RELATIONAL MEMORY REVEALED BY EYE MOVEMENTS: MANIPULATION EFFECTS AND THE ROLE OF AWARENESS

by

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ABSTRACT

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Eye movements are an integral part of visual information processing and permit us to align objects of interest with the high-resolution fovea for the acquisition of detailed information. Changes in eye movement behavior have been reported in studies exploring the effects of general knowledge on scene processing, and in studies that have examined memory for arbitrary relationships between objects or for object locations in scenes. Some evidence suggests that relational memory-based viewing effects occur even without corresponding awareness of the remembered content. These findings, however, have not always been replicated, which means that there is not consensus about whether awareness is a requirement for the expression of eye-movement-based relational memory effects. The objective of this investigation was to use memory-sensitive eye movement measures to elucidate the role of awareness in memory-based viewing by specifically examining the influence of testing instruction and manipulation type (i.e., objects added to versus removed from scenes). Results showed that recognition of scene changes was better when objects were added to scenes, and that greater viewing was directed toward objects than toward empty space within a scene. Critically, results revealed that when memory was tested indirectly, and the changed region was now-filled (i.e., an object was added), there was a trend for unaware memory-based viewing effects. These findings indicate that

manipulation type and testing instructions are important factors that should be considered separately in studies that are designed to examine unaware memory-based viewing effects.

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Introduction

Much work has been directed toward understanding the behavioral and cognitive properties of eye movements (Braun and Schutz, 2022; Wedel et al., 2023). Important discoveries in this pursuit discerned that eye movements could be deployed voluntarily or reflexively (Hallett, 1978; Theeuwes et al., 1998) and serve as an important index of the allocation of attention during viewing tasks (Yarbus, 1967; Fischer and Breitmeyer, 1987). From this basis, the examination of eye movements during scene viewing revealed that certain scene properties (e.g., physically salient features) were associated with prioritized visual attention (indexed by increased fixation frequency and duration in locations of high physical salience) when instructions were simply to look at the scenes (Itti et al., 1998; Parkhurst et al., 2002). When task instructions differed during scene viewing (e.g., participants were asked questions pertaining to perceptual or semantic scene elements), the pattern of fixation locations and durations changed as a function of task demand (Yarbus, 1967).

With this understanding that eye movements may be linked to both top-down and bottom-up processing operations, the potential for eye movements to reveal memory – a process that may be initiated by top-down goals and objectives or spontaneously when a stimulus is repeatedly presented (e.g., priming) – offered a compelling avenue for investigation. Findings have since shown robust effects of associative (semantic) priming and semantic memory on viewing behavior (Odekar et al., 2009; Henderson, 2003), as well as the ability for eye movements to reveal contents held in working memory (Theeuwes, et al., 2009), and information retrieved from long-term memory (Ryan et al., 2000). Some consistent patterns emerged, such as decreased viewing of familiar compared to novel scenes or objects (Althoff et al., 1998; Smith and Squire, 2017), and increased viewing of objects or scenes that were part of a pair encoded into long-term memory, when one item from the pair was presented as a memory cue (Hannula et al., 2007). Thus, eye movements are sensitive to different types of memory (e.g., semantic, relational), but an outstanding question remains as to whether this occurs without awareness.

Surprisingly, results suggest that eye movements are sensitive to the location or features of stimuli even when participants do not "see" the stimulus (e.g., they cannot consciously report the presence or characteristics of these stimuli) – an effect of implicit perception on viewing behavior (Rothkirch et al., 2012; Spering et al., 2011). These results are consistent with observations that suggest eye movements can reveal memory effects despite incorrect explicit recognition responses and may therefore reveal content from memory that is unavailable to conscious awareness (Ryan et al., 2000; Hannula et al., 2009). This would prove useful in interrogating memory theories proposing the existence of multiple memory systems which dissociate on the basis of conscious awareness of memory representations (Moscovitch, 1992; Squire and Dede, 2015). However, while some evidence has suggested that eye movements are sensitive to memory representations without awareness (Ryan et al., 2000), this result has not always been replicated which means that there is currently no consensus regarding this capacity (Smith et al., 2006; Smith and Squire, 2008; 2018). A comparison of studies at the crux of this debate, including methodological differences and the approach to data analysis, may elucidate factors that have affected reported outcomes and clarify whether awareness is a requirement for the expression of eye-movement-based relational memory effects when the materials are modified scenes. Therefore, the objective of this experiment was to systematically examine a paradigm which has previously yielded discrepant results to determine whether eye movements can reveal relational memory content unavailable to awareness. In this task, participants viewed a set of scenes. Then, some of the scenes were manipulated (e.g., an object is added to or removed from a scene) and viewing directed to this modified region was compared to viewing of the same region when scenes were repeated. Here, I examined the effects of manipulation type (i.e., empty versus filled critical region) and testing instructions (i.e., indirect or incidental test instructions versus direct, recognition-based instructions) on the expression of eye-movement-based memory effects with and without awareness.

Eye Movements

Human optical physiology is organized to filter high volumes of visual stimuli in our environment and relay this sensory information to our brain for further processing. The biological structure supporting this function involves a gradient of increasing cone density from the periphery to the fovea of the retina. The greater proportion of cones in the fovea than in the periphery of the retina, and the convergence of inputs from more receptors onto a single retinal ganglion cell in the periphery than in the fovea, lead to disproportionate representation of the fovea that is continued throughout the hierarchy of the visual system (Stewart et al., 2020). That is, more optic nerve fibers, lateral geniculate nucleus, and cortical neurons are involved in processing and transmitting information about the portion of the retinal image representing the center of the visual field than the portion representing the periphery. Arising from this gradient, visual acuity is highest for information picked up by foveal photoreceptors. An implication of this feature in scene viewing is that the sharpest visual information comes only from the part of the scene that is projected onto the fovea, and therefore constrains the amount of high-quality scene data that can be processed at each moment. The visual system responds to this constraint by employing eye movements to foveate regions or objects of interest in a scene (Buswell, 1935). A fixation typically lasts between 200 to 300 milliseconds and is characterized by a halt to scene scanning while the eyes hold the foveal area of the visual field in one place with relative stability. The eye movements that rapidly shift the fovea between points of interest are commonly referred to as saccades. The term “saccade” was first coined in the context of reading, when jerking movements of the eyes were observed, combatting the notion of smooth, continuous scanning of the eyes during reading (Javal, 1878). This discovery was soon followed by examinations of saccades and fixations during picture (e.g., art depicting faces or objects) and scene viewing (Stratton, 1906; Buswell, 1935; Yarbus, 1967) as was explored in my study.

Instructional Effects on Viewing

The path traveled by the eyes (i.e., the “scan path” or spatial and temporal pattern of fixation and saccades) during scene viewing has been shown to change depending on viewing instructions (Yarbus, 1967; Borji and Itti, 2014). For instance, it has been reported that fixation characteristics (e.g., location, duration) vary according to task requirements (e.g., free viewing, targeted search) (Tatler et al., 2006). A seminal demonstration of instructional effects on visual scan paths came from a study by Yarbus (1967) in which participants viewed a painting, “The Unexpected Visitor” by I.E. Repin, under different viewing instructions (e.g., give the ages of the people, remember the clothes worn by the people, etc.). Different task instructions led to qualitatively different viewing patterns. For instance, when instructed to “give the ages of the people,” fixations clustered at six points in the image – the locations of the faces of the people in the scene. When instructed to “remember the position of the people and objects in the room,” the scan path traveled over more of the scene, and fewer fixations were observed for any specific feature or object.

