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THE EFFECTS OF LONG-TERM MEMORY PRIORITIZATION ON ATTENTION DURING VISUAL SEARCH

by

Joshua L. Hoelter

A Dissertation Submitted in

Partial Fulfillment of the

Requirements for the Degree of

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The University of Wisconsin-Milwaukee

August 2020

ABSTRACT

THE EFFECTS OF LONG-TERM MEMORY PRIORITIZATION ON ATTENTION DURING VISUAL SEARCH

by

Joshua L. Hoelter

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

Attention has traditionally been divided into a dichotomy, however mounting evidence suggests a third attention process is at work, one that shows attention capture because of previous experiences with a stimulus, not its physical properties. In line with this, items that have been paired with a rewarding or aversive outcome, items held in working memory, and items incidentally retrieved from long term memory have all been shown to capture attention in an obligatory fashion similar to bottom-up attentional processes. More recent work into how items in working memory capture attention, has demonstrated that items can attain a special status that is reflected by more brain activity and greater capture for a prioritized item than a non-prioritized item. We do not yet know how intentional retrieval or prioritization of information held in long term memory affects capture. Two experiments studied how attention capture by information retrieved from long term memory is affected by prioritization (Experiment 1) and whether capture effects change over time (Experiment 2). Based on studies of working memory and retro-cueing, it was expected that retrieval alone may not be enough to capture attention, but that information must also be prioritized. Furthermore, capture effects should decrease as the time between retrieval and visual search increases. Both hypotheses were supported; prioritized material captured attention significantly more than non-prioritized material and capture by

retrieved material decreased as time from the initial cue increased. This is similar to results in studies that used working memory and suggests that information captures attention the most when it is in a prioritized, active state, which only lasts for a short time.

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THE EFFECTS OF LONG-TERM MEMORY PRIORITIZATION ON ATTENTION DURING VISUAL SEARCH

Everyday behavior is guided by the interaction of several qualitatively distinct cognitive processes. For instance, to navigate your way home from work you must keep in mind the rules of the road, any changes to your route, or errands you need to run, all the while directing your attention to the other cars on the road, pedestrians trying to cross the street, and traffic signals directing you to stop or go. However, when flashing lights are visible or sirens are wailing, it becomes compulsory to direct your attention to the police car approaching from behind, everything else temporarily forgotten. Much of the empirical work on attention and memory has been focused exclusively on memory or on attention, though a growing number have examined interactions between the two.

One way in which memory and attention have been shown to interact is through long-term memory (LTM) guiding attention during visual search. Whether it's a T among L's (Chun & Jiang, 1998) or searching for a teapot in a kitchen scene (e.g., Brockmole & Henderson, 2006), search benefits can occur as a result of repeated exposure to identical search context and/or as a consequence of semantic knowledge (e.g., knowing that a tea pot is likely to be on the stove and not under a table). Likewise, when attention is divided during learning it adversely affects the encoding of new information, as is the case when trying to memorize a list of spoken words while performing arithmetic, or focusing on one feature – e.g., color – at the expense of another feature – e.g., location (Craik et al., 1996; Uncapher & Rugg, 2009).

Attention: The Standard Dichotomous Model, Possible Shortcomings, and Attention Capture

Attention has long been under investigation and has historically been divided into processes that are salience driven and somewhat automatic, often called bottom-up attention, or processes that support goal directed attention, often called top-down attention. Processes that support top-down attention help us to be a safe driver allowing us to voluntarily direct attention to goals that help us accomplish a task (e.g., attending to critical objects that permit us to follow the rules of the road). But when attention is drawn inadvertently by objects or events (e.g., flashing lights or sirens), attention is said to be automatically *captured* because the physical properties of that stimulus are highly salient. It might also be the case that materials can capture attention when they are not physically salient. Consistent with this possibility, recent evidence has suggested that information held active in working memory (WM) can attract attention (Mallet & Lewis-Peacock, 2018; Olivers, 2009; Olivers et al., 2006; van Moorselaar et al., 2014), even when that information is not goal-relevant or physically distinctive. A few recent studies from our lab have also found that LTM is capable of capturing attention (Nickel et al., 2020). The studies proposed here will further explore the potential limits of attention capture by information retrieved from LTM.

Top-down attention is engaged to support current goals and can be aided by past experiences. For instance, you might search for a person in uniform to ask directions on your way out of a parking lot after a baseball game because a police officer is likely to be present and knowledgeable. Unlike bottom-up attention, top-down attention is mostly voluntary. It has recently been argued that the top-down, bottom-up dichotomy may be insufficient, as it does not readily account for observations in the literature of attention capture by stimuli that are not physically salient (Awh et al., 2012). Awh et al. propose a third component of attention, selection history, defined by the deployment of attention to stimuli that are not physically distinctive, but stand out by virtue of prior experience (e.g. because they are active in working memory or based on their learned aversive value). As was done recently (Chelazzi &

Santandrea, 2018), I will refer to this third class as experience-dependent attentional control because the act of *selection* may not be a prerequisite for this kind of capture.

Evidence for capture by physically salient materials has been documented in the context of the *irrelevant singleton task* (Theeuwes, 1991, 1992; Theeuwes et al., 2003; Theeuwes & Godijn, 2001). A *singleton* is an object in the display possessing unique physical characteristics (e.g., color, shape, orientation). In this task, participants are presented with a simple visual search display – e.g., simple shapes located on the circumference of an imaginary circle surrounding a center location. Typically, participants are asked to look at or otherwise locate a shape target (e.g., a green diamond among green circles) as quickly as possible following display onset. Sometimes, one of the green circles is replaced with a red circle, a singleton distractor, which is salient because of its unique color. Though the red circle should be ignored, results indicate that it captures attention in the form of an eye movement towards its location (Theeuwes et al., 2003) or overall slowing of response times, which is a primary measure of attention capture (Theeuwes, 1991, 1992). When participants were asked to search a display of red circles and find the circle more luminous than the rest, the presence of a green circle distractor in the display again slowed reaction time (RT) suggesting the unique color captured attention (Theeuwes, 1991, 1992). However, if people were instead asked to find a distinctly colored green circle placed among four red circles and one red square, RT was no different than a green circle target amongst all red circles, meaning that the unique shape did not capture attention. Only when the search task is made more difficult (e.g., target is defined by a different shade of the same color), has shape been shown to capture attention. This suggests that whatever feature is most distinct is what captures attention, which usually means a physical property, e.g. color but also shape or size. For experience-dependent capture to occur then, the representations of items without physically distinct qualities (e.g., associative value, WM maintenance) must be strong enough to override physical salience.

There is mounting evidence that experience-dependent distractors are able to capture attention despite lacking physical salience. These distractors were associated with rewarding or aversive stimuli (Hickey et al., 2011; Hopkins et al., 2016; Theeuwes & Belopolsky, 2012) or could be identical to items held in WM (Mallet & Lewis-Peacock, 2018; Olivers 2009; Olivers et al., 2006; van Moorselaar et al., 2014). This runs counter to notions that only physically salient material (e.g., flashing lights or sirens) captures attention, as the materials mentioned above are not physically distinct from simultaneously presented stimuli. For example, by design, the mere sight of a police car in your rearview mirror should not be so distinct from other cars that it attracts attention, however it does capture your attention because you received a speeding ticket last week. This idea is not well supported by the traditional view of attention as a dichotomy, which only accounts for involuntary capture by salient material. However, these more recent findings could be an example of experience-dependent attention (Awh et al., 2012; Chelazzi & Santandrea, 2018) which could better explain attention capture when it occurs as a result of prior experience with stimuli, and not because of physical salience.

As with police cars capturing your attention because you've frequently been punished for your reckless speeding habits, stimuli paired with aversive or rewarding outcomes have been shown to capture attention. In one example, a conditioned stimulus (CS+) captured attention during visual search (Hopkins et al., 2016). In that experiment, six red circles, one red triangle, and either a vertically or horizontally oriented red rectangle were presented during a learning phase, with participants instructed to make a saccade to the rectangle as quickly as possible. During learning, participants were told they would receive a shock when they did not find the target quickly enough, but in actuality shocks did not depend on performance measures at all but rather on orientation of the rectangle. For example, on 80% of the trials including a horizontal rectangle (CS80), a shock was delivered, while only 20% of the trials with a vertical rectangle (CS20) included a shock; orientation of the rectangle as CS80 and CS20 was counterbalanced. During a test phase, visual search displays included seven red circles and one gray target circle. Participants were instructed to fixate the target as quickly as possible, however on a subset of trials the displays also included either the CS20 or the CS80 red rectangle. Though the additional presence of a rectangle in the display did slow participants' search, orientation mattered – i.e., saccades to the target were slower in the presence of the CS80 relative to the CS20. Visual stimuli paired with an aversive experience also led to more erroneous saccades, which is evidence of attention capture. Whether affectively neutral information held active in WM might also capture attention has also been subject to investigation.

One set of experiments measured the effects of affectively neutral information on attention capture with the additional singleton paradigm and found that capture was influenced by how closely features of the task-irrelevant singleton matched those of an item held in WM (Olivers 2009; Olivers et al., 2006). In these examples, stimuli most often captured attention during visual search when they matched the item being maintained for a difficult recognition test. Prior to a search display, an item was presented to be maintained in WM and could be a distinct color, pattern, or shape etc. During the search, a singleton distractor, sometimes matching the item in WM, could then be included. Reaction time during search was slowed most by matching distractors, and a higher number of erroneous saccades to that item was also recorded. However, capture results were most apparent when the recognition test required participants to differentiate between subtle variations of the memorized item, which requires a precise representation be maintained. This work demonstrates that representations held active in WM can capture attention (here, in the form of eye movements) during performance of a simple visual search task (for a brief review see Theeuwes et al., 2009).

When Might Information in LTM Capture Attention

As described above, recent studies contradict the idea that capture of attention is limited to physically salient materials. These studies indicate that learned value (Hickey et al., 2011; Hopkins et al., 2016; Theeuwes & Belopolsky, 2012) or active retention (Olivers 2009; Olivers et al., 2006) can also affect the efficiency of search for a target stimulus. Whether and when information stored in episodic memory might disrupt search is something that was recently investigated in our lab (Nickel et al., 2020). That this might occur was suggested by early work showing that eye movements go rapidly and perhaps obligatorily to encoded associates of scene cues (Hannula et al., 2007). In these experiments, faces were paired individually with scenes during a learning phase and then during test, 3-face overlays, which sometimes contained a learned associate face, were presented with scenes from the learning phase. Results show that within 500-750ms after the test display was presented, people spent more time looking at faces that had been paired with the scene. Even when a scene was masked and presented subliminally (Nickel et al., 2015), or when efforts were made to conceal memory (Mahoney et al., 2018), participants again viewed matching faces disproportionately to non-matching ones. All these studies suggest an obligatory eye movement to encoded information in the presence of retrieval cues. Importantly, in this work the associated face was never task irrelevant. Often-times, participants were purposefully searching for the associates, so attention was deployed voluntarily to critical faces and whether encoded associates might draw attention involuntarily, in conflict with task demands, was not addressed.

To fill this gap, recent work from our lab examined whether task-irrelevant material (e.g., simple shapes or colored circles) from LTM affects attention during visual search (Nickel et al., 2020). Experiments began with an encoding phase, where single objects were paired with pictures to create unique scene-object pairs. In a subsequent phase, a visual search display consisting of five distractors and one target was presented and participants were instructed to fixate the target object ignoring all distractors. For a subset of trials an encoded scene was displayed prior to visual search. Participants likely recalled the associated object but were not explicitly instructed to do so. During search, the associate could be included as a critical distractor. Eye movements in the presence of these associates were compared to eye movements for encoded objects without cues and search trials where the critical distractor was a non-encoded object. When an encoded scene was presented and the associated object was used as a distractor, participants' saccade deployment to targets was slowed and the critical distractor drew a disproportionate number of erroneous saccades compared to encoded material without retrieval or a set of non-encoded objects.

Based on these outcomes, it seems that encoded material is most likely to capture attention when a cue is presented and triggers retrieval of a learned associate prior to search. Importantly though, in these experiments, participants were simply instructed to look at the scenes when they were presented – they were not told to retrieve the associates. This leaves us with questions about whether and how items that are purposely retrieved affect attention? In the current studies we examined whether attention capture by retrieved information depends on prioritization (Experiment 1) and whether intervening search displays and recognition probes reduce capture (Experiment 2).

Are there Limitations for Attention Capture by LTM?

In the preceding section, some preliminary evidence for capture by information retrieved from LTM was described. In five experiments (Nickel et al., 2020), saccades were made in error to encoded objects, an effect that was especially strong following presentation of scenes that had been paired with the object during encoding. However, in those experiments there were no instructions to retrieve the associates and only one item was retrieved per trial.

