter, Fred J., & Hannula, Deborah E. (2018). *Does Oculomotor Capture by a Fear Conditioned Stimulus Depend on Contingency Awareness?* Poster presented at 10th Annual UWM Undergraduate Research Symposium, 2018, Milwaukee, WI

**Nickel, Allison E.**, Hopkins, Lauren S., Hannula, Deborah E. (2018). *The Effects of Category Membership and Encoding History on Attention Capture.* Oral presentation at annual AGSIP symposium, 2018, Milwaukee, WI

Mahoney, Elaine J., **Nickel, Allison E.**, Hannula Deborah E. (2018). *Identifying New Targets for Detecting Memory Malingering: Insights from a Combined fMRI and Eye Tracking Investigation.* Presentation at International Neuropsychological Society Meeting, 2018, Washington, DC

Hoelter, Joshua L., **Nickel, Allison E.**, & Hannula, Deborah E. (2017). *Long-term Memories Capture Attention Following Retrieval Cues, but only When They are Actively Represented*. Poster presented at 58th annual conference of Psychonomic Society, 2017, Vancouver, BC, Canada.

**Nickel, Allison E.**, Hopkins, Lauren S., Hannula, Deborah E. (2017). *Influence of Category Membership and Encoding History on Attention Capture.* Oral presentation at annual AGSIP symposium, 2017, Milwaukee, WI

**Nickel, Allison E.**, Hopkins, Lauren S., Hannula, Deborah E. (2017). *Influence of Category Membership and Encoding History on Attention Capture.* Poster presented at UW-Milwaukee Neuroscience mini-symposium, 2016, Milwaukee, WI

**Nickel, Allison E.**, Hopkins, Lauren S., Hannula, Deborah E. (2016). *Influence of Category Membership and Encoding History on Attention Capture.* Poster presented at Psychonomic Society Meeting 2016, Boston, MA

**Nickel, Allison E.**, Hopkins, Lauren S., Hannula, Deborah E. (2016). *Episodic Long-Term Memories Capture Attention Disproportionately in the Presence of Retrieval Cues.* Poster presented at Vision Sciences Society Meeting 2016, St. Pete Beach, FL

Krueger, Josephine R., **Nickel, Allison E.**, Hannula, Deborah E. (2016). *Long-Term Memories Capture Attention.* Poster presented at 8th Annual UWM Undergraduate Research Symposium, 2016, Milwaukee, WI

**Nickel, Allison E.**, Hopkins, Lauren S., Hannula, Deborah E. (2016). *Episodic Long-Term Memories Capture Attention Disproportionately in the Presence of Retrieval Cues.* Oral presentation at annual AGSIP symposium, 2017, Milwaukee, WI

**Nickel, Allison E.**, Hopkins, Lauren S., Hannula, Deborah E. (2016). *Episodic Long-Term Memories Capture Attention Disproportionately in the Presence of Retrieval Cues.* Poster presented at UW-Milwaukee Neuroscience mini-symposium, 2016, Milwaukee, WI

**Nickel, Allison E.**, Hopkins, Lauren S., Hannula, Deborah E. (2016). *Episodic Long-Term Memories Capture Attention Disproportionately in the Presence of Retrieval Cues.* Oral presentation for UW-Milwaukee Neuroscience mini-symposium, 2016, Milwaukee, WI

**Nickel, Allison E.**, Henke, Katharina, Hannula, Deborah E. (2014). *Relational Memories are Evident in Eye Movement Behavior Following Subliminal Memory Cues*. Poster presented at Psychonomic Society Meeting 2014, Long Beach, CA

**Nickel, Allison E.**, Henke, Katharina, Hannula, Deborah E. (2014). *Relational Memories are Evident in Eye Movement Behavior Following Subliminal Memory Cues.* Oral presentation for UWM Neuroscience Seminar Series 2014, Milwaukee, WI

**Nickel, Allison E.**, Henke, Katharina, Hannula, Deborah E. (2014). *Relational Memory Expression Following Subliminal Presentations of Retrieval Cues.* Poster presented at Society for Neuroscience Milwaukee Chapter Meeting 2014, Milwaukee, WI

Le Veque, Jeremy F., **Nickel, Allison E.**, Hannula, Deborah E. (2013). *Eye-Movement-Based Relational Memory Effects Precede Explicit Deadline-Based Recognition Responses.* Poster presented at Society for Neuroscience Milwaukee Chapter Meeting 2013, Milwaukee, WI