The effect of instructional demands on viewing behavior reported by Yarbus paved the way for other work examining factors influencing the scene scan path. More recently, it has been reported that when comparing the viewing of naturalistic scenes under two types of instructions –

visual search and memorization – different areas were fixated (Castelhano et al., 2009). Under memorization instructions, which informed participants that a test would examine memory for specific objects in the scenes, participants viewed more regions in the scene and made more fixations throughout the scene than under search instructions to look for a specific item. During search for specific items, viewing was constrained to the parts of the scene where the target object was likely to be found, reflecting an influence of semantic knowledge for object-scene context. Despite the difference in the number and location of fixations, the duration of individual fixations remained similar between tasks. In another study, when instructions have departed from memorizing specific objects within a scene and instead emphasized overall scene memory, additional changes in fixation duration have been observed (Mills et al., 2011). Different tasks were employed with the same stimulus set and fixation durations were greater for free-viewing (i.e., participants were free to direct their eyes in any manner they saw fit) and general scene memory instructions (i.e., participants were told to memorize the scenes) compared to instructed object search (i.e., participants were to search through a scene for a small "N" or a small "Z."). These findings indicate that differences in task instructions may have contributed to the inconsistent pattern of results in studies that have addressed questions about eye-movement-based memory effects and awareness. I have addressed this in my study by comparing memory-based viewing effects when participants are not told that their memory is being tested (i.e., an indirect test of memory) and when explicit testing instructions (i.e., a direct test of memory) are given.

In addition to task instructions, the types of eye movement measures that are examined can affect reported outcomes. For instance, in the study described above by Castelhano and colleagues (2009), average fixation duration was relatively insensitive to the instructional manipulation, but there was an effect of task type on first gaze duration (i.e., the sum of all fixations made from first entry to first exit in a specified scene region). Gaze durations on objects were longer in the memory task than the search task. Because a number of studies on scene viewing have reported that fixation durations change over time within a viewing period, average fixation duration may not be the most informative measure of whether or how viewing behavior changes across instructional conditions (Unema et al., 2005; Pannasch et al., 2008; Antes, 1974). Therefore, some experiments may not have reported effects of instruction on viewing patterns because of how the data were analyzed. Several different eye-tracking measures were used in my experiment to address this concern.

Free Viewing Behavior

During free viewing conditions (i.e., instructions are simply to look at the pictures), the low-level perceptual features of a scene have been shown to guide saccade trajectory and influence fixation-based viewing behaviors. For example, features with greater complexity (e.g., more edges) or lower discriminability (e.g., due to low levels of luminance) are associated with longer fixation durations (Nuthmann, 2017; Rayner, 2009). Furthermore, research has indicated that during free viewing, the salience of visual information (e.g., color, orientation, luminance, local contrast) is positively correlated with fixation locations (Parkhurst et al., 2002; Tatler et al., 2005; Le Meur and Lieu, 2015). Citing this evidence as support, the 'saliency hypothesis' posits that in the absence of specific task instructions, gaze is directed to physically (or perceptually) salient regions of scenes distinguished by low-level features, and therefore gaze patterns can be predicted by using a 'salience map' of a complex scene (Itti and Koch, 2000; Itti et al., 1998). The effect of salience on gaze prioritization is important to consider in scene-viewing studies. Because equating scenes for physical salience is challenging, counterbalancing plays an integral role in allowing for the comparison of viewing to the same region of a scene across multiple conditions (e.g., when the scene is novel, repeated, or manipulated during test), thus ensuring that viewing effects are not due to differences in physical salience and are instead produced by the variable of interest – here, memory.

There are, however, additional factors that impact scene viewing. For example, the presence of objects in scenes also influences saccades and fixations, with increased viewing directed toward features that make up objects (i.e., more fixations made within object boundaries) than background features of a scene (Henderson, 2003; Nuthmann and Henderson, 2010; Nuthmann et al., 2020). The influence of object information on viewing behavior has important implications for my work. The addition of an object in a scene was one type of manipulation used in studies examining memory through eye movements and the corresponding role of awareness (Smith et al., 2006; Smith and Squire, 2008). However, potential differences in viewing behavior associated with adding an object versus removing one have not been examined. Instead, analyses were performed on data that was collapsed across manipulation types (object absent, object present). This approach means that any potential influence of object presence (or absence) on viewing behavior would have been missed. My experiment included more scenes so that data can be binned by manipulation type in the analyses.

Eye Movements and Memory

Semantic Memory and Viewing

As with 'saliency maps' in the discussion above, it has been posited that 'meaning maps' can be generated to predict fixation locations. In recent studies (Henderson and Hayes, 2017; Henderson and Hayes, 2018), meaning maps were generated by extracting 300 patches from 40 scenes and having participants rate each patch according to its meaningfulness (i.e., how informative or recognizable it was). By averaging and smoothing these patches across a total of 48,960 ratings, meaning maps were developed for each scene to quantify the spatial distribution of meaningful semantic content within scenes. When eye movements were recorded to these scenes, results indicated that more fixations were made to regions rated as having high meaning, and that this preferential viewing effect was evident not only for scene regions that were in close proximity to each other, but also for more distant scene regions. Additionally, although salience and meaning were highly correlated in these maps, when correlations were statistically controlled, meaning maps accounted for additional unique variance in the distribution of fixation locations in scenes. Thus, meaning, an index of semantic knowledge, appears to play an important role in the pattern of eye movements during scene viewing.

This is further supported by evidence showing that gaze may be biased towards semantically incongruent objects (Loftus and Mackworth, 1978; Henderson, Weeks, & Hollingsworth, 1999; Hollingworth and Henderson, 2000; LaPointe and Milliken, 2016). Participants make longer and more frequent fixations on objects that are surprising in a scene (semantically incongruent with scene context) compared to unsurprising objects. In a classic example, an octopus embedded in a farm scene is fixated more than a tractor presented in the same location. This effect was replicated when the critical object was added to the scene after initial scene viewing (Brockmole and Henderson, 2008). Thus, object viewing seems to be driven in part by the meaning of a scene. As with physical salience, intentional structuring of experimental materials and conditions is essential to control for the effects of meaning and object congruence within scenes, factors which were considered in the design of my experiment.

Relational Memory and Viewing

Eye movements can also reveal memory for experimentally encoded relationships among materials. Studies have typically used arbitrary, pre-experimentally unfamiliar stimulus relationships (e.g., face-scene pairs, manipulated objects within a scene) (Ryan et al., 2000; Hannula et al., 2007; Whitlock et al., 2020; Ryan and Villate, 2009). Memory has been expressed for the location (Ryan et al., 2000) or presence (Smith et al., 2006) of an object in a scene by an increased number of saccades into and fixations within the region of a scene that has been manipulated after an encoding phase. For example, when participants view a scene for the second time, and an object (e.g., lamp beside the bed) that was present during the first exposure is no longer there, participants may make an increased number of eye movements to the now empty region. In a visual search task, a preview of a naturalistic scene prior to search enhanced search performance for a target object in that scene. The scene preview provided participants with a head start, permitting them to focus more quickly during search on scene regions where the target object was likely to be located. However, there was an even larger benefit if the target object was present in the scene during the preview (even though participants did not know the identity of the target object at that point in the trial) (Hollingworth, 2009). In this case, memory for the location of the object in the scene made target detection more efficient than guidance by general semantic knowledge alone. This binding of objects to scene locations depends upon relational memory, which guides viewing behavior to the target object, resulting in more efficient search.