Typical experiences require frequent shifts of attention, both unintentionally and intentionally. We can purposefully shift between representations in the brain to achieve different goals, evidence for this comes from the *retro-cue* task. During this task, two pieces of information are presented to be held in WM, and then an attentional cue is given indicating one item should be prioritized retroactively. This is similar to earlier work that showed a pre-attentive cue aided reaction time or improved accuracy during task performance (Posner, 1980). Like pre-cueing, retro-cueing leads to improved memory performance, and can aid in detecting changes of visual displays or responding more quickly or more accurately to tests of visual information, among other benefits (see review by Souza & Oberauer, 2016).

As is outlined in more detail below, research in the WM literature using the retro-cue task suggests that when content is active and prioritized it captures attention more often than non-prioritized material (van Moorselaar et al., 2014). We do not know if the same holds true for retrieved LTM representations. Experiment 1 examined whether the act of retrieval is sufficient for capture or whether retrieved information must also be held in a prioritized state to capture attention. In other words, if information has been retrieved, but then rendered irrelevant (because it will not be tested) will it still capture attention? Results from neuroimaging studies that have used the retro-cueing task suggest that the neural signature for information retained in

WM which isn't prioritized falls to baseline levels which could make capture less likely (LaRocque et al., 2013; Lewis-Peacock et al., 2012; Lewis-Peacock & Postle 2012).

Through the use of neuroimaging and multivoxel pattern analysis, it has been found that shifting the prioritization of information in WM from one item to another decreases the detectable activity for the first item to a baseline level (LaRocque et al., 2013; Lewis-Peacock et al., 2012; Lewis-Peacock & Postle 2012). A typical approach in these experiments involves the use of materials from three different categories (e.g., line segments, words, and pseudo-words) allowing for clearly distinguishable patterns of brain activity (LaRocque et al., 2013). Data from a pre-experimental phase was used to identify unique activity patterns for each category. During a subsequent testing phase, participants were shown two items from different categories (e.g., a line segment and a pseudo-word), instructed to retain both for an upcoming test, and were then given a retro-cue indicating which item would be tested with a recognition probe (e.g., line orientation, pseudo-word rhyme, or semantic judgment). After the first test a second retro-cue was given that indicated they either needed to switch or maintain the currently prioritized item for the second test. In this way, trials could be separated into *switch* or *stay* trials. Activity during the first probe sequence was greatest for the prioritized item while activity for the second item fell to the same level as the third category (i.e., baseline) which was not relevant for that trial. This shows that a memory item that is prioritized has a special status – i.e., heightened activity level – in the brain, while activity for non-prioritized items is significantly reduced. It was found that after the second retro-cue, activity was always greater for the prioritized item, whether the same item was prioritized (stay trial) or not (switch trial). Hence, items might be flexibly transitioned between prioritized and non-prioritized states. The studies here did not address how prioritized and non-prioritized information affected external deployment of attention, they only demonstrated that category specific activity increased or decreased relative to the state of prioritization.

Evidence consistent with the possibility that prioritization affects the external deployment of attention has been reported by van Moorselaar et al. (2014) who measured attention capture by information held in WM and prioritized by a retro-cue. Two colored circles (e.g., red and blue) were presented at the start of the trial and held active for a memory test at the end of the trial. A retro-cue prioritized one of the circles (e.g., red) and then a search display including six white circles, one white diamond, and a colored distractor circle, was presented. Inside the diamond shaped target was either the letter M or N, and participants indicated with a button press which letter they detected. Importantly, the colored distractor circle would either match the prioritized item (e.g., red), the not-prioritized item, (e.g., yellow) or was a trial-irrelevant color (e.g., blue). Finally, the test display presented six circles in three variations of the prioritized item's color (e.g., circles in three shades of red) and three variations of the not-prioritized color (e.g., three shades of yellow), making it critical that people hold an accurate representation of the prioritized item in memory. Results indicated that response times during search when the prioritized item served as a distractor were significantly slower than when other distractors were used. These results suggest that capture is most likely to occur when information is held in an active state – here, for an upcoming test. However, it may have been the case that participants used the distractor, purposely, to refresh the representation in WM before the probe, a possibility that could not be completely ruled out.

A more recent study attempted to establish the time-course of capture by information held inside and outside the focus of attention (Mallet & Lewis-Peacock, 2018). A sample display of two colored circles was presented at the beginning of each testing block, one of which was prioritized with a retro-cue for a memory test. The sample was followed by a retro-cue, a series of 12 search displays, and a memory test. Following the first test, a second retro-cue indicated whether participants should continue to prioritize the same item or switch to the second item from the sample display. This was again followed by a series of 12 search displays and a test. Only the second retro-cue allowed for one of the memory items to become completely irrelevant, so during the first series of search displays, it was possible that both items spent time in the focus of attention. Visual search displays included two colored circles, each containing a single line segment, which was either oriented vertically or tilted. Participants were told to respond to the direction of the tilted line. Sometimes, one of the colored circles in the search display was the prioritized exemplar from the sample phase. The investigators were interested in whether the presence of this circle would affect search efficiency – i.e., result in faster response times when the tilted line segment was in the prioritized circle (valid trials) and slower response times when the to-be-ignored vertical line segment was in the prioritized circle (invalid trials). If valid trials resulted in faster detection of the target than invalid trials, the authors concluded that capture had occurred. By including two series of several search displays for each trial, the researchers could measure the difference in capture over an extended period of time following presentation of the sample display. Results indicated that capture for prioritized items was greatest at the start of the search series but was generally present during the whole of both series, however, capture by non-prioritized material was only found during the first 3 search displays after a corresponding retro-cue had been presented. The researchers concluded that only when an item is in the focus of attention is it reliably able to capture attention.

Questions remain about the persistence of capture effects when information has been retrieved from LTM and whether prioritization is important in determining whether capture will occur. As described in more detail above, recent work from our lab has indicated that information retrieved from long-term memory can capture attention. Whether prioritization might drive capture up or down was not explored. Questions also remain about the persistence of capture by retrieved long-term memory representations (i.e., whether, and to what extent, capture declines as a function of time or across search displays following a retrieval cue or the corresponding recognition test). The present studies address these questions by using the retro-cueing procedure (Experiment 1), and by including retrieved objects in search displays at different intervals after presentation of a retrieval cue and administration of the corresponding recognition test (Experiment 2).

Experiment 1

Neuroimaging studies indicate that activity for items encoded into WM that are subsequently prioritized is greater than activity for competing items that are not prioritized (LaRocque et al., 2013; Lewis-Peacock et al., 2012; Lewis-Peacock & Postle 2012). Furthermore, it has been reported that these prioritized items are more likely to capture attention (van Moorselaar et al., 2014). Recent work from our lab has indicated that information retrieved spontaneously from long-term memory can capture attention (Nickel et al., 2020). In Experiment 1, I examine whether capture by items encoded into LTM is affected by whether a retrieved item has been prioritized or not.

Method

Participants

Participants were students from the University of Wisconsin Milwaukee (UWM) between the ages of 18-45 with normal or corrected to normal vision. A G*Power™ (v. 3.1.9.2; Faul et al., 2007) analysis was conducted with pilot data from a task similar to this one using a contrast that compared oculomotor capture by novel singleton distractors to capture by singleton distractors that were retrieved from LTM and prioritized for a recognition test. With power set to .80 and effect size equal to .46, results indicated that a minimum sample size of 40 participants would be required for this study. The number of participants was increased to 48 to accommodate the counterbalanced design. A total of 58 participants were recruited, one was dropped because the program terminated unexpectedly, nine more were removed from analysis because recognition performance was more than two times lower than the interquartile range. All of the procedures used were approved by the UWM Institutional Review Board.

Apparatus

Eye movements were recorded using the EyeLink 1000 eye tracking system (SR Research LTD: Ontario, Canada). This system operates with a temporal resolution of 1,000 Hz and spatial resolution of .01°. Saccades were identified using an automated algorithm and defined by a change in eye position with minimum velocity of 30°/s and acceleration of 8,000°/s. The Experiment Builder and Data Viewer software packages (SR Research LTD: Ontario, Canada) were used to program the experiment and to analyze the data. Stimuli were displayed on a 22-inch View Sonic monitor with 1,680 x 1,050 pixel resolution and a refresh rate of 60 Hz. A chinrest, 26 inches from the monitor, was used to keep head position fixed during testing.

Materials

Materials included 80 full color scenes (40 indoor scenes, 40 outdoor scenes) selected from an existing database (cf. Hannula et al. 2007) and 12 gray (CIE L*a*b*: 50, 0, 0) line drawings, each superimposed on a black background. The line drawings were selected from the Snodgrass and Vanderwart (1980) set and included an anchor, bottle, cup, heart, leaf, bow, nut, key, mitten, lock, moon, and star. A set of circles drawn in Microsoft Power Point™ and edited in Adobe Photo Shop™ were also used. Circles were gray (CIE L*a*b*: 50, 0, 0), blue (CIE L*a*b*: 50, 24, -79), red (CIE L*a*b*: 50, 71, 62), green (CIE L*a*b*: 50, 51, 52) and fuchsia (CIE L*a*b*: 50, 85, 55).

Design and Procedure

Upon entering the room, participants were seated and asked to adjust the height of their chair to a comfortable position with their chin in the chinrest. After the participant signed a consent form, instructions that were supplemented with visual examples of the stimulus materials and trial structure were used to describe the experiment. As outlined in more detail below, the experiment consisted of two interleaved sets of encoding and test blocks. Test blocks included stand-alone visual search trials and hybrid search/recognition trials. Following the instructions, a calibration process was performed. Participants fixated a ring-shaped target presented at the center of the screen. Upon central fixation, the ring was removed from view, and then randomly reappeared eight times in different locations. The calibration process was repeated until participants' fixations were no more than 2° of visual angle from each of the nine target locations. Upon successful calibration, participants practiced each part of the task before the experiment began.

Participants completed a 2-part practice protocol. First, they practiced the basic visual search task. Six circles were presented, one was a distinctly colored circle, and participants were told to initiate a saccade to fixate the target whereupon the trial was terminated. If participants went to an object in the display other than the target, an error message was displayed. This continued until a criterion of at least 30 trials (10 in a row correct) was met. In the second part of the practice phase, participants completed a shorter version of the experiment including encoding, retrieval, retro-cue, search, and test. A set of scenes and objects was created specifically for practice ensuring that none of the materials from the experiment proper had been encoded during practice.

After any remaining questions about the task were addressed, the experiment began. The experiment consisted of two interleaved sets of encoding and search/recognition test blocks (i.e., encoding block 1 → search/recognition block 1, encoding block 2 → search/recognition block 2). A single encoding block included 36 scene-object pairs. Each pair was presented three times, with trial order independently randomized across repetitions. Six objects, from the available set of 12, were used during encoding. The objects were subdivided into two sets (set A: nut, key, mitten, lock, moon and star; set B: anchor, bottle, cup, heart, leaf, and bow) and the experiment was counterbalanced so that each set was used during encoding equally often across participants. Across trials, each object from the selected set was paired with six different scenes, resulting in 36 distinct pairs. Individual encoding trials began with central fixation. When eye position remained fixed for 500ms, a scene (16.24° x 12.2°) was presented for 2s. An object (3.06° x 3.06°) was then superimposed on top of the scene, and the pair remained in view for 2s (see Figure 1). Participants were told to learn the scene-object associations and were encouraged to use repeated exposures as an opportunity to test their memory (i.e., to retrieve the associate before it was superimposed on the screen).

Following encoding, the corresponding search/recognition test block was run. Individual test blocks included 90 trials, 18 each, assigned to five different conditions. Every trial began with the presentation of a central fixation cross. The trial only advanced after participants spent 500ms fixating the center of the screen. What happened next depended upon the experimental condition. Sometimes, the fixation cross remained in view for an additional 500-1,000ms and then was replaced immediately with a search display (n = 56 trials). Use of a variable duration fixation cross was meant to discourage anticipatory saccades (Saslow, 1966). In each case, the search display included a target circle, identified by its color (i.e., blue, red, green, or fuchsia) and four or five gray circles, which served as distractors. The standard search display, a **baseline** control condition, was described above (i.e., a colored target circle among five gray distractor circles). In a second control condition, one of the gray circles was replaced with a **novel singleton distractor**. This object came from the set of six novel objects that was not seen during encoding. The final condition included an **encoded singleton distractor**, an object pulled from the set of six that was seen during encoding. In each case, the search display remained in view for 1,500ms and participants were told to make a single eye movement to the location of the colored circle ignoring everything else in the display. Furthermore, they were told that sometimes an object would be present in the search display, but that like other distractors, it should be ignored.