## Teaching Assistantships

| | |
|---|---|
| 2019 | Grader (Psych 101/Instructor: Peter Lenz, Psych 319/Instructors: Caroline Engler & Kristen Payne, Psych 555/Instructor: Gary Stark, Psych 627/Instructor: Deborah Hannula) |
| 2018 | Grader (Psych 101/Instructor: Sarah Kienzler, Psych 101/Instructor: Peter Lenz, Psych 319/Instructors: Caroline Engler & Kristen Payne, Psych 454/Instructor: Krista Lisdahl)<br>Cognitive Neuroscience (Psych 627/727/Instructor: Deborah Hannula)<br>Research Methods (Psych 325/Instructor: Peter Lenz) |
| 2017 | Physiological Psychology (Psych 254/Instructor: James Moyer) |
| 2016 | Freshman Psychology Seminar Guest Lecturer (Psych 193/Instructor: Deborah Hannula) |
| 2016 | Visual Cognition Guest Lecturer (Psych 611/711/Instructor: Deborah Hannula) |
| 2013-2015 | Experimental Social Psychology (Psych 677/Instructor: Pamela Schaefer) |
| 2012 | Psychology of Women (Psych 320/Instructor: Pamela Schaefer)<br>Developmental Child Psychology (Psych 260/Instructor: Kelly Janke) |

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| 2011 | Developmental Child Psychology (Psych 260/Instructor: Hobart Davies) |

## Current Research

- Attention Capture Studies
  - Attention Capture by Fear Conditioned Stimuli (PIs: Deborah Hannula, Fred Helmstetter)
    Examines whether or not previously learned associations between a previous neutral stimulus and an aversive stimulus (i.e., shock) draw attention away from the instructed goal. Uses overt and covert measures.

  - Attention Capture by Long-Term Memories (PI: Deborah Hannula)
    Task examines whether previously studied items or items from previously studied categories draw attention away from the instructed task. Uses overt and covert measures.

  - Attention Capture by Long-Term Relational Memories (PI: Deborah Hannula)
    Examines whether or not previously learned associations draw attention away from the instructed goal. Uses overt and covert measures.

  - Eye Tracking Investigations of Long-Term Memory and Attention (PI: Deborah Hannula)
    Collection of studies designed to investigate whether and under what circumstances learned associations or materials can capture attention and slow down or disrupt goal-directed behavior.

- Recognition Memory
  - Effect of Recognition on Indirect Measures of Memory (PI: Deborah Hannula)
    Collection of studied designed to investigate the effects of concealing memory on eye-movement based memory effects. Was combined with fMRI techniques to investigate neural correlates of these effects.

  - Eye Tracking Investigations of Picture Recognition (PI: Deborah Hannula)
    Task was designed to investigate memory for items and memory for relationships between items. Used implicit and explicit measures.

  - Eye Tracking Investigations of Visual Processing and Attention (PI: Deborah Hannula)
    Investigated whether processing of a subliminal memory cue could trigger retrieval of previously encoded associations. Used implicit and explicit measures.

  - Eye Tracking and Deadline-Based Investigation of Memory (PI: Deborah Hannula)
    Examined memory in the presence and absence of explicit recognition. Used implicit and explicit measures.

## Professional Memberships

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| 2014-present | Psychonomic Society |
| 2016-present | Vision Sciences Society |

## Community Outreach

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| 2019-2020 | Mentored an Undergraduate SERA Awardee, University of Wisconsin-Milwaukee, Milwaukee, WI |
| 2017-2018 | Mentored an Undergraduate SURF Awardee, University of Wisconsin-Milwaukee, Milwaukee, WI |
| 2016-2017 | Go Milwaukee: Science Day for Milwaukee Public School Students, University of Wisconsin-Milwaukee, Milwaukee, WI |
| 2016 | Lab Tour for Franklin High School Psychology Club, University of Wisconsin-Milwaukee, Milwaukee, WI |
| 2015-2018 | Lab Tours for UWM Psychology Day, University of Wisconsin-Milwaukee, Milwaukee, WI |
| 2015-2018 | Future Success: Science Day for Underprivileged Milwaukee Public School Students, University of Wisconsin-Milwaukee, Milwaukee, WI |
| 2014-2015 | Mentored an Undergraduate SURF Awardee, University of Wisconsin-Milwaukee, Milwaukee, WI |
| 2013-2019 | Volunteer for Meet Milwaukee: A Campus Preview for High School Students 1-2 times a semester, University of Wisconsin-Milwaukee, Milwaukee, WI |
| 2013-2016 | Upward Bound: Science Day for Underprivileged Milwaukee Public School Students, University of Wisconsin-Milwaukee, Milwaukee, WI |