To examine whether memory-based viewing effects are the result of familiarity, or instead represent the retrieval of relational memory, one approach has been to create arbitrary object-scene or face-scene pairs, rather than measuring viewing of objects within scenes

(Hannula et al., 2007; Hannula and Ranganath, 2009; Whitlock et al., 2020). This allows for the separation of familiarity and relational memory effects by including displays at test which feature all previously viewed objects and only one previously paired with the scene cue. In this paradigm, at test, participants viewed a three-face display superimposed on a background scene, which had been paired with one of the faces during a prior encoding block (Hannula et al., 2007; Hannula and Ranganath, 2009). Notably, since the other two faces were familiar from encoding but had been studied with different scenes, all of the faces in the test display were familiar. The result was increased viewing of the face that had been paired with the scene context, an effect of relational memory on eye-movement behavior.

Adapting this face-scene paradigm to generate different memory strength conditions for object-scene pairs, it was observed that associate viewing during test differed according to memory strength and reported confidence (Whitlock et al., 2020). Preferential viewing of the associate increased with memory strength (i.e., when object-scene pairs had been presented twice versus once). These results indicated that in addition to revealing memory for scene-object relationships, eye movements are sensitive to the strength of relational memory representations. Importantly, participants also spent more time viewing unselected associates than other unselected objects in the display, suggesting that memory affects viewing even when recognition responses are incorrect. These memory-based viewing effects have typically been smaller than they are with awareness, but they still suggest that a memory representation has been encoded and accessed. In studies that have investigated changes to scenes, weak “unaware” effects in eye-movement behavior may be further obscured by collapsed data across different manipulation types, a potential problem addressed here.

Eye Movements and Awareness

Eye Movements are Sensitive to Visual Features that are not Explicitly Perceived

Several studies indicate that eye movement behavior is sensitive to the visual features of stimuli that are not visible to the participant because, for example, masking procedures have been used that hide the stimulus from view. Visual processing of perceptual features has been observed through eye movement behavior without reportable awareness of the features themselves (Rothkirch et al., 2012; Van der Stigchel et al., 2009; Spering et al., 2011; for review, see Spering and Carrasco, 2015). In one example, saccades were directed with greater frequency to a Gabor patch in the corner of the screen, rendered invisible with continuous flash suppression, compared to surrounding areas that were devoid of visual stimulus information (Rothkirch et al., 2012). The Gabor patches were also associated with longer fixational dwell time than empty control areas, despite participants' inability to report the presence of the Gabor patch – measured as trials in which participants selected the incorrect corner and answered "very unsure" when asked about the location of the Gabor patch following presentation.

Distraction by stimuli unavailable to awareness has also been reported, where the onset of subliminal distractors, characterized by chance levels of reporting distractor location, reliably interfered with the instructed execution of vertical eye movements to a target (Van der Stigchel et al., 2009). Interestingly, when saccades were made to the target (upwards and downwards), a task-irrelevant distractor presented in the opposite hemifield influenced saccade trajectories such that eye movements deviated away from the distractor. Eye movements have also been shown to track motion without awareness (Spering et al., 2011). To examine this, researchers presented two orthogonally drifting gratings superimposed in space, each with a different direction of motion (component motion). Together, they made a moving plaid pattern (pattern motion).

Participants reported the direction of motion according to one component motion direction, but their eye movements tracked the vector direction of the combined plaid pattern motion (a diagonal angle between the two orthogonal component motion directions). Thus, while perceptual responses followed one component motion direction exclusively, eye movements tracked the diagonal pattern motion of both gratings. This occurred despite observers' reports of not perceiving the combined pattern motion, and only perceiving the direction of a single drifting grating (either vertical or horizontal). Although this collection of results suggests that eye movements are sensitive to certain types of perceptual stimuli (e.g., Gabor patches, drifting gratings) without corresponding awareness of the stimuli, it is of interest to investigate whether and how this sensitivity extends to other stimulus features, such as emotional content.

In an experiment conducted by Vetter and colleagues (2018), eye movements were sensitive to the presence of emotional stimuli without awareness. Eye movements were consistently directed away from angry faces and toward fearful faces, despite the faces being rendered invisible using continuous flash suppression with chance-level face localization and emotion categorization. Altogether, these findings reveal distinct eye movement behavior across different levels of processing (e.g., perceptual, emotional), in the absence of awareness of the viewed stimulus or stimulus features. In each case, eye movements change in response to particular visual features (e.g., object pattern, sudden onset, motion direction), even though observers are unable to report these features. Importantly, this indicates the existence of dissociable explicit and implicit processing systems for visual stimuli and highlights the ability of eye movements to reveal these implicit processes which would remain undetected by other testing methods such as button-press or verbal responses.

Eye Movements, Memory, and Awareness

Viewing Behavior may be Sensitive to Implicit Memory Effects

With evidence indicating that eye movements can reveal perceptual processing without awareness, and that relational memory content can shape and guide viewing, it was of interest for the purpose of my study to investigate whether eye movements may also reveal memory for visual stimuli without corresponding awareness of the remembered content. Several studies have explored this possibility and produced evidence to suggest that eye movements may indeed reveal memory effects when participants have no conscious awareness of the memory content (Smith and Squire, 2017; Ryan et al., 2000; Hannula, 2010; Hannula et al., 2012; Nickel et al., 2015; Hopkins et al., 2015). Some of the earliest evidence for implicit expressions of relational memory in eye movement behavior came from the study by Ryan et al. (2000) in which participants directed a greater proportion of fixations to manipulated regions of previously viewed scenes (i.e., locations where an object was added, removed, or had change positions) than to matched regions in repeated scene where no change had occurred. This increased viewing of the manipulated region, indicative of memory for the object's relationship to the scene, was observed without corresponding awareness of the manipulation. And, by some measures (i.e., number of transitions into the critical region), this implicit effect was stronger than memory-based viewing effects with awareness. In this experiment, participants were not told that their memory was being tested. Eye-movement data were collected in two encoding blocks and an indirect test block. In each case, participants were told to study the scenes for an upcoming test. A final (direct) test of memory was completed at the end of the experiment to determine whether participants could report scene changes or not. Modified scenes were categorized as "aware" if participants correctly identified the scene as changed *and* successfully reported what had changed; remaining trials were considered “unaware”. Similar implicit memory effects have been reported for whole scenes when memory was tested indirectly (Smith and Squire, 2017). The repetition effect (i.e., fewer fixations to repeated than to novel scenes) was evident in viewing behavior even when participants made incorrect recognition responses on a direct test of memory administered after the eye-movement data had been collected. In each case, eye movement behavior revealed memory for scenes or changes within scenes, even when explicit reports of scene status or scene changes failed.

In the studies by Hannula and colleagues discussed above, preferential viewing of the face previously paired with the background scene at test was observed regardless of whether participants selected that face in recognition responses, thus also demonstrating a viewing effect despite lack of awareness for the relational memory content revealed through eye movements (Hannula, 2010; Hannula et al., 2012). Following these findings, to further probe the role of awareness by directly manipulating awareness levels, a similar paradigm was used which also paired scenes and faces during encoding. Here, scene cues prior to a three-face display at test were obscured by masking, rendering them inaccessible to conscious awareness (Nickel et al., 2015). A memory-based viewing effect was evident in time-course analyses, despite the subliminal presentation of the scene cue, and similar effects were evident following visible scene cues when faces had not been successfully identified as the paired associate. These results indicate that eye movements can reveal memory for paired associations, despite their inaccessibility to awareness. Based on these observations, I predicted that eye-movement-based relational memory effects would be evident in viewing behavior when memory was tested indirectly although, as outlined below, this effect may depend on manipulation type.