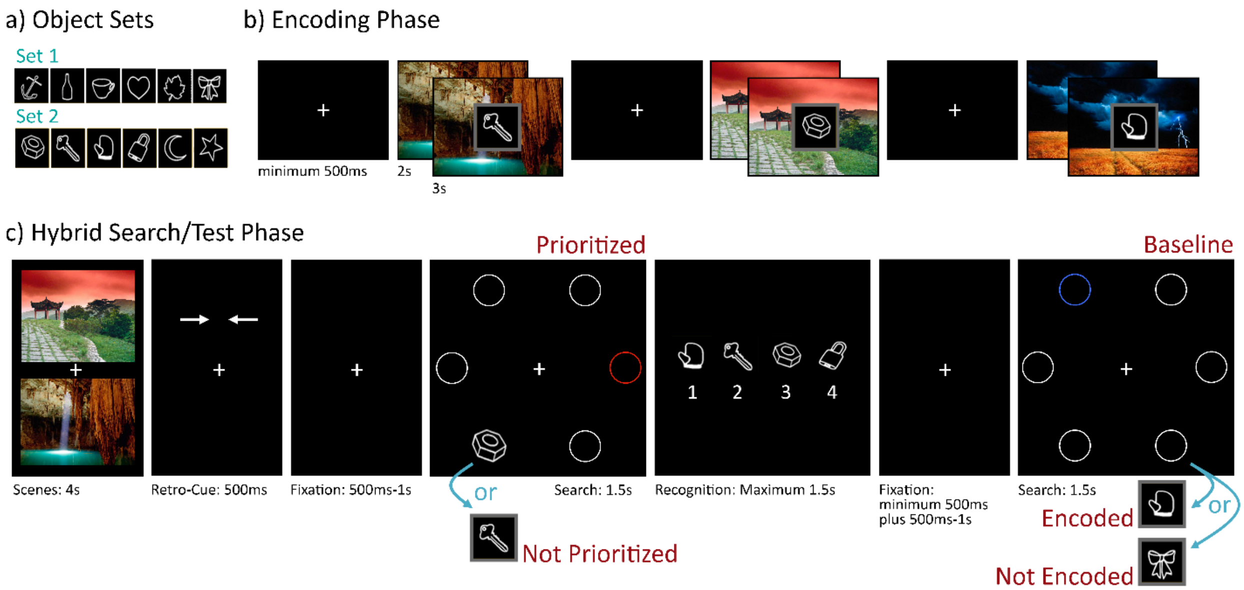
For the remaining test phase trials (n = 36), the fixation cross at the start of the trial was replaced with two encoded scenes presented simultaneously for 4s, one above, and one below fixation. Participants were instructed to retrieve the objects that were associated with these scenes during encoding. Two different scenes were always presented, and they had been paired with different objects during encoding; as such, participants attempted to retrieve two different objects when the scenes were presented. Every scene presented during encoding was used twice during test, appearing once above and once below fixation and in the prioritized and not prioritized conditions for each participant. Pairs of participants were yoked so that each scene was prioritized and not prioritized equally in both locations. Immediately after the scenes were removed from view, a retro-cue (i.e., a pair of inwardly facing arrows) was presented for 500ms in the location that was occupied by one of the scenes. The retro-cue indicated which one of the retrieved objects (i.e., the one associated with the top scene or the one associated with the bottom scene) should be **prioritized** for the memory test at the end of the trial. Participants were told that when scenes are presented, memory for just one of the retrieved objects, the associate of the cued scene, would be tested; no explicit instructions were given for the object that was **not prioritized**. Following the retro-cue the screen reverted to a fixation cross for 500-1,000ms and then a visual search display was presented. In each case, one of the gray circles was replaced with a singleton object. For half of the trials, this object was the one that was retrieved, but not prioritized by the retro-cue; for the remaining trials, this object was the one that was retrieved and prioritized for the recognition test at the end of the trial (see Table 1 for a summary of the experimental conditions.

Table 1
Summary of Experimental Conditions

	Trial Characteristics				
	Scene Cue	Distractor Present	Distractor Encoded	Distractor Retrieved	Distractor Prioritized
Baseline	No	No	No	No	No
Novel Singleton	No	Yes	No	No	No
Encoded Singleton	No	Yes	Yes	No	No
Not Prioritized	Yes	Yes	Yes	Yes	No
Prioritized	Yes	Yes	Yes	Yes	Yes

Finally, after the search display was removed from view, four objects from the set of six that was encoded were presented, each with a corresponding number (1 through 4). One of these objects had been retrieved and prioritized based on the position of the retro-cue and another one was the object that was retrieved, but not prioritized. The remaining two objects were selected randomly from the available set, with the constraint that each object was used equally often across blocks. Participants were told to select the prioritized object by making a button press corresponding to its number from the alternatives that were available; the objects remained on the screen until a response was made, up to a maximum of 1.5s (see Figure 1).

Figure 1
Experiment 1 trial structure and event timing



Note. **a)** Snodgrass objects – in this example, objects from Set 1 served as singletons during search that were not encoded; objects from Set 2 were encoded. **b)** Illustration of representative encoding trials and event timing. **c)** Two representative test phase trials and corresponding event timing. Trial one begins with the presentation of two encoded scenes followed by a retro-cue indicating which of two retrieved objects should be prioritized for a recognition test at the end of the trial. Prior to the recognition test, a search display is presented. In this example, the prioritized associate (i.e., the nut) is a singleton distractor. Following a button-press recognition response, the next trial is initiated. In this case, the trial is limited to search (i.e., no retrieve or recognition). A baseline trial is illustrated here, but on some trials one of the gray circles would be replaced with an item from either Set 1 (not encoded) or Set 2 (encoded).

Across blocks, participants encoded 72 scene-object pairs. Each object, from the set of six that was encoded (either Set A or Set B), was paired with 12 different scenes (six indoor scenes and six outdoor scenes). Counterbalancing ensured that, across participants, all six objects from the encoded set were presented equally often with every scene (six participants each for Sets A and B were recruited to meet this requirement). In addition, each individual from this initial sample of 12 was yoked to a new participant. This yoking procedure ensured that the same scene-object pairs used in the *prioritized* test condition for one participant were assigned to the *not prioritized* condition for a second participant. All the other procedural details (e.g., the encoded pairs and search display configurations) were exactly matched for these pairs of yoked participants. The use of this yoking procedure means that the full design was counterbalanced across 24 participants. Consistent with the results of our power analysis, this number was doubled, bringing our sample size to 48. Targets were blue, red, green, and fuchsia, and occupied each of the six possible search display locations equally often across trials and test conditions. Singleton distractors were never directly adjacent to the target but occupied each of the remaining possible locations (i.e., two steps forward, two steps backward, or three steps away from the target) equally often. Furthermore, across trials and conditions, singleton distractors occupied each of the six possible search display locations equally often.

Eye Movement Analysis

Analysis of eye tracking data began by removing trials with saccades that were made away from center fixation prior to 80ms or later than 600ms (Theeuwes & Belopolsky, 2012), this included trials where participants never left center. On average 8.76% (*S.D.* = 6.5%) of trials were dropped due to these parameters. Additionally, all of the trials with incorrect recognition responses were removed from analysis because it was assumed that participants had not successfully retrieved or prioritized the associate on those trials. On average, this resulted in the removal of 2.66% (*S.D.* = 2.4%) of the search task trials.

Three eye-tracking measures were used to address questions about capture by task-irrelevant singleton distractors. First was **saccade errors**, which measured the proportion of initial saccades that landed on distractors rather than targets. These errors represent *overt deployment of attention* to task-irrelevant information which is dependent on attention priority. Second was **dwell time,** which measured the amount of time singleton distractors were fixated after a saccade error was made. Dwell time may correspond to the amount of time it takes to process a stimulus after capture has occurred. When information is in the focus of attention, such as when it is prioritized, that item may hold attention longer because of the match between an internal representation and external stimulus information, resulting in longer dwell times (Nickel et al., 2020). Third was **saccade latency,** which measures how long it takes to initiate saccades to the target as instructed. Evidence suggests that latency is sensitive to the *covert deployment of attention* to a distractor without a corresponding saccade to its location. This results in slower initiation of saccades to targets when irrelevant singletons are present (Theeuwes, 1991 & 1992). Based on work in our lab (Nickel et al., 2020) and results from the WM literature (Mallet & Lewis-Peacock, 2018; van Moorselaar et al, 2014) the longest saccade latencies should occur for prioritized trials. If items that are not prioritized by the retro-cue are quickly discarded, then the presence of these items in search displays may not affect saccade latency to targets (i.e., will not be statistically different from the baseline condition).

Statistical Contrasts

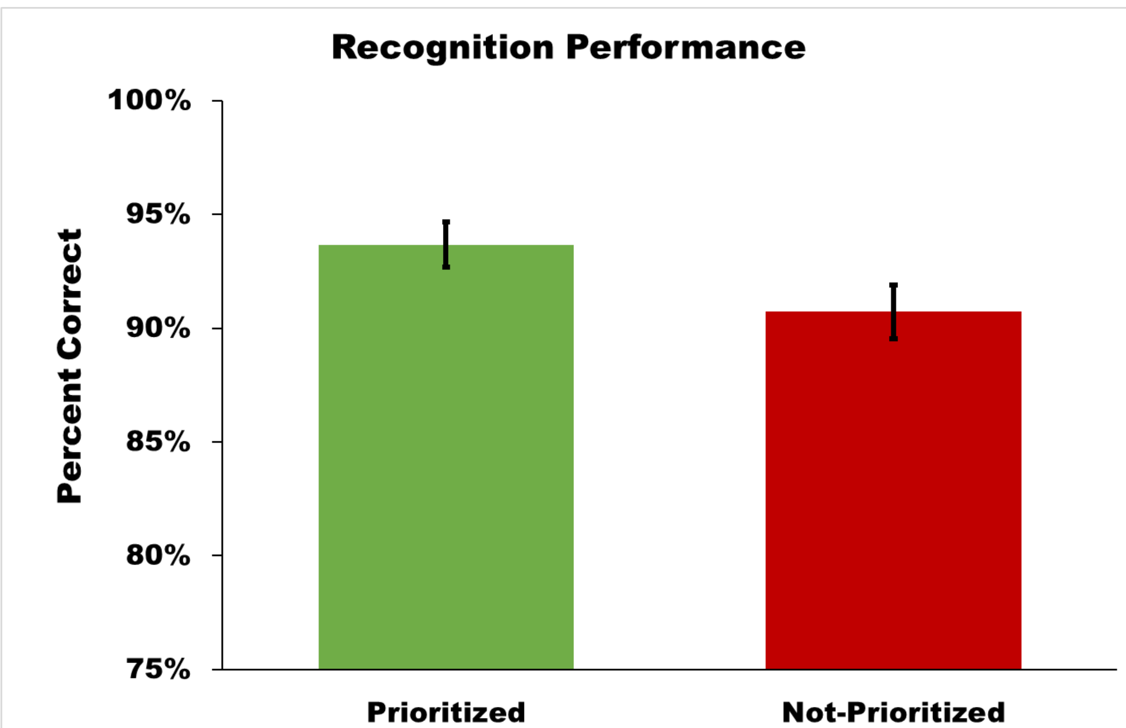
Mauchly's test of sphericity was calculated for all ANOVAs with more than one degree of freedom in the numerator. When sphericity was violated, Greenhouse-Geisser adjusted statistics and epsilons (ε) are reported. I corrected for multiple comparisons using Bonferroni corrected *t*-tests based on the number of tests that were performed, and corrected *p*-values are reported. Partial eta-squared (η^2) and Cohen's *d* were calculated as indices of effect size.

Results

Recognition Performance

Participants recognition performance demonstrated that the correct item had been retrieved and prioritized at the start of the trial. Participants were only tested on the prioritized item and chance performance was 25%. Scores ranged from 77 to 100% (*M* = 92.34, *S.D.* = 6.67%). A repeated-measures ANOVA showed that recognition performance on prioritized trials (*M* = 93.67%, *S.D.* = 6.8%) was significantly better than on not-prioritized trials (*M* = 90.73%, *S.D.* = 8.17%), $F(1, 47) = 11.97$, $p = .001$, $\eta^2 = 0.203$ (see figure 2).

Figure 2
Recognition Performance for Experiment 1



Note The percentage of hybrid trials with correct memory responses divided as a function of which irrelevant singleton was present in the search display (i.e., the distractor matched the prioritized associate, or matched the non-prioritized associate)

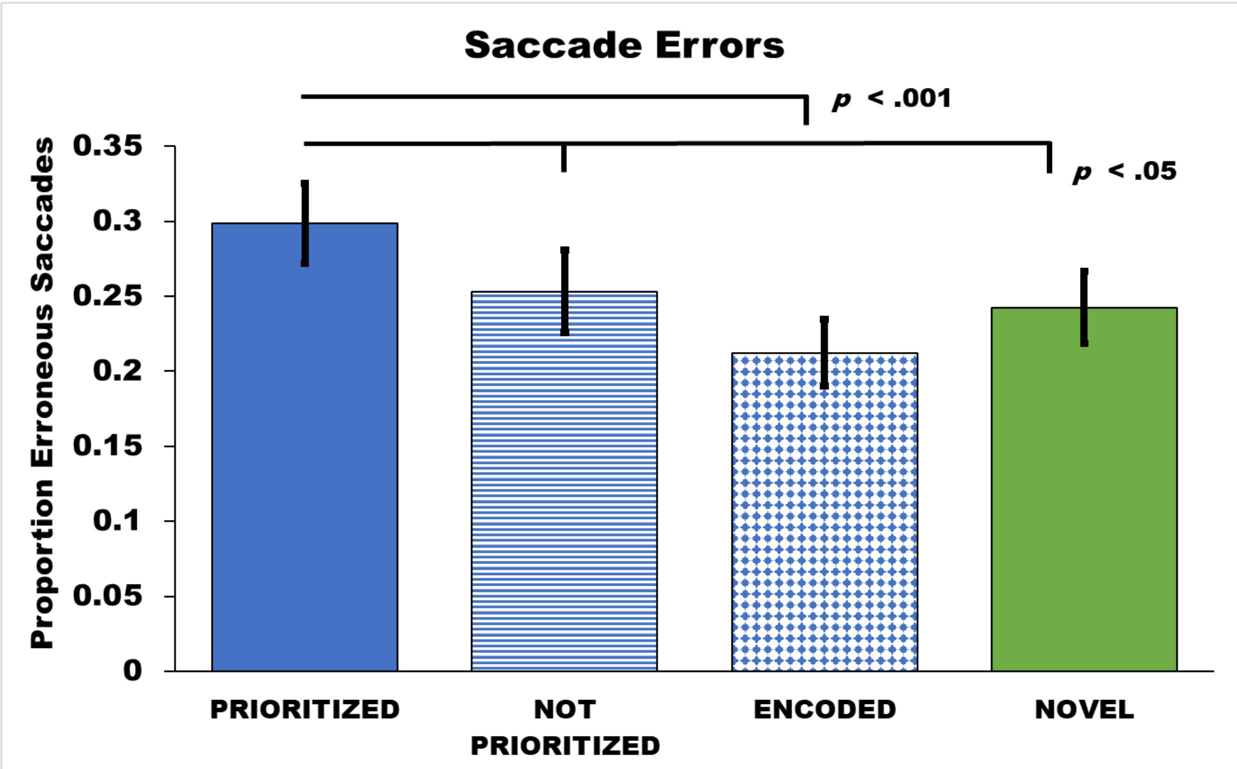
Viewing Behavior

Based on what has been reported in the WM literature (Mallet & Lewis-Peacock, 2018; van Moorselaar et al., 2014), it was expected that information retrieved from LTM and prioritized for the recognition test would lead to the greatest number of erroneous saccades, the longest dwell time following an erroneous saccade, and the longest saccade latencies when first saccades went to the target, as instructed. Items that were retrieved, but not prioritized, might also capture attention more often than encoded items that were not retrieved prior to search, a result that would be consistent with observations of temporally-limited capture by non-prioritized WM items (van Moorselaar et al., 2014).

Erroneous Saccades

A repeated-measures analysis of variance (ANOVA) was conducted comparing search performance across four conditions (prioritized, not-prioritized, encoded, and novel singleton). Results indicated that there were differences in the proportion of erroneous saccades to singleton distractors across conditions, $F(5.23, 119.28) = 7.983$, $p < .001$, $G\text{-}G\ \varepsilon^2 = .80$, $\eta_p^2 = 0.145$ (see Figure 3). Bonferroni corrected pairwise comparisons indicated that prioritized associates captured attention significantly more often than any of the other singleton distractors, t's $(47) \geq 2.89$, p's $\leq .034$, d's ≥ 0.24. While there were numerical differences in capture across the remaining conditions, none of these were significant, t's ≤ 2.22, p's $\geq .19$, d's ≤ 0.24.

Figure 3
Oculomotor capture Experiment 1

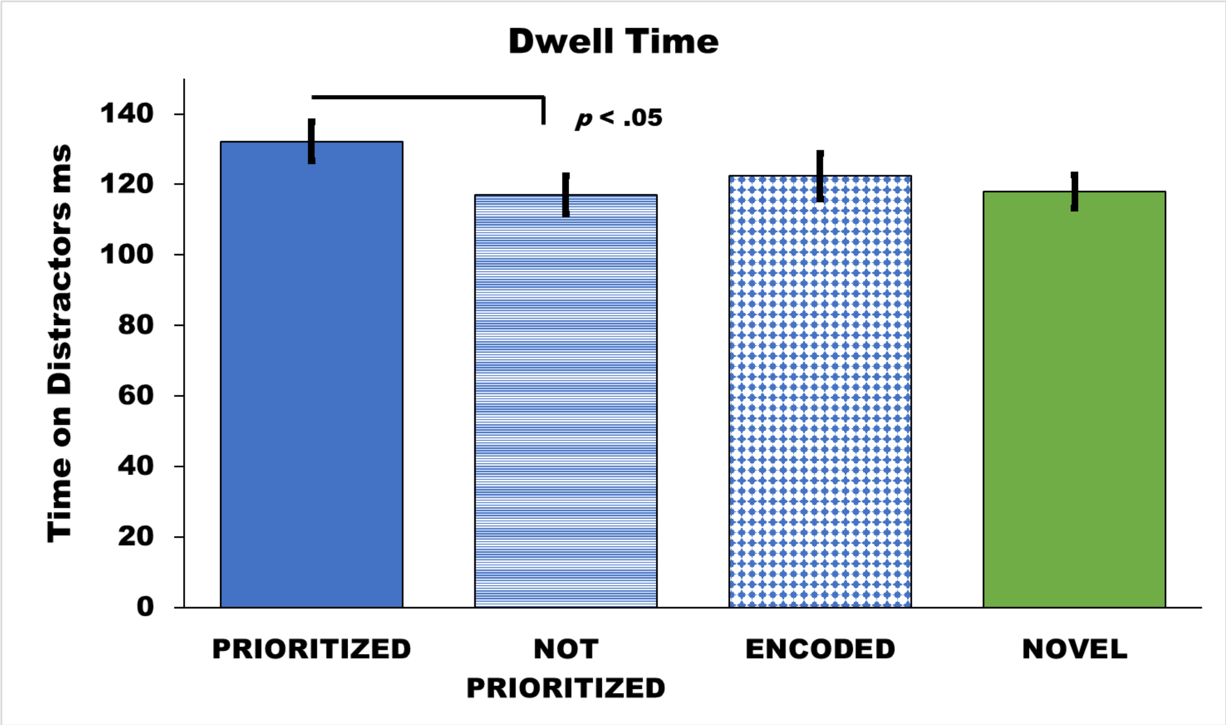


Note The proportion of trials on which participants made an initial, erroneous saccade to a distractor in the search display for Experiment 1.

Dwell Time

A repeated-measures ANOVA was calculated to determine whether there were differences in dwell time across conditions following capture by the singleton distractor. Results indicated a significant effect of condition F(3, 141) = 3.843, p = .011, η_p^2 = 0.076 (see Figure 4). Bonferroni corrected pairwise comparisons revealed that prioritized associates were fixated longer than not-prioritized associates, t(47) = 2.92, p = .015, d = 0.44, and while the same pattern was evident for encoded and novel distractors, the differences were not significant, t's ≤ 2.378, p's ≥ .072, d's ≤ 0.35. Small numerical differences in dwell time across the remaining conditions were not significant, t's ≤ .884, p's = 1.00, d's ≤ 0.35.

Figure 4
Dwell time Experiment 1

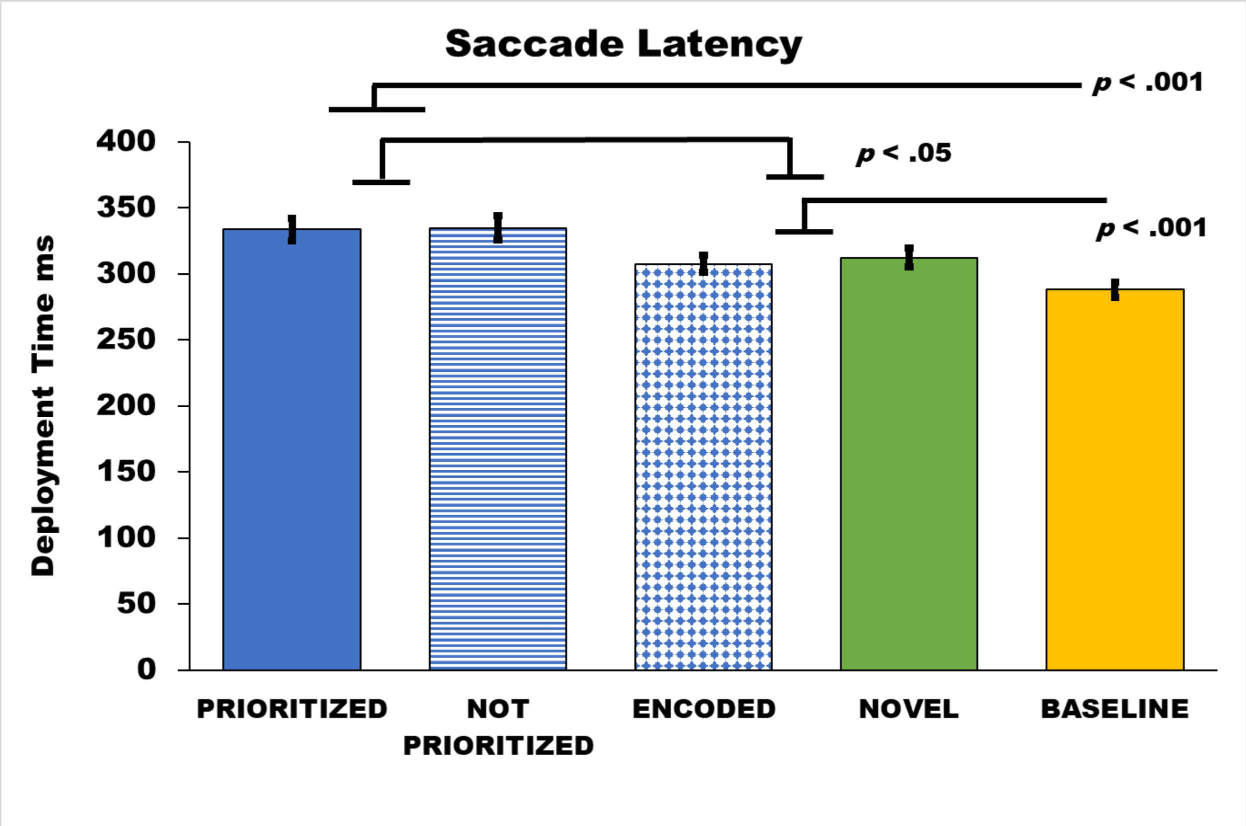


Note The amount of time, in milliseconds, that was spent fixating the ROI occupied by a distractor when oculomotor capture had occurred.

Saccade Latency to Targets

To determine whether there were differences in saccade latency when first saccades were made to targets, as instructed, a repeated-measures ANOVA was conducted comparing the prioritized, not-prioritized, encoded, novel, and baseline conditions. Once again, there was a significant difference between conditions, $F(1.84, 86.44) = 23.386$, $p < .001$, $G\text{-}G\ \varepsilon^2 = .46$, $\eta_p^2 = 0.332$ (see Figure 5).

Figure 5
Saccade latency for Experiment 1



Note. The average time, in milliseconds, required to initiate saccades to targets, as instructed, for Experiment 1.

Bonferroni corrected pairwise comparisons showed that trials with retrieved material (both prioritized and not prioritized) resulted in significantly longer latencies then the remaining conditions, t's ≥ 3.25, p's ≤ .017, d's ≥ 0.39, but in contrast to predictions prioritized and not-prioritized conditions were not statistically different from each other $t(47) = -0.24$, $p = 1.00$, $d = 0.015$. A similar result was found for the encoded and novel singleton distractor conditions where latencies were significantly longer than baseline search, t's ≥ 6.04, p's ≤ .001, d's ≥ 0.53, but not different from each other, $t(47) = -1.34$, $p = 1.00$, $d = 0.099$.