Implicit Effects of Memory on Viewing Behavior are Contested

While there appear to be numerous results showing relational memory revealed by eye movement behavior separable from conscious awareness of the memory content, a major reason for conducting my experiment was because these results have not always been replicated. With an experimental structure closely following that of Ryan et al. (2000), Smith and colleagues observed increased saccades into, and number of fixations within, the region of manipulation (region in which an object was added or removed from the scene) in previously viewed scenes. However, this effect was only evident when participants were aware of, and could describe, the manipulation that had occurred (Smith et al., 2006; Smith and Squire, 2008; 2018). This finding persisted across different task instructions – when participants were informed of an upcoming memory test prior to scene viewing (Smith et al., 2006), and when participants were simply told to pay full attention to each scene, in a free viewing condition (Smith and Squire, 2008). In another study, a set of scenes presented for viewing was followed by a multiple-choice memory test in which participants were shown three scenes (one which was previously seen, and two foils that were similar to the previously encoded scene). Participants were instructed to select the previously viewed scene from these three alternatives. Participants directed a greater proportion of viewing time to the studied scene when their choice was correct but not when their choice was incorrect (Urgolites et al., 2018), indicating an influence of memory accuracy (and awareness) on viewing.

One possibility is that conscious and unconscious memory are evident in different eye movement measures, and that these types of memory may differentially impact attention (Ramey et al., 2019). When participants searched for embedded targets in real-world scenes, conscious memory for the scenes influenced the precision of the first saccade directed toward the remembered location. In contrast, unconscious memory was shown to facilitate search following the initial saccade, by directing gaze increasingly toward the target location throughout the remainder of the search trial. Although these findings make strides to differentiate the impact of memory with and without corresponding awareness on visual search, the discrepant results for eye movement behavior within similar scene-viewing paradigms (Ryan et al., 2000; Smith et al., 2006; Smith and Squire, 2008; 2018) remain a noteworthy issue. Here, other factors such as testing instruction or manipulation type, may contribute to incompatible results. For example, although findings of eye movement differences only with awareness persisted across task instruction (e.g., whether participants knew their memory was being tested or not), evidence demonstrating the same viewing differences without awareness came only from instances in which participants were not aware that their memory was currently being tested. Thus, test phase instructions (i.e., the type of test – indirect versus direct) may be a contributing to differences in reported outcomes across studies, perhaps especially in combination with other factors, such as the type of manipulation introduced, which will be discussed further below.

Theoretical Implications

Importantly, the implications of this replication failure extend to the continued divide among theories describing the involvement of the hippocampus in long-term memory. In the above scene viewing paradigms, eye movements reflecting relational memory representations (increased viewing of manipulated regions) were observed for healthy participants, but this effect was absent in amnesic patients with bilateral lesions to the hippocampus (Ryan et al., 2000; Smith et al., 2006; Smith and Squire, 2018). Thus, results from Ryan and colleagues observing this increased viewing effect without corresponding awareness of the remembered content indicate the necessary recruitment of the hippocampus for relational memory without corresponding awareness. This suggests the usefulness of a memory theory which characterizes hippocampus-dependent memory according to the processing operations and memory representations involved, and not based on the role of awareness. Some theories, such as the relational memory theory (Cohen and Eichenbaum, 1993; Eichenbaum, 2004) and Henke's processing mode model of memory (Henke, 2010) have adopted this view. However, the declarative memory theory, which links the hippocampus specifically and selectively to conscious memory continues to be a mainstay in the literature (Squire & Dede, 2015). The divergence of these theories stems in part from the failure to replicate the findings of eye-movement-based relational memory effects without corresponding awareness, maintaining that hippocampus-dependent memory is observed only with awareness of the memory content (Smith et al., 2006; Smith & Squire, 2008; 2018). While theories of hippocampus-dependent memory may be informed by efforts to elucidate the factors underlying the divergent results from these scene viewing paradigms, my primary aim was to shed light on the relationship between eye movements, relational memory, object presence, and corresponding awareness.

Do Eye-Movement-Based Memory Effects Depend on Awareness?

There is not currently a consensus about whether, or under what circumstances, eye-movement-based memory effects might occur without awareness when materials are modified scenes. As discussed above, one study found an increased number of gaze transitions in the manipulated region of a scene compared to the matched region in a scene where no change had been applied. Notably, this increased viewing occurred at higher levels when participants were unaware of the change (i.e., either could not identify the scene as changed, or could not describe the change that occurred) (Ryan et al., 2000). However, Smith et al. (2006) found greater viewing of the changed region of scenes only when participants could report that the scene was changed and could describe the change that had occurred. Repeating the study under different viewing instructions at encoding (Smith and Squire, 2008), and binning awareness into three levels (aware, intermediate, and unaware) (Smith and Squire, 2018), the same results of memory-based viewing only with awareness were upheld. A closer look into these studies is necessary to provide insight into methodological differences that may have contributed to incompatible outcomes.

One methodological factor that may play an important role in the expression of memory-based viewing without awareness is testing instruction. Currently, no experiment has examined viewing-based memory for scene changes when indirect and direct tests are both used. This has been done in an experiment measuring the repetition effect, and importantly showed that when memory was tested indirectly (i.e., participants are not aware their memory is being tested during viewing), the repetition effect was observed for scenes regardless of whether participants could identify them as old or new (Smith and Squire, 2017). However, when memory was tested directly (i.e., participants required to give explicit recognition response after the presentation of each scene), the repetition effect was only observed in scenes that participants could correctly identify as old or new. Thus, testing instruction appears to influence the expression of memory-based viewing without awareness. Experiments investigating memory-based viewing behavior for changes within scenes have either included an indirect test (i.e., recognition responses collected in a final, separate block after viewing was recorded), or a direct test (i.e., explicit recognition responses collected after the presentation of each scene, with concurrent eye tracking). My study combined these two types of testing instructions in a single experiment to examine their effects on memory-based viewing for scene changes with or without awareness in the same participants (rather than in a between-subjects design).

The other factor I have addressed in my experiment is the type of manipulations that were used in prior studies. In the work by Ryan et al. (2000), the changes made to manipulated scenes were either the addition of a new object, the removal of an object previously present, or a left-right position shift of an object in the scene. Changes made to manipulated scenes in studies by Smith et al. (2006, 2008; 2018) were either the addition of an object or the removal of an object, with no left-right position shifts included. Manipulated scenes were subdivided for analysis based on awareness – i.e., whether or not participants can report the change – without considering whether the critical region was filled (i.e., an object was added) or empty (i.e., an object was removed). It is possible that unaware memory-based viewing effects have been obscured in reported results because analyses were not subdivided by manipulation type. One reason for this possibility is that participants may be more likely to detect the addition of a new object than the absence of a missing object. In other words, awareness may be confounded with object presence. Additionally, viewing may also be affected by manipulation type. Because studies have shown that participants look longer at objects than at empty locations (Yarbus, 1967; Nuthmann and Henderson, 2010), above-baseline viewing for aware, but not unaware, trials may be due to the presence (or not) of an object in the critical region. In my study, I have increased the number of encoded scenes so that trials can be binned not only by awareness but also by object presence or absence. This meant that scenes with a filled critical region were compared (i.e., filled aware, filled unaware, filled repeated), as were scenes with an empty critical region (i.e., empty aware, empty unaware, repeated aware). This approach permitted me to examine effects of awareness on memory-based viewing, without the potential object-presence confound that may have affected results reported by Smith and colleagues. The objective was to adjudicate between competing claims about eye-movement-based memory effects and awareness.

Method

Participants

Thirty-three individuals were recruited from the University of Wisconsin-Milwaukee (UWM) community to participate in this study in exchange for course credit. This number was based on power calculations performed with the ‘pwr’ package in R to determine an adequate sample size for my study. Power analysis was based on an effect size reported in Ryan et al. (2000; Experiment 3), d = .639 from an analysis which examined the number of eye movement transitions into and out of the critical region of a manipulated scene compared to a repeated scene when participants were unaware of the manipulation. Due to replication failures to observe this viewing effect without awareness, as well as overestimation of true effect sizes related to publication bias (Lakens, 2022), I set a medium effect size for my analysis to provide a conservative sample size requirement. Using a medium effect size (d = .5), results from a power analysis calculated using ‘pwr’ package in R indicated that a minimum sample of 33 participants would be required to achieve power equal to .80 (with alpha set to 0.05) for a paired samples t-test. Data from 5 additional participants was collected but discarded due either to failure to comply with task instructions, technical issues with the experimental software, or unreliable eye tracking data (i.e., calibration issues during the experiment). Recruitment will end when I have usable data from 48 participants (this number was selected for counterbalancing purposes). Written informed consent was obtained from each participant in accordance with the UWM Institutional Review Board prior to beginning the study.

Materials and Apparatus

Stimuli were 144 rendered color images of indoor and outdoor scenes (each 1043 x 782 pixels) generated using Punch! software (Hannula et al., 2006; Hannula et al., 2010). Each scene contained a critical object (an object that will be manipulated), and two copies of each scene were used in the experiment: one with the critical object present (filled version), and another with the critical object removed (empty version), for a total of 288 scenes. Each scene contained between 5 to 10 moveable objects, the minimum serving to reduce the probability that participants would correctly select the critical object by chance rather than from memory when previously encoded scenes had been manipulated. Furthermore, because the number of fixations made to a scene increases with the number of potentially changing objects (Zelinsky, 2001), use of this narrow range helped to ensure that the number of overall number of fixations made to each scene should be relatively well matched. Finally, all objects were semantically congruent with the scene in which they appeared, since studies have indicated that gaze can be biased toward objects that are semantically incongruent with a scene context (Loftus and Mackworth, 1978; Hollingworth and Henderson, 2000; LaPointe and Milliken, 2016).

Eye movements were recorded with an EyeLink 1000 eye tracking system (SR Research LTD: Ontario, Canada). This system has a temporal resolution of 1000 Hz and head-supported spatial resolution of .01º. Saccades were identified using an automated algorithm that requires a minimum velocity of 30º/s and a minimum acceleration of $8000º/s^2$. Samples below this threshold were labelled fixations, so fixation onset was determined by the offset of the previous saccade, and fixation offset was determined by the onset of the following saccade. The Experiment Builder and Data Viewer software packages (SR Research LTD: Ontario, Canada) were used to program the experiment and to extract the eye movement data for analysis, respectively. Button press responses were made on the screen via a mouse click and change descriptions were made verbally so that participants were not required to shift their gaze away from the screen to a keyboard while responding.

Design and Procedure

After participants had an opportunity to read and sign the consent form, and any questions were addressed, the eye tracker was calibrated using an automated process with 9 target points to map fixation locations to screen coordinates. During calibration, participants were asked to fixate a disk when it appeared in each of the respective screen locations. Provided that calibration was successful, the experiment began. Participants completed five blocks -- two encoding blocks, followed by an indirect test block, and then two direct test blocks. A 1-minute break and task instructions separated consecutive experimental blocks.

<u>Block 1 (Encoding 1):</u> Before initiating the first encoding block, participants were read the following instructions (adapted from Smith and Squire, 2008):

> "We are interested in how people look at pictures during full attention. It is important that you pay attention to each picture and remain alert. Each picture will be presented for 5 seconds. Look at the photo the entire time it is on the screen, and try to commit each one to memory, paying specific attention to the objects and their locations."

Each trial began with the presentation of a central gaze-contingent fixation cross. The fixation cross remained in view until it was fixated by the participant and then remained in view for a prescribed time of 500ms. The fixation cross was replaced with a scene subtending 18.5 by 24.5 degrees of visual angle, presented for 5 seconds (see Figure 1 for trial structure and event timing). In this first encoding block, participants saw 72 trial-unique scenes, presented in a pseudo-randomized order so that no more than 5 scenes assigned to conditions of interest (i.e., to-be-repeated, to-be-manipulated) were presented in a row. Thirty-six of these scenes were repeated, without any changes, during the test blocks, and 36 were manipulated.

Block 2 (Encoding 2): Instructions and trial events were the same for the second encoding block. During this encoding block, participants saw 108 scenes. Seventy-two of these were repeated from the first encoding block and 36 scenes were new. This set of new scenes appeared only in this encoding block and was not carried forward. Scenes were presented in a new pseudorandomized order, ensuring that no more than 5 scenes assigned to each condition (i.e., to-be-repeated, to-be-manipulated, novel) were presented sequentially.

Block 3 (Indirect Test): Procedures remained the same for the first test block. Participants were told to commit the scenes to memory, paying close attention to objects and their locations, as in the encoding blocks – memory was tested incidentally based on viewing patterns. In this first test block, participants viewed 54 scenes. Eighteen of these scenes were new, 18 were repeated, and 18 were manipulated. The critical region was filled for 9 scenes and empty for 9 scenes in each condition. When manipulated scenes included a filled critical region, a new object was added to the scene where there was previously empty space (i.e., an addition); when manipulated scenes included an empty critical region, an object was removed from the scene, resulting in an empty space where an object had previously been located (i.e., a deletion; see Figure 2). Across participants, each version of a scene (i.e., with the critical object present or not) was presented equally often in every experimental condition (i.e., novel, repeated, manipulated).

Block 4 (Direct Test 1): The same 54 scenes from block 3 were re-presented, in the same order, in block 4 so that memory for the scenes could be tested directly. Participants were given the following verbal instructions at the outset of the block (adapted from Smith, Hopkins, and Squire, 2006):

> "I am going to show you the same images that you just saw in that last block of scenes. This time you will make some decisions about what you noticed about the scenes you saw in the last block. You may have noticed that some were new, some were exactly the same as when you had seen them in earlier blocks, and some were the same, but something about them had changed. For example, if it was an outdoor scene maybe a tree was added to the image where there wasn't one there before. It could also have been that a tree was removed from the image where there was one there before. The changes will *not* be something like a shift in camera perspective or a small, minute change like a leaf on a tree".

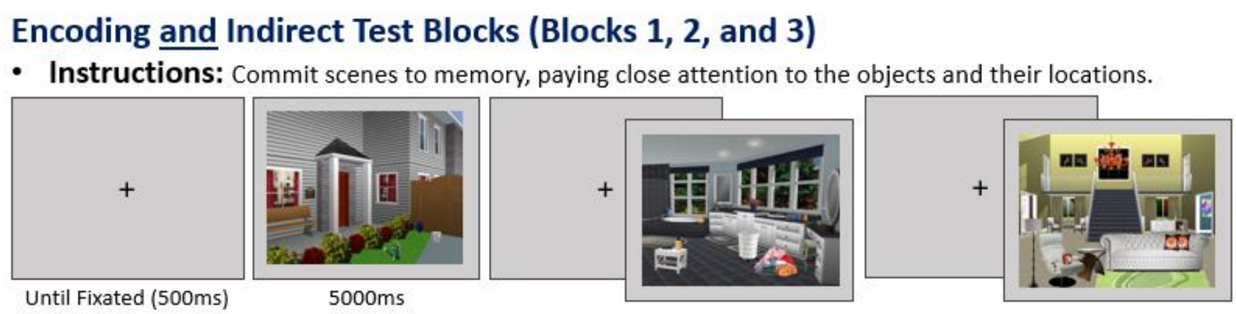
Each trial began with the presentation of a central gaze-contingent fixation cross. The fixation cross remained in view until it was fixated by the participant and remained in view for a prescribed time of 500ms. Then, a scene subtending 18.5 by 24.5 degrees of visual angle was presented for 5 seconds. Following the presentation of each scene, participants were asked to 'select the best description of the scene you just saw.' As in Smith et al. (2006), three choices appeared on screen: 'It was new', 'It was identical', or 'It was changed'. Each option had a box to its left, and participants used the computer mouse to select their answer by clicking on the corresponding box. The scene remained in view until a response was made by the participant.