Discussion

Results from Experiment 1 indicated that retrieved associates which were prioritized for the recognition test led to more erroneous saccades and were fixated for longer periods of time than other singleton distractors. However, the presence of any distractor in the search display resulted in slower saccade latencies, a result that is consistent with previous studies that indicate singletons are distracting and slow down search for a target (Theeuwes, 1991, 1992).

Capture by objects that have been retrieved and prioritized is consistent with observations of fast, obligatory viewing of retrieved associates when participants are instructed to identify those items or are not explicitly told to ignore them (e.g., Hannula et al., 2007; Mahoney et al, 2018; Nickel et al., 2015). These results are also consistent with recent observations of overt, oculomotor capture by task-irrelevant associates retrieved spontaneously from LTM following the presentation of a scene cue (Nickel et al., 2020). Now, however, capture effects were limited to information that was retrieved *and* prioritized – i.e., the subset of items likely to have been active and in the focus of attention when search displays were presented. This result is consistent with what has been reported in the working memory literature (Mallet and Lewis-Peacock, 2018; van Moorselaar et al., 2014) and with the possibility that information which was not prioritized had been removed from the focus of attention by the time that the search display was presented. As such, it seems possible that for capture to occur information must be held in an active state whether it was recently encoded into WM or was retrieved from LTM.

Similar to previous work from our lab (Nickel et al., 2020), participants spent more time fixating distractors that had been retrieved following the presentation of a scene cue, but now retrieval was required rather than spontaneous, and the dwell time difference was limited to the subset of retrieved items that were prioritized by the retro-cue. There was no difference in dwell time between prioritized and encoded trials. Collectively, this pattern of results is consistent with the expectation that items with the most active representation are more likely to capture attention. It suggests that the most active representation (i.e., prioritized items) required the most time to process and subsequently disengage from.

When participants did not make saccade errors, the time required to initiate target-directed saccades was longer when a task irrelevant singleton distractor was present in the search display. Encoded and novel distractors slowed down saccade latencies to a similar degree compared to baseline displays, and initial saccades were slower still when distractors had been retrieved, whether they were prioritized or not. The general slowdown in saccade latency relative to the baseline condition supports previous work (Theeuwes, 1991, 1992) which demonstrated that the presence of an additional singleton in a search display is distracting and can attract attention covertly. A surprising outcome is the absence of a difference in saccade latency to targets when irrelevant singletons were retrieved and prioritized versus not prioritized, as other measures did distinguish these conditions. A potential explanation for this effect comes from our previous work which indicates that the presence of *any* visual information prior to search is distracting and slows the deployment of saccades to the target stimulus (Nickel et al., 2020). In that work, saccades to targets were made more slowly when encoded scenes were presented before baseline search displays and when scrambled scenes (i.e., meaningless) were presented before search displays with encoded distractors. This outcome suggests that the observed slowdown does not depend on a match between retrieved content and the identity of a singleton distractor because there was not a match in either of these conditions. Consequently, observations of increased latencies to targets in the presence of prioritized and not-prioritized distractors in the present experiment were likely due to the presence of visual information before the search rather than any match between those distractors and retrieved memory representations.

Finally, it is important to acknowledge the small, but significant, difference in recognition performance that was evident when the singleton distractor was the prioritized (i.e., to-be-test) item. One possibility is that the difference in performance occurred because participants used the prioritized distractor to check or confirm their memory for to-be-tested items, improving recognition performance. Alternatively, it may be the case that the presence of an item in the search display that had been retrieved but not prioritized interfered with active retention of the prioritized item, resulting in poorer recognition performance in the not prioritized condition. If interference occurred, we could expect participants to choose the not-prioritized object at test instead of the prioritized object. However, participants chose non-prioritized items and trial irrelevant items equally often when they answered incorrectly. Thus, it seems more likely that prioritized representations were being refreshed on prioritized trials.

While this experiment demonstrated that capture is greatest when information is in a prioritized state, it does not directly address questions about the persistence of capture by retrieved content in the face of distraction or across time. It has been shown in the WM literature that capture by prioritized objects decreases over time (Mallet & Lewis-Peacock, 2018). In Experiment 2, I examine whether similar effects are evident for retrieved information when search displays follow the presentation of a retrieval cue or the recognition test.

Experiment 2

Having demonstrated that prioritization increases attention capture for retrieved information, I sought to understand how attention capture by retrieved information changes as a result of increased time and the presentation of intervening tasks between retrieval and search displays that included the retrieved associate. In this experiment, the trial structure was modified so that two consecutive search displays were either presented after the scene cue or after the recognition test on a given trial. Sometimes, the singleton distractor in a search display was the object that had been retrieved following presentation of the scene cue. Mallet and Lewis-Peacock (2018), found that capture by colored circles retained in WM declined as the number of search displays presented following a retro-cue increased. Despite this reduction in the magnitude of capture, the effect remained significant even when data analysis was limited to the final few search displays prior to test. The present study was designed to examine what happens to information that is retrieved from LTM and how long it might remain in the focus of attention.

Method

Participants

Twenty-five participants between the ages of 18-45, with normal or corrected to normal vision, were recruited from UWM to participate in this experiment. Data from six participants were excluded from analysis because they disclosed to the experimenter that they had purposely looked for and at retrieved objects in the search displays, a clear violation of the task instructions. Our objective was to collect data from 24 participants, a number based on our previously published work (Nickel et al., 2020) which used a basic procedure similar to the present design (e.g., only one scene cue, not two, and no retro-cueing). Results reported here are based on data from 19 participants, as testing was discontinued due to Covid-19 closures. All procedures were approved by the UWM IRB.

Materials and Apparatus

Materials included 96 full color scenes (48 indoor scenes, 48 outdoor scenes) selected from an existing database (cf. Hannula et al. 2007) and the internet, and eight gray (CIE L*a*b*:

50, 0, 0) line drawings selected from the Snodgrass and Vanderwart (1980) set including an anchor, cup, leaf, bow, star, lock, mitten, and nut. Colored circles were identical to those in Experiment 1 including, blue (CIE L*a*b*: 50, 24, -79), red (CIE L*a*b*: 50, 71, 62), green (CIE L*a*b*: 50, 51, 52) and fuchsia (CIE L*a*b*: 50, 85, 55). The eye tracking apparatus, software, and settings were the same as reported for Experiment 1.

Design and Procedure

Basic procedural details were similar to those described for Experiment 1. After consent was obtained, and following instructions, participants went through a practice protocol and had opportunities to ask questions before the experiment began. Practice, like before, started with a simple visual search task where arrays of six circles, one possessing a unique color, were displayed and participants were directed to make a saccade from center to the target ignoring everything else. In the event of an error, a message was displayed "Error Look at the Unique Object". This practice was identical to that used in Experiment 1 (see description above) and participants completed between 30 and 60 of these trials before meeting the imposed criterion (i.e., a minimum of 20 trials plus 10 consecutive correct trials) for satisfactory performance. After practicing the basic visual search task, a practice version of the full task was run which included materials different from the experiment proper.

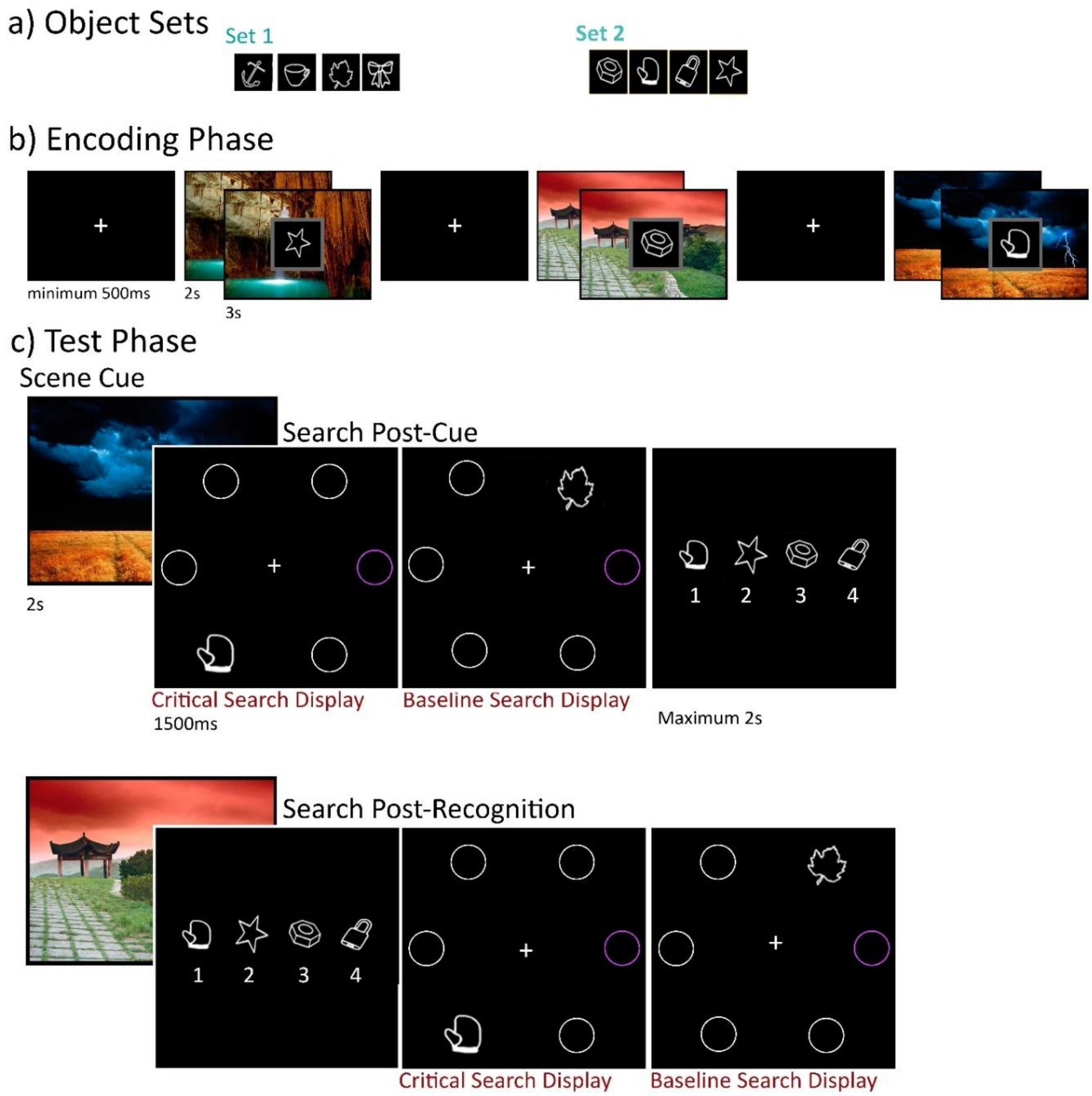
Following practice, participants completed the experiment which consisted of four interleaved blocks of encoding and test, which allowed us to determine whether a retrieved representation continues to capture attention after intervening search and test. The structure of each test block was also meant to obscure the relationship between retrieved objects and the identity of critical distractors in corresponding search displays. Encoding followed the same basic procedure that was described for Experiment 1. On every trial, a scene was presented for

2s and then the corresponding object was superimposed on top and the pair remained in view for 2s, each pair was presented three times, with trial order independently randomized across repetitions. In contrast to Experiment 1, each object (from the set of four used for encoding) was paired with six different scenes per block, which meant that 24 scene-object pairs were encoded. Across all four blocks, the total number of encoded pairs was 96.

After each encoding block, memory for learned pairs was tested and participants performed the visual search task. Unlike the previous experiment, Experiment 2 testing was distinguishable by the presentation of just one scene prior to a corresponding recognition test. Here, whether the retrieved object was "prioritized" when search displays were presented was determined by when, in the set of events that defined a trial, the critical search display was presented – i.e., following the scene cue and prior to test, when the retrieved item should still be active, or subsequent to test, when the retrieved item is no longer useful and might therefore be discarded.