If participants correctly selected 'it was changed' when manipulated scenes were presented, they were then prompted to describe the change that occurred, verbally, to the experimenter (e.g., a standing lamp was added). If the scene was manipulated, but participants failed to identify it as changed, then they were then told that the image was changed, and they were asked to try and verbally describe the change that occurred while the scene was in view. In either case, following their verbal description, the manipulated scene was presented again, exactly as it was seen in blocks 3 and 4, and participants were instructed to 'click on the location in the scene where the manipulation occurred' (procedure adapted from Smith and Squire, 2018). The scene remained on the screen until the participant made a mouse click within the boundaries of the scene at which point, the next trial began with a fixation cross in the center of the screen (see Figure 1 for trial structure and event timing).

Block 5 (Direct Test 2): Instructions and trial events were the same as in block 4 with just one exception. Rather than being told that they would make decisions about what they had noticed about the scenes presented in the preceding block, participants were told to "make decisions about the scenes presented in the current block". In this second direct test block, participants saw 54 scenes. Eighteen scenes came from the encoding blocks (blocks 1 and 2) but had not been used in blocks 3 and 4, and were repeated without a change. Eighteen scenes came from the encoding blocks but had not been used in blocks 3 and 4, and were manipulated (i.e., an object was added to or removed from the scene). An additional 18 novel scenes (not seen in any previous blocks) were presented. Participants answered the same questions as in block 4 about this new set of scenes. After completing the experiment, debriefing was provided, and participants had the opportunity to ask any remaining questions about the research.

For counterbalancing purposes, 9 individual scenes were assigned to one of 16 lists. These lists were rotated across conditions (new, repeated, manipulated), blocks, and critical region type (filled, empty). This meant that each scene was presented equally often as a "new" picture in blocks 2, 3, and 5 with a filled critical region and an empty critical region. Similarly, each scene was presented equally often as a "repeated" or "manipulated" picture in blocks 3 and 5 with filled and empty critical regions. The counterbalanced set will be used three times, to test 48 participants (here, results are reported for 33 participants) to ensure sufficient power and a fully counterbalanced design. This design ensures that across participants, each individual picture is seen equally often as repeated-filled, manipulated-filled, and novel-filled, repeated-empty, manipulated-empty, and novel-empty in both test blocks. Comparisons were made with data sorted by test type, condition, and critical region type, so that, for example, viewing directed to the critical region of manipulated scenes with a new object (i.e., manipulated-filled) was compared to critical region viewing of scenes that were repeated and always filled (i.e., repeated-filled).

A.



B.

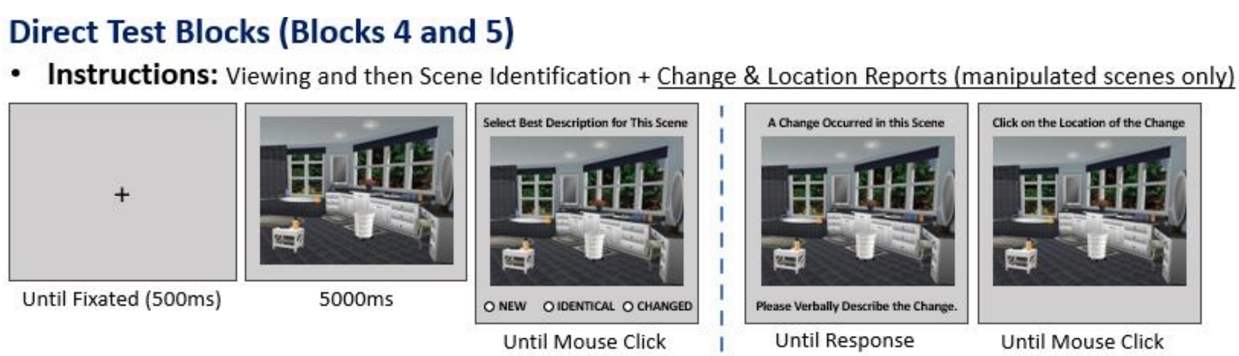


Figure 1. Illustration of trial structure and event timing. **A)** Encoding and indirect test blocks. In blocks 1, 2, and 3, each trial began with a gaze-contingent fixation cross, which, upon fixation, remained visible for 500ms. A scene was then presented for 5s. **B)** Direct test blocks. In blocks 4 and 5, following the presentation of each scene, participants were asked to select the best description of the scene in view. Once participants made their choice, the screen changed, and they were asked to verbally describe the change. Following the verbal description, participants saw the same scene and were asked to click on the location in the scene where they believe the change occurred. The next trial began with a center fixation cross.

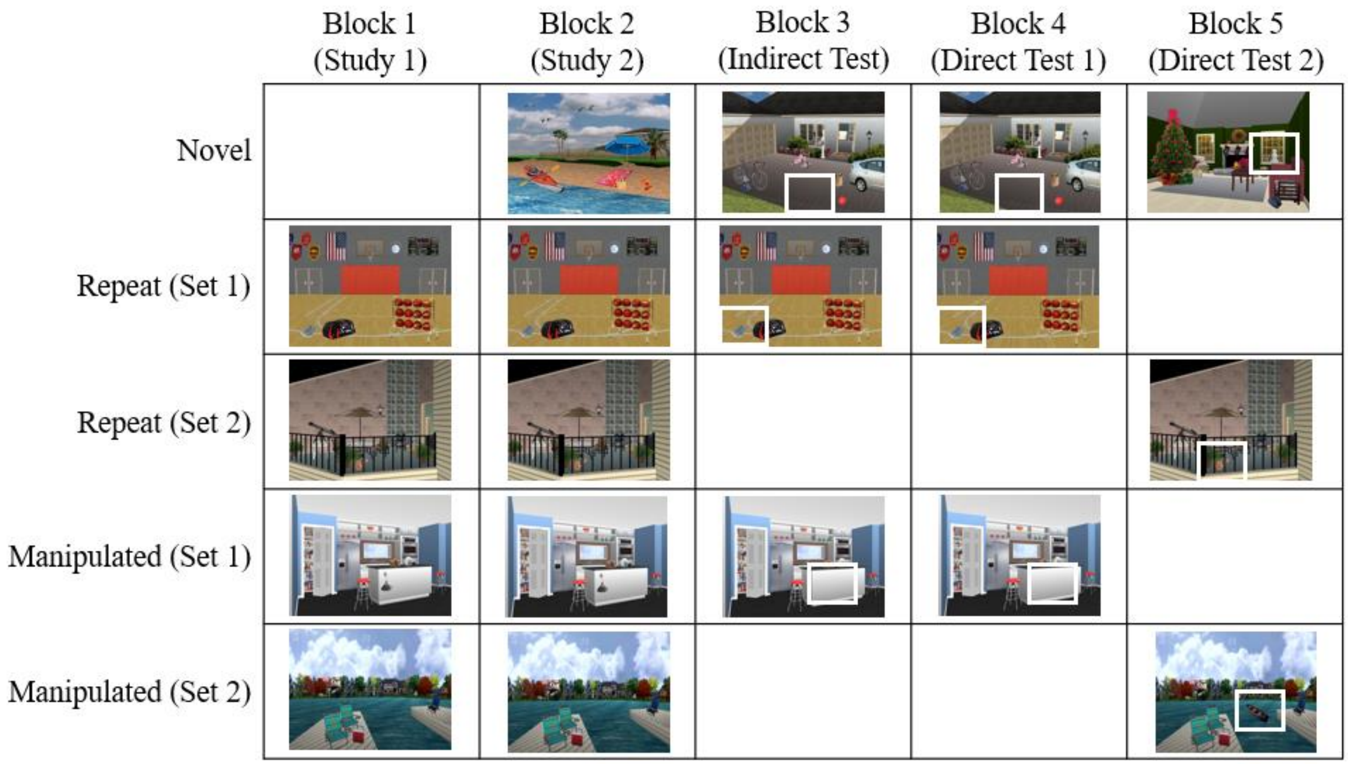


Figure 2. Schematic illustration of scenes across conditions and blocks. In the first row are novel scenes which appeared only once in a given block (with the exception of block 4, which is a repeat of the scenes in block 3). In the second row are the first set of repeated scenes, which appeared for the first time in block 1, and were repeated in the identical form in blocks 2, 3, and 4. In the third row are the second set of repeated scenes, which appeared for the first time in block 1, and were repeated in the identical form in blocks 2 and 5. In the third row is the first set of manipulated scenes, which were presented in their original form in blocks 1 and 2, and then appeared with a change made to them in blocks 3 and 4 (note, the change made here was the deletion of an object). In the fourth row is the second set of manipulated scenes, which were presented in their original form in blocks 1 and 2, and then appeared with a change made to them in block 5 (note, the change made here was the addition of an object). Blanks squares represent instances where there were no trials of a certain condition, and an illustration is non-applicable. The white box marks the critical region and was not visible during testing.

Data Processing and Analysis

Behavioral Responses

Scene identification and change specification. My **first prediction** was that changes would be more easily identified when the critical regions of *manipulated* scenes were now-filled versus now-empty. If this is the case, then awareness in published studies may have been confounded with manipulation type. To test this prediction, corrected recognition scores (i.e., manipulated hits minus manipulated false alarms) were calculated from the scene identification responses. The hit rate was the percentage of manipulated scenes correctly identified as "changed" and the false alarm rate was the percentage of repeated and novel scenes incorrectly called "changed". The corrected recognition scores were calculated separately for scenes with empty critical regions and scenes with filled critical regions, from the first (Block 4) and second (Block 5) *direct tests* of memory. This process resulted in four corrected recognition scores for each participant – i.e., empty region direct test 1, filled region direct test 1, empty region direct test 2, filled region direct test 2. A repeated-measures ANOVA was calculated with the factors AOI type (empty, filled) and test type (direct test 1, direct test 2) to examine whether successful identification of manipulated scenes was affected by these factors.

In addition to scene identification, I also examined whether AOI type affected change specification in verbal reports. Change specification was considered correct if participants reported *both* the type of change that had been made (i.e., addition, deletion) and the identity of the object. This was examined once for trials with correct scene identification decisions – i.e., manipulated scenes identified correctly as changed – and then again for trials with incorrect scene identification decisions – i.e., manipulated scenes identified incorrectly as new or repeated. In the first case, the dependent variable was the percentage of correctly identified scenes with a manipulation that *also* had correct change specification responses. These percentages were calculated separately for scenes with filled critical regions and empty critical regions and were further subdivided by test type (direct test 1, direct test 2). Next, I looked at how often participants got the verbal change specification response correct without having identified the manipulated scene correctly as "changed" (i.e., incorrect recognition trials). Recall that even if participants had made an incorrect scene identification response, manipulated scenes were re-presented, and participants were asked to specify the change. As above, these percentages were calculated separately for scenes with filled and empty critical regions, further subdivided by test type (direct test 1, direct test 2) (See Table 1 for descriptive statistics of these measures). As was done for the scene identification decision, repeated-measures ANOVAs with the factors AOI type (empty, filled) and test type (direct test 1, direct test 2) were calculated to examine whether change specification was affected by these factors.

An exploratory analysis was also conducted to examine the identification of novel scenes as a function of AOI type and test type. As above, corrected recognition scores (i.e., novel hits minus novel false alarms) were calculated from the scene identification responses. The hit rate was the percentage of novel scenes correctly identified as "new" and the false alarm rate was the percentage of repeated and manipulated scenes incorrectly called "new". The corrected recognition scores were calculated separately for scenes with empty critical regions and scenes with filled critical regions, and from the first (Block 4) and second (Block 5) *direct tests* of memory.

Eye-Tracking Analyses

The **second prediction** in this experiment was that participants would look longer at critical regions when they were filled (versus empty) and the **third prediction** was that participants would look longer at the critical regions of manipulated (versus repeated scenes), an eye-movement-based memory effect, but that these effects might be stronger when participants were aware of the change that had been made. To address these predictions, critical regions were defined for each scene and three eye-tracking measures were calculated based on viewing directed to the critical region (i.e., proportion of total viewing time, first gaze duration, number of transitions). Eye-tracking analyses were based on data from the indirect test block (Block 3) and the second direct test (Block 5). I did not look at eye-movement data from the first direct test (Block 4) because the purpose of this block was to obtain behavioral responses that could be used to back-sort eye-tracking data from the indirect test block.

Critical Regions (Areas of Interest, AOIs). Two AOIs were defined for each scene – one corresponded to the location occupied by the critical object (whether it was present in, or absent from, the scene) and the other AOI corresponded to the boundaries of the whole scene. The critical object AOI extended 20 pixels beyond the boundaries of the critical object itself (e.g., 20 pixels above the top-most part of the object, 20 pixels below the bottom-most part of the object). This means that the size of individual AOIs varied, as they were determined by the size of a given critical object (see Figure 3 for examples). The AOI surrounding the scene was always the same size because the scenes themselves had a uniform size (1043 x 782 pixels). Fixations that fell outside of the scene boundaries were excluded from data analysis and individual trials were flagged for insufficient total viewing time and removed from analyses if the time spent looking within the bounds of the scene was less than 65% of the total possible viewing time (i.e., less than 3250 ms; Hannula et al., 2010). This was done to eliminate trials where data acquisition was problematic (e.g., eye position was lost, participants were looking away from the screen). On average, 0.58 trials (SD = 1.65) were removed from analyses based on eye-tracking data from the indirect test, and 3.18 trials (SD = 5.47) were removed from analyses based on eye-tracking data from direct test 2.

Figure 3. Example areas of interest (AOIs) drawn around critical objects. The AOI (white border and space within) was used to index which eye movements were directed to the critical object within a scene. Fixations landing on the object itself or within the white border (20 pixels extending on each side of the object) were labelled as a fixation made to the critical region. AOIs were determined by the boundaries of the critical object, and therefore varied in size. Note: the white borders depicted in the figure are for the purpose of analysis only and did not appear to participants during scene presentation.

Eye-Tracking Measures. Three eye-tracking measures were calculated to examine eye-movement behavior directed to the critical regions of scenes during the indirect test (Block 3) and the second direct test (Block 5): 1) proportion of total viewing time, 2) first gaze duration, and 3) number of transitions into the critical region. The proportion of total viewing time is the total amount of viewing time (in milliseconds) directed to the critical region divided by the total amount of viewing time directed to the whole scene. First gaze duration is the summed duration (in milliseconds) of fixations within the bounds of the critical region upon first entry until a saccade is made out of the critical region to a different scene location. Finally, the number of transitions is a count of the number of saccades that crossed into the critical region for each trial. These measures may differ in their sensitivity to viewing effects with and without awareness. Measures used by Ryan et al. were the proportion of total fixations and the number of transitions into/out of the critical region; Smith and Squire (2006; 2008) reported the proportion of viewing time, the proportion of fixations, and the number of transitions into/out of the critical region. Here, I have included one additional measure, first gaze duration, based on reports that suggest this measure may be particularly sensitive to differences that are not detected in full-trial averaged data (Castelhano et al., 2009).