Six trials in each test block came from each of four experimental conditions of interest (i.e., 72 critical trials per test block; 288 trials across all four test blocks). Twenty-four additional search displays (half with an encoded distractor; half with a novel distractor) were randomly inserted between trials to provide estimates of capture by encoded and novel distractors without cues. As indicated briefly above, these conditions could be distinguished by when, in the sequence of events, critical search displays – i.e., those that include a retrieved distractor – were presented. Sometimes the critical search display was presented after the scene cue, but before the corresponding recognition test, and sometimes the critical search display was presented after participants made their recognition response. The basic trial structure in this experiment included a scene cue and a 4-alternative forced-choice recognition test. Furthermore, two search displays (one with an encoded singleton distractor, one with a novel singleton distractor) were either presented after the cue and before recognition, or after recognition. In the latter case, the scene cue and the corresponding recognition test were only separated by central fixation. This means that scene cues were followed equally often, across trials, by search or by the recognition test. Again, the assumption was that active representation of the retrieved object would be strongest following the scene cue and prior to recognition. After participants made a response, the retrieved object could be discarded in anticipation of the next scene cue. To more precisely measure capture effects due time, testing, and the search process itself, critical search displays (i.e., those with the encoded associate included as the singleton distractor) were either presented immediately after the corresponding scene cue (**1 Post-Cue: 1PC**) or followed the appearance of a novel search display (**2 Post-Cue: 2PC**). The same basic rules applied after the recognition test – critical search displays were either presented immediately (**1 Post-Test: 1 PT**) or were one event removed from test (**2 Post-Test: 2PT**; see Figure 6). Novel search displays included an object from the novel set. When search displays were presented, one object was distinctive by color and participants were told to make a single saccade to its location, ignoring everything else. Scene cues were presented for 2s, search displays for 1.5s, and participants had 1.5s maximum to make their recognition responses. Each event (i.e., scene cue, search, and recognition) was separated by a 1s delay plus mandatory central fixation for no less than 500ms. Once again, objects were assigned to two sets (encoded and novel) which were yoked between participants– test trials were identical, but novel search displays for one participant were encoded search displays for their yoked partner. As in Experiment 1, target identity, color, and location were balanced across trials and conditions. Critical distractors (encoded singleton distractors, novel singleton distractors) were either 1-back, 1-forward, 2-back, 2-forward, or 3 positions away from targets, and occupied each position in the search display equally often across trials.

Figure 6
Experiment 2 trial structure and event timing



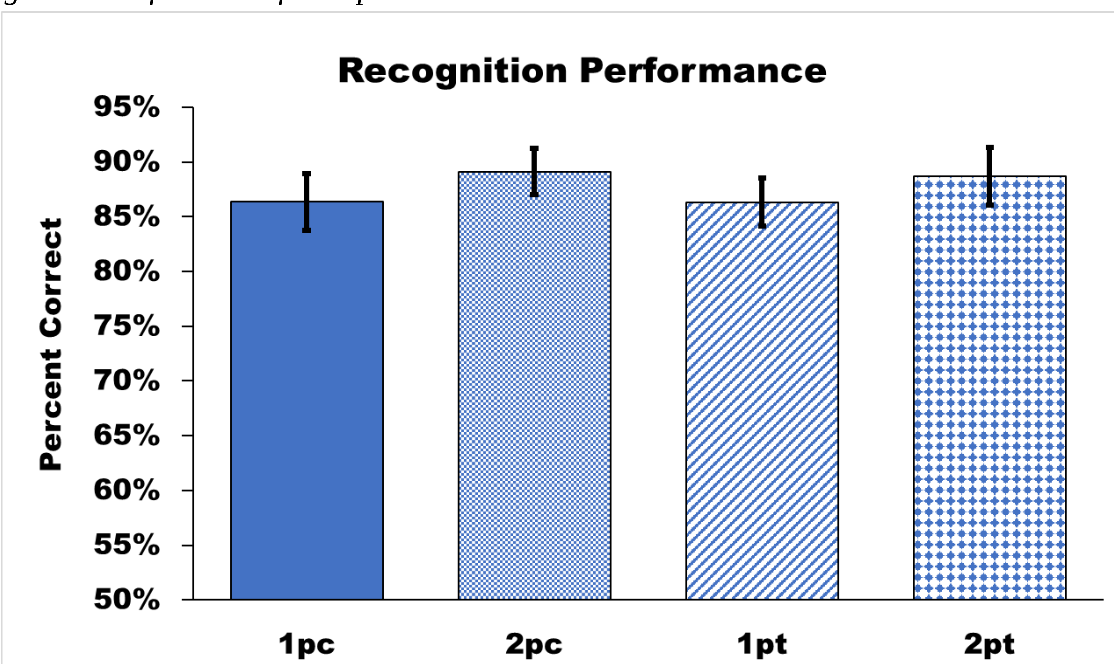
Note **a)** Snodgrass objects – in this example, objects from Set 1 served as singletons during *novel* object search; objects from Set 2 were encoded. **B)** Illustration of representative encoding trials and event timing. Trial one begins with the presentation of a single scene cue followed by sequential search displays. In this example the first singleton distractor is the encoded item (i.e., mitten) retrieved from LTM, followed by the novel distractor display (i.e., leaf). Following a button-press recognition response, the next trial is initiated. In the following trial recognition response immediately follows the scene cue.

Results

Recognition Performance

Memory for all of the encoded scene-object pairs was tested, and with 4-alternatives, chance performance was 25%. A repeated-measures ANOVA with the factors search condition (post-cue, post-test) and search display position (1 or 2) was calculated. Results showed no significant differences between testing conditions, $F(1, 17) = 0.016$ $p = .901$, $\eta_p^2 = 0.001$, no effect of position, $F(1, 17) = 4.24$, $p = .055$, $\eta_p^2 = 0.20$, and no interaction $F(1, 17) = 0.033$, $p = .86$, $\eta_p^2 = 0.002$ (see Figure 7). Unlike Experiment 1 there is no evidence that participants used the irrelevant singleton to refresh their memory, otherwise post-cue would be much higher than post-test.

Figure 7
Recognition Performance for Experiment 2



Note Percent correct on memory test as a function of when in a trial the search display including the irrelevant singleton matching retrieved material was presented.

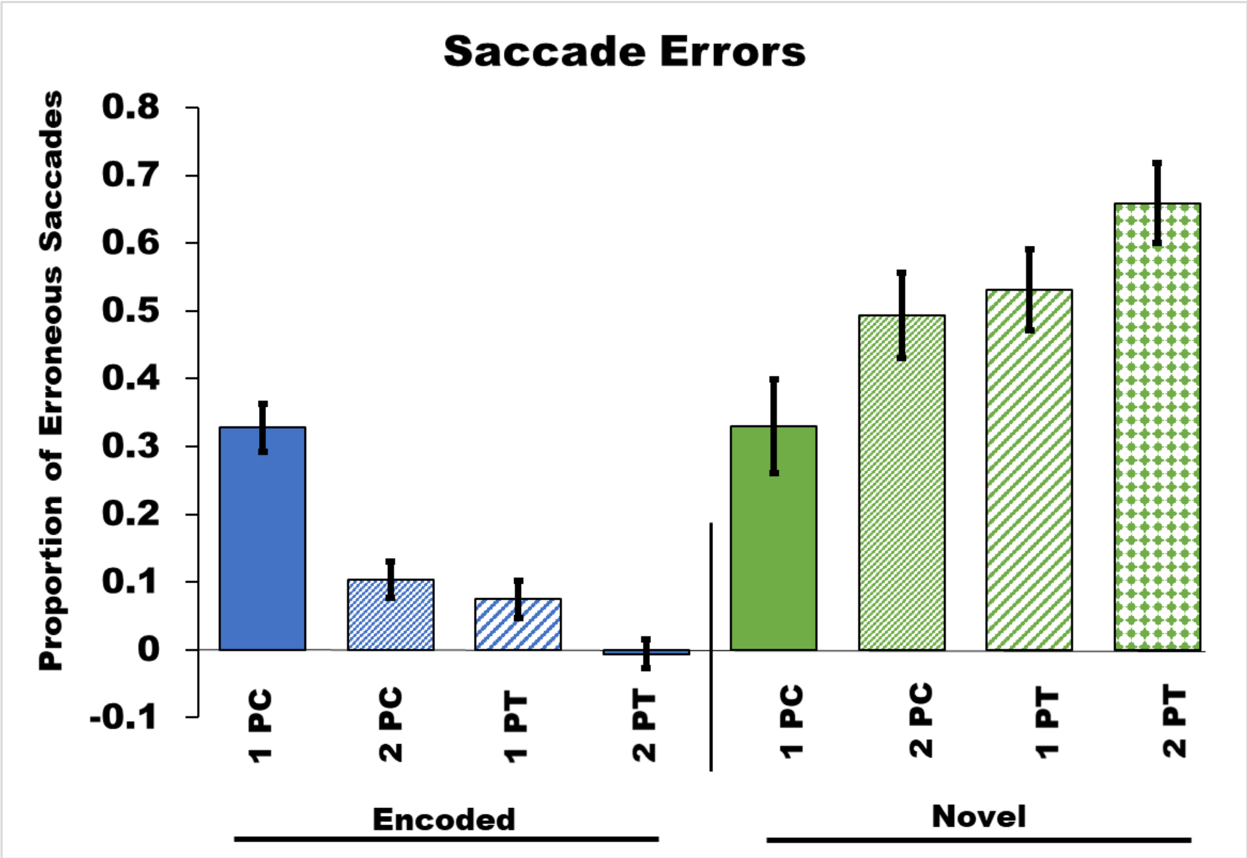
Viewing Behavior

Data used to analyze the differences between conditions in saccade errors, dwell times, and saccade latencies, was computed as a difference score. An equal number of encoded distractor and novel distractor search displays were included as fillers between post-cue and post-test trials. Average saccade errors, dwell time, and saccade latencies to these filler displays were subtracted from the post-cue and post-test data. For example, the average proportion of saccade errors made to encoded singleton distractors in filler trials was subtracted from saccade errors to encoded singletons distractors that were presented 1 post-cue. The critical distractors came from the same set of items, the difference was that in one case, the item was retrieved prior to search (e.g., 1 post-cue) and in the other case (i.e., encoded filler trials) it was not. Eye-tracking analyses were based on these differences scores, which were subdivided by distractor type (encoded and novel), condition (post-cue and post-test), and position (1 and 2).

Saccade Errors

An omnibus repeated-measures ANOVA was used to determent whether there were differences in saccade errors between distractor types (encoded and novel), across condition (post-cue and post-test), or by position (1 vs. 2). As can be seen in Figure 8 novel singleton distractors resulted in more erroneous saccades than encoded distractors, $F(1, 18) = 36.17$, $p < .001$, $\eta_p^2 = .67$, but there were not significant effects of condition, $F(1, 18) = 0.002$, $p = .96$, $\eta_p^2 = 0.00$ or position, $F(1, 18) = 0.091$, $p = .766$, $\eta_p^2 = 0.005$. The 3-way interaction was significant, $F(1, 18) = 57.43$, $p < .001$, $\eta_p^2 = 0.76$.

Figure 8
Oculomotor capture Experiment 2



Note The amount of time as a difference score, in milliseconds, that was spent fixating the ROI occupied by a distractor when overt, oculomotor capture had occurred.

To unpack the interaction, and because my primary objective was to determine how time, search, and testing affect capture by retrieved information analyses were performed separately for trials with encoded distractors and for trials with novel distractors. A repeated-measures ANOVA for encoded distractors showed more errors were made post-cue than post-test, $F(1, 18) = 36.09$, $p < .001$, $\eta_p^2 = 0.67$, and that more errors occurred when critical search displays were presented in the first rather than the second position, $F(1, 18) = 28.11$, $p < .001$, $\eta_p^2 = 0.61$. There was also a significant condition by position interaction, $F(1, 18) = 17.68$, $p = .001$, $\eta_p^2 = 0.496$. Bonferroni corrected pairwise comparisons revealed the greatest number of errors occurred when the critical search display was presented immediately after the scene cue (i.e., 1 post-cue vs. 2 post-cue, 1 post-test, and 2 post-test), t's ≥ 6.43, p's $\leq .001$, d's ≥ 1.66. In addition, saccade errors were made more often to encoded (and retrieved) singleton distractors 2 positions post-cue as compared to 2 positions post-test, $t(18) = -3.39$, $p = .019$, $d = 1.03$. No other differences were significant, t's ≤ 2.52, p's $\geq .13$, d's ≤ 0.76.

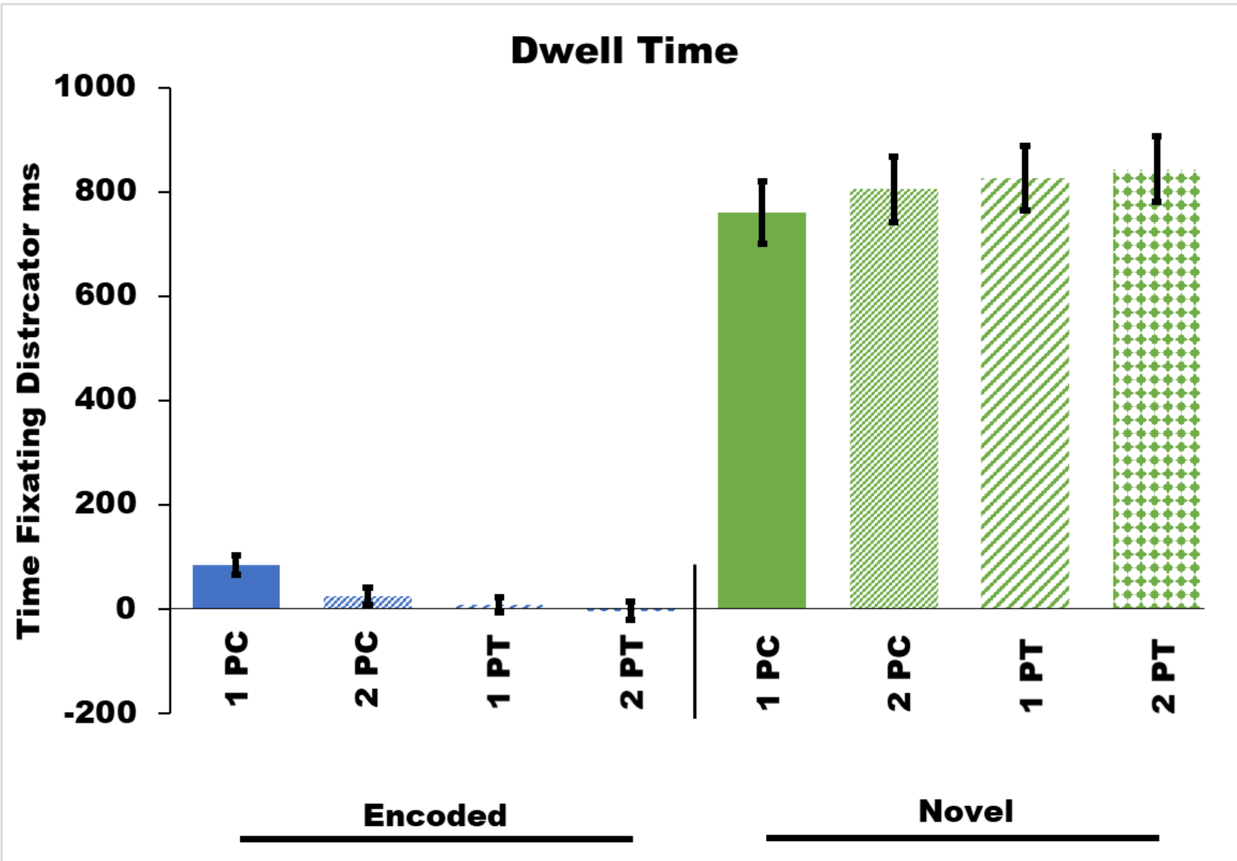
To determine whether or not capture by retrieved singleton distractors was higher than baseline levels of capture by *the same encoded items* when they had not been retrieved, 1-sample t-tests were calculated to determine whether capture effects were greater than 0. Results indicated that above-baseline capture was evident in both post-cue positions and the 1st position post-test, t's ≥ 2.65, p's $\leq .016$. No evidence was found for disproportionate capture by recently retrieved items when they were presented as singleton distractors in search displays 2 positions post-test, $t = -.029$, $p = .776$.

Finally, a separate, exploratory analysis was performed using data from search displays that contained novel singleton distractors. A repeated-measures ANOVA showed that more errors occurred post-test than post-cue, $F(1, 18) = 42.34$, $p < .001$, $\eta_p^2 = 0.702$, and in position 2 versus position 1, $F(1, 18) = 113.475$, $p < .001$, $\eta_p^2 = 0.86$. There was no condition by position interaction, $F(1, 18) = 1.58$, $p = .224$, $\eta_p^2 = 0.081$. Bonferroni corrected comparisons revealed that the likelihood of saccade errors to novel singleton distractors was greater with increased distance from the retrieval cue, t's ≥ 5.31, p's $< .001$, d's ≥ 0.71, with the exception that there was no difference between 2 post-cue and 1 post-test, $t(18) = -1.27$, $p = 1.32$, $d = 0.14$.

Dwell Time

A repeated-measures ANOVA revealed longer dwell times for novel distractors than encoded distractors, $F(1, 18) = 166.36$, $p < .001$, $\eta_p^2 = 0.90$, but there were no differences between post-cue and post-test, $F(1, 18) = 0.00$, $p = .985$, $\eta_p^2 = 0.00$ or between positions 1 and 2, $F(1, 18) = 0.085$, $p = .77$, $\eta_p^2 = 0.005$. There was a significant 3-way interaction, $F(1, 18) = 38.75$, $p < .001$, $\eta_p^2 = 0.68$, (see figure 9).

Figure 9
Dwell time Experiment 2.



Note The amount of time as a difference score, in milliseconds, that was spent fixating the ROI occupied by a distractor when overt, oculomotor capture had occurred.

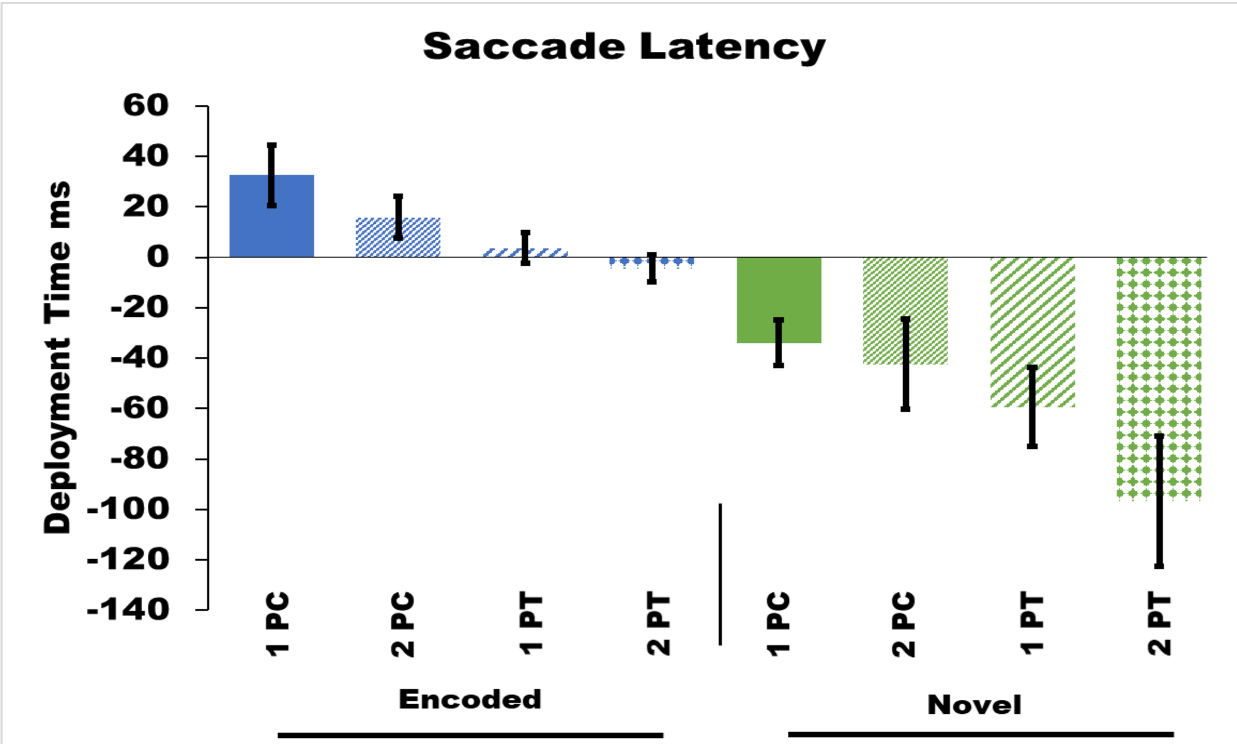
Again, because my primary objective was to determine how capture by retrieved items is affected by distance from the scene cue and performance of the recognition test, a repeated-measures ANOVA was used to compare dwell times across conditions (post-cue and post-test) and by position (1 vs. 2). This revealed significantly longer dwell times post-cue versus post-test, $F(1, 18) = 26.94$, $p < .001$, $\eta_p^2 = 0.599$, and longer dwell times for position 1 versus position 2, F(1, 18) = 13.61, p = .002, η_p^2 = 0.43. The condition by position interaction was not significant, F(1, 18) = 3.89, p = .064, η_p^2 = 0.178. Bonferroni corrected pairwise comparisons showed that fixations lasted significantly longer for retrieved material 1 post-cue compared to 2 post-cue, 1 post-test, and 2 post-test, t's ≥ 3.19, p's ≤ .03, d's ≥ 0.77. No other statistically significant differences were found, t's ≤ 1.47, p's ≥ .95, d's ≤ 0.28. Difference scores were then compared to zero using a 1-sample t-tests to determine whether dwell time for each position occurred more than encoded trials which did not follow retrieval. For these comparisons only dwell time 1 post-cue was above baseline levels, t(18) = 4.53, p < .001, there were no other statistically significant differences, t's ≤ 1.43, p's ≥ .17.

Finally, a separate, exploratory analysis was performed using data from search displays that contained novel singleton distractors. A repeated-measures ANOVA revealed dwell times were longer post-test than post-cue, F(1, 18) = 19.93, p < .001 , η_p^2 = 0.525, and also longer in position 2 compared to position 1, F(1, 18) = 5.20, p = .035 , η_p^2 = 0.224. There was no condition by position interaction, F(1, 18) = 2.49, p = .132 , η_p^2 = 0.12. Bonferroni corrected pairwise comparisons showed that dwell times 1 post-test and 2 post-test were significantly longer than 1 post-cue, t's ≥ 4.35, p's ≤ .001, d's ≥ 0.25, but no other differences were significant, t's ≤ 2.76, p's ≥ .078, d's ≤ 0.14.

Saccade Latency to Targets

A repeated-measures ANOVA was used to compare saccade latencies for each distractor type (encoded vs. novel) by condition (post-cue vs. post-test) and position (1 vs. 2). Latencies were longer for encoded distractors than for novel distractors, F(1, 18) = 18.48, p < .001, η_p^2 = 0.51, they were also longer post-cue compared to post-test, F(1, 18) = 15.29, p = .001, η_p^2 = 0.46, and longer in position 1 versus 2, $F(1, 18) = 5.23$, $p < .035$, $\eta_p^2 = 0.225$. The 3-way interaction was not significant, $F(1, 18) = 0.804$, $p = .38$, $\eta_p^2 = 0.043$, (see figure 10).

Figure 10
Saccade latency Experiment 2



Note The amount of time as a difference score, in milliseconds, required to initiate saccades to targets, as instructed, for Experiment 2.

To examine differences in latency when retrieved information was present in the search displays, a repeated-measures ANOVA was run comparing latencies by retrieved material across conditions (post-cue vs post-test) and position (1 vs. 2). Latencies were significantly longer post-cue than post-test, $F(1, 18) = 11.096$, $p = .004$, $\eta_p^2 = 0.38$, and for position 1 than position 2, $F(1, 18) = 6.27$, $p = .022$, $\eta_p^2 = 0.26$. There was no condition by position interaction, $F(1, 18) = .579$, $p = .456$, $\eta_p^2 = 0.031$. Bonferroni corrected pairwise comparisons revealed latencies were significantly longer 1 post-cue than 2 post-test, $t(18) = 3.62$, $p = .012$, $d = 0.91$, and marginally longer 1 post-cue and 1 post-test, t(18) = 2.95, p = .051, d = 0.697, but no other differences between conditions were significant, t's ≤ 2.278, p's ≥ .211, d's ≤ 0.323. To determine whether or not capture by retrieved singleton distractors was higher than baseline levels of capture by *the same encoded items* when they had not been retrieved, 1-sample t-tests were calculated to determine whether latencies were greater than 0. Results showed that only latencies 1 post-cue were longer than baseline, t(18) = 2.71, p =.014, no other differences were significant, t's ≤ 1.89, p's ≥ .56. This suggests that saccade latencies were slowed immediately after the cue but then decreased to baseline levels.

Finally, a separate, exploratory analysis was performed using data from search displays that contained novel singleton distractors. A repeated-measures ANOVA revealed latencies were longer post-cue than post-test, $F(1, 18) = 7.03$, $p = .016$, $\eta_p^2 = 0.28$, but not different for position 1 and 2, $F(1, 18) = 3.24$, $p = .089$, $\eta_p^2 = 0.152$. There was not a condition by position interaction, $F(1, 18) = 1.02$, $p = .325$, $\eta_p^2 = 0.054$. Bonferroni corrected pairwise comparisons revealed that saccade latencies for novel displays were no different from each other, t's ≤ 2.33, p's ≥ .186, d's ≤ 0.74, but note that in every case, latency to targets was *faster* than it was for baseline novel distractor trials (i.e., negative-going difference scores).

Discussion

My primary objective in Experiment 2 was to determine whether capture by encoded items is affected by the passage of time, the presence of intervening visual search displays, and/or memory testing. Consistent with predictions, LTM representations are less likely to capture attention when more information separates the retrieval cue from a corresponding search display. In the present experiment I found little evidence that capture occurred post-test which is consistent with data following presentation of the second retro-cue in Mallet and Lewis-Peacock

(2018), for items that were not prioritized and therefore no longer needed for a memory test. Indeed, even analyses limited to the first few search displays following the second retro-cue indicated that there was no capture by the items that were not prioritized. In contrast, my results suggest that some time was required after test for capture by information retrieved from LTM to completely disappear.

It is important to note the unusually high levels of capture by *novel* singleton distractors in this experiment. Before subtractions were performed to convert to difference scores, erroneous saccades to novel items occurred on 67% of trials, averaged across conditions, and average dwell time following capture was 934ms. This pattern of results suggests that participants misunderstood the instructions and were trying to direct first saccade to novel distractors rather than colored targets. Indeed, close inspection of the raw data indicated that when participants made a first saccade to a novel distractor, eye position most often remained fixed at that location until the end of the trial. In contrast, when saccades were made in error to retrieved objects, participants made corrective saccades to the colored target. Collectively, these observations indicate that participants did not understand what they were supposed to do when novel items were present in search displays following retrieval cues. It is possible that the instruction to initiate a saccade to the "unique object" was interpreted as, *look for the object that was not paired previously with the scene cue*. In this case, participants might have thought they were supposed to direct first saccades to novel items following the presentation of a scene cue or the corresponding recognition test. Additional testing, with modified instructions and confirmation that participants understand those instructions is required.

General Discussion

The goal of the present study was to further examine interactions between attention and LTM. The specific objectives were to determine whether prioritization affects capture by items retrieved from LTM and to determine whether capture by information retrieved from LTM is reduced in the face of intervening search and testing tasks. In Experiment 1 we found that associates purposefully retrieved from LTM capture attention, especially if they have been prioritized for an upcoming recognition test. This result is in line with examples of capture from the WM literature (Mallet & Lewis-Peacock, 2018; Olivers, 2009; Olivers et al., 2006; van Moorselaar et al., 2014) and suggests that a determining factor in when information captures attention is whether or not a corresponding representation of that information is active, or in the focus of attention (LaRocque et al., 2013; Lewis-Peacock et al., 2012; Lewis-Peacock & Postle 2012). Results from Experiment 2 indicated that capture by items retrieved from LTM was greatest when a critical search display was presented immediately after the retrieval cue. Capture by retrieved distractors in search displays 2-away from the cue or presented immediately after the recognition test was also evident but reduced in magnitude. A surprising outcome from Experiment 2 was that erroneous saccades and dwell times for novel distractors were both much higher than for retrieved associates. This result strongly suggests that participants did not understand the task instructions and purposely looked at novel distractors when they were presented in search displays following scene cues or the corresponding recognition tests. As indicated above, an additional experiment with modified instructions and confirmation of comprehension is required. It is anticipated that results will remain the same for retrieved singleton distractors, but that capture by novel distractors will be substantially reduced.

Results from neuroimaging studies (LaRocque et al., 2013; Lewis-Peacock et al., 2012; Lewis-Peacock & Postle 2012) provide some important insight into why capture occurs disproportionately for items that have been prioritized. As described in the introduction, these experiments used the retro-cue paradigm and results indicated that activity for items that had been prioritized for an upcoming WM test was higher than activity for items that were not prioritized. Indeed, activity for items that had not been prioritized fell to baseline levels. It was further demonstrated that items prioritized for an upcoming WM test were more likely to capture attention than non-prioritized items (Mallet & Lewis-Peacock, 2018; van Moorselaar et al., 2014), a result that is consistent with our findings from Experiment 1, when items had been retrieved from LTM.

The capture effects reported in Experiment 1 replicate and extend previous results from our lab (Nickel et al., 2020). In the studies conducted by Nickel et al., just one scene cue was presented prior to search and retrieval was incidental. Despite the absence of requirements to retrieve the encoded associates of scene cue, those items captured attention disproportionately when they were present in the search displays. Results from Experiment 1, here, are consistent with our claim (Nickel et al., 2020) that the associate must have been retrieved when scene cues were presented and suggests that without competition that item likely had prioritized status, even though memory was not tested at the end of the trial. This also indicates that encoded material retrieved in Experiment 2 of the present study had a prioritized status and all that entails.

A critical difference between the studies conducted by Nickel et al. (2020) and the ones reported here was that none of the previous studies used the additional singleton paradigm (i.e., a single task-irrelevant distractor in an otherwise homogenous search display). The search displays used in my experiments were more closely matched to the ones that had been used in studies that examined capture by WM (Olivers, 2009; Olivers et al., 2006; van Moorselaar et al., 2014). Despite this difference, overt, oculomotor capture by information retrieved from LTM was documented.

While overt eye movements to a distractor clearly indicate the misallocation of attention, it is assumed that other measures (e.g., response time, saccade latency to targets) are sensitive to the misallocation of attention as well. For instance, one might reasonably conclude that if target-directed saccades are slower when a task-irrelevant singleton is present in a search display that the singleton was distracting and may have attracted attention covertly (i.e., in the absence of a corresponding eye movement). Consistent with previous examples of additional singletons slowing deployment to target (Olivers, 2009; Olivers et al., 2006; Theeuwes, 1991, 1992; van Moorselaar et al., 2014) saccade latencies in Experiment 1 were slower for encoded and novel trials compared to the baseline trials. Latencies in Experiment 1 were slower still for trials beginning with a scene cue and retrieval of encoded material, consistent with Nickel et al. (2020). This suggests that encoded and novel distractors captured attention, but that capture was greater when participants retrieved encoded material before search. However, results in Nickel et al. (2020) indicated that increased latencies could be an effect of visual processing costs related to a scene presentation at the start of a trial rather than a capture effect. To test this, Nickel et al. presented scrambled scenes prior to search displays with encoded distractors and encoded scenes prior to baseline search displays. Saccade latencies were longer when visual information was presented prior to search increased saccade latencies, and results from the present set of experiments supports this conclusion. Similarly, in Experiment 2, saccade latencies were longest immediately following cue/retrieval, but only decreased significantly for 2nd position post-test. Unlike the differences in saccade errors and dwell times between critical novel trials and critical retrieved trials, the direction of the saccade latency effects was opposite for novel trials than for retrieved trials (i.e., novel trials resulted in shorter latencies not longer). The simplest explanation for this as previously mentioned, is attention was deployed to critical novel objects as targets not distractors. Future studies should determine whether differences in latencies are a result of trial structure before calling them memory related capture effects.

Patterns of erroneous saccades and saccade latency results, and similar to Nickel et al. (2020), dwell times in the current studies were longest for distractors matching an item retrieved from LTM prior to search. One explanation for increased frequency of erroneous saccades and longer dwell times is that mechanisms of suppression employed to deter capture (Feldman-Wusefeld & Vogel, 2019; Gaspelin & Luck, 2018) are not strong enough to overcome the higher activity levels associated with prioritization. Two suppression effects have been proposed (Gaspelin & Luck, 2018), one that would prevent capture, and one that allows participants to disengage from material after capture has occurred. As mentioned earlier, material which is most active (LaRocque et al., 2013; Lewis-Peacock et al., 2012; Lewis-Peacock & Postle 2012), also captures attention most (Mallet & Lewis-Peacock, 2018; van Moorselaar et al., 2014). Therefore, a stronger signal is required, but not always present, to suppress the higher level of activity associated with prioritization. This would explain why prioritized material results in more erroneous saccades and longer dwell times.

There is also a question of whether there are memory costs related to attention capture. In Experiment 1 there was a significant difference in memory performance between trials with a distractor matching the prioritized material and those trials where it matched the not-prioritized material. This was a numerically small difference but something similar has been reported in the WM research (van Moorselaar et al., 2014). As van Mooreselaar et al. suggested, one explanation is that during visual search participants take the opportunity to refresh the maintained representation for the subsequent memory probe. A similar explanation could be offered here. In both cases though, if participants were willfully refreshing their memory, we might expect capture to be much higher. We might also expect not-prioritized material to be selected in error when that material matches the distractor in the display. In Experiment 1, not-prioritized trials led to worse recognition performance, but participants selected objects that weren't prioritized equally often as trial irrelevant options during the memory probe. This suggests that if refreshing is occurring, it seems likely that it is not because of an active effort by participants, but a passive effect from being captured.

Together, the present studies suggest that prioritization of information is important to predicting attention capture and capture by items retrieved from LTM is most robust immediately following the retrieval cue. The present results further suggest that the information that was incidentally retrieved in Nickel et al. (2020), was an active representation similar to prioritized information in Experiment 1, though a future imaging study could directly compare incidental and effortful retrieval to determine whether they result in different levels of activity or different amounts of capture. Importantly, a direct comparison cannot be made here due to the differences in search display and recognition testing, which have both been shown in the WM literature (Olivers et al., 2006) to affect capture. Though the percentage of trials with saccade errors was similar between Nickel et al. and the present experiments, as has been discussed in the WM literature (Olivers et al., 2006; Theeuwes 1992) the amount of effort it takes to find targets as a function of distractor physical similarity can influence the amount of capture that occurs.

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Curriculum Vitae

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Education

Ph.D. Student Psychology-Neuroscience, University of Wisconsin-Milwaukee	2013-2020
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Awards & Honors

Department of Psychology Summer Research Fellowship	2018
NMU Scholars Award	2006-2010
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Teaching

Graduate Assistant, University of Wisconsin Milwaukee	August 2013-2020
PY 325 Research Methods Discussion	2018 Fall/2019 Spring
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PY 205 Personality Discussion 10 sections	2017 Fall/2018 Spring
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PY 205 Personality Discussion 10 sections	2015 Fall/2016 Spring
PY 210 Statistics Online	2015 Spring Semester
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PY 205 Personality Discussion 5 sections	2014 Fall Semester
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Graduate Assistant, Northern Michigan University	August 2010-May 2012
PY 305 Statistics Graduate Assistant	2011-2012 Academic Year
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Research Experience

Dr. Deborah E Hannula's Lab 2016-2020

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Master's Thesis: Practice and Memory Load in a
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Mental Rotation Lab: 2010 – 2012
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Presentations & Publications

Hoelter, J.L., Nickel, A.E., & Hannula, D.E. (2017, November). *Long-term Memories Capture Attention Following Retrieval Cues, but only When They are Actively Represented*. Poster presented at 58th annual conference of Psychonomic Society.

Coutinho, Mariana; Held, Sara; Hoelter, Joshua; Nimm, Joseph; Kaiver, Christine; Na, Ahila; Bartlein, Alexander; Echeveste, Carla; & Greene, Anthony. (2015, November). *Variants in transitive inference training yield distinct outcomes in performance and awareness.* Poster presented at 56th annual conference of Psychonomic Society.

Hoelter, J.L.; Kaiver, C.M.; Held, S.J.; Echeveste, C.E.; Greene, A.J. (2015, October). *Disambiguation in an auditory serial reaction time task.* Poster presented at 45th annual conference of Society for Neuroscience.

Leith, C. R., Burns, S. L., Savord, A., Hoelter, J., Morrison, D., Lewis, M., Aiyash, T., Boudreas, R. (2012, May). *Stimulus familiarity is more important than size in a mental rotation task.* Poster presented at 24th Annual Conference of Association for Psychological Science, Chicago, IL.

Leith, C. R., Burns, S. L., Savord, A., Hoelter, J., Morrison, D., Lewis, M., Aiyash, T., Boudreas, R. (2012, May) *Father's education level is related to need for cognition.* Poster presented at 24th Annual Conference of Association for Psychological Science, Chicago, IL.

Leith, C. R., Burns, S. L., Savord, A., Morrison, D., Hoelter, J. (2011, May). *Lack of equivalence between the Vandenberg mental rotation test and mental rotation: Replication of a validity check.* Poster presented at 23rd Annual Conference of Association for Psychological Science, Washington, D.C.

Leith, C. R., Burns, S. L., Savord, A., Morrison, D., Hoelter, J. (2011, March) *Lack of equivalence between the Vandenberg mental rotation test and mental rotation: Replication of a validity check.* Presented at Michigan Academy of Science, Arts, and Letters Poster, Saginaw, MI.