Viewing effects to filled versus empty critical regions. Analyses that examine the effects of item presence (versus absence) on critical region viewing were performed using repeated scenes and novel scenes, but not manipulated scenes. This was done because the critical regions of manipulated scenes were changed in Blocks 3 (indirect test) and 5 (direct test 2), so any differences in viewing directed to these regions could be contaminated by memory. Three repeated-measures ANOVAs with the factors scene type (novel, repeated), AOI type (filled, empty), and test type (indirect, direct test 2) were calculated. These contrasts address my **second prediction**, which is that more time would be spent viewing filled critical regions than empty critical regions. If this is true, then viewing effects may have been confounded with manipulation type in published studies. In this case, analyses that examine effects of awareness on eye-movement behavior should include AOI type as a variable of interest.

Memory-based viewing effects and awareness. The primary question in this experiment is whether eye-movement-based memory effects are evident when recognition responses are incorrect and AOI type is taken into account. My **third prediction** is that memory-based viewing effects would be evident with and without awareness, though the effects may be stronger when participants are aware of scene changes. Furthermore, these effects may depend on test type (i.e., indirect versus direct) as has been reported by Smith and Squire (2017) for the repetition effect. To test this prediction, I compared viewing directed to critical regions of manipulated scenes with viewing directed to the critical regions of repeated scenes using the eye-tracking measures described above. For purposes of these analyses, data from both repeated and manipulated scenes were subdivided by AOI type (empty, filled) and test type (indirect test, direct test 2). In addition, data from manipulated scenes were subdivided by awareness, into “aware” trials and “unaware” trials. Manipulated scenes were categorized as *unaware* when participants failed to identify the scene as “changed” *and* could not specify the change after having been told that there was in fact a difference (i.e., neither of these responses could be correct). This strict criterion was adopted to minimize any potential residual awareness in *unaware* trials. Two different schemes were used to classify manipulated scenes as *aware*. According to the *strict awareness* criterion, participants had to identify the scene as “changed” *and* report the change successfully. According to the *liberal awareness* criterion, scenes were classified as *aware* when participants had either one of these responses (or both of them) correct. As indicated above, change specification responses (i.e., participants’ description of the change) were considered correct if participants indicated what kind of change was made (object removed, object added) and they also named the object (e.g., the blender was added to the scene). If participants simply said an object was added or removed, but could not name the object, the change specification response was considered incorrect. Location was not examined here because these choices were frequently redundant with change specification responses when the critical region was filled (but not when it was empty). For instance, if participants identify the critical object when a manipulated scene is now-filled, they will necessarily get the location information correct because the object is visible in the scene; this is not the case when a manipulated scene is now-empty. Repeated-measures ANOVAs were calculated separately based on how awareness had been defined. In each case though, factors included in the analyses were trial type (repeated-aware, manipulated aware, manipulated-unaware), AOI type (filled, empty), and test type (indirect, direct test 1). Data from repeated scenes was collapsed as a function of accuracy.

Statistical Contrasts

All statistical tests were two-sided and p-values <0.05 were considered statistically significant. Sphericity violations were identified for ANOVAs with more than one degree of freedom in the numerator using Mauchley's test. When sphericity was violated, Greenhouse-Geisser adjusted degrees of freedom p-values are reported, and epsilons (G-Gε) are reported. Partial eta-squared (η_p^2) and Cohen's *d* were calculated as indices of effect size for the reported ANOVAs and t-tests, respectively.

Results

Behavioral Results

Manipulated Scene Identification Performance. To examine manipulated scene recognition as a function of AOI type and testing instructions, I performed a 2 (AOI type: filled, empty) x 2 (test type: direct test 1, direct test 2) repeated-measures ANOVA. As predicted, there was a significant main effect of AOI type, $F(1,32)=4.987$, $p=.033$, $\eta_p^2=.135$, where corrected recognition performance was greater for scenes with filled critical AOIs (M=28.010, SE=3.560) than for scenes with empty critical AOIs (M=18.197, SE=2.403). There was also a main effect of test type, $F(1,32)=7.302$, $p=.011$, $\eta p^2=.186$, where corrected recognition scores for manipulated scenes were higher in the second direct test (Block 5: M=28.114, SE=2.606) than in the first direct test (Block 4: M=18.093, SE=2.979). There was not an interaction between AOI type and test type, $F(1,32)=1.267$, $p=.269$ (Figure 4A).

Manipulated Scene Change Specification Performance. Whether there were differences in how frequently participants provided correct verbal descriptions of changes to manipulated scenes that had, themselves, been identified correctly as "changed" was examined with a 2 (AOI type: filled, empty) x 2 (test type: direct, indirect) repeated-measures ANOVA. There was a main effect of AOI type, $F(1,32)=60.767$, $p<.001$, $\eta_p^2=.660$, where correct scene identification and change specification were greater when an object was added to the scene (M=34.027, SE=2.665) versus removed from the scene (M=11.280, SE=1.743). There was also a main effect of test type, $F(1,32)=11.591$, $p=.002$, $\eta_p^2=.269$, where both responses were correct more often in direct test 2 (Block 5: M=26.860, SE=2.011) compared to direct test 1 (Block 4: M=18.456, SE=2.223). Finally, there was a significant interaction between AOI type and test type, $F(1,32)=24.650$, $p<.001$, $\eta_p^2=.440$. The difference between AOI types was greater for direct test 2 (Block 5) than for direct test 1 (Block 4), $t(32)=4.965$, $p<.001$, $d=.864$

Change Identification and Description Summary Statistics					
		Both Responses Correct	**Scene Identification Only**	**Change Description Only**	**Neither Response Correct**
Direct Test 1 (block 4)	**Empty**	M = 12.46 SD = 11.36	M = 19.72 SD = 16.17	M = 4.17 SD =7.70	M = 63.47 SD = 19.83
	Filled	M =26.47 SD =20.76	M =16.43 SD =13.63	M =14.44 SD =10.13	M = 42.66 SD = 21.73
Direct Test 2 (block 5)	**Empty**	M =11.03 SD =12.24	M =23.76 SD =19.25	M =3.93 SD =7.37	M = 61.28 SD = 23.09
	Filled	M =43.74 SD =21.07	M =13.94 SD =13.30	M =19.57 SD =13.60	M = 22.75 SD = 16.00

Table 1. Mean and standard deviation of the percentage of manipulated scene trials in which both scene identification (i.e., correctly called "changed") and verbal change description were answered correctly, the percentage of manipulated scene trials in which only scene identification was correct, the percentage of manipulated scene trials in which only the verbal change description was correct, and the percentage of manipulated scene trials in which neither response was correct. Statistics reported here are split by test type (direct test 1, direct test 2), and by AOI type (empty, filled).

Next, I performed a 2 (AOI type: filled, empty) x 2 (test type: direct, indirect) repeated-measures ANOVA on the percentage of manipulated scenes where the scene was not identified correctly as changed, but participants went on to correctly describe the change. As above, there was a main effect of AOI type, F(1,32)=40.292, p<.001, $\eta_p{}^2$=.561, where change specification was greater for objects added to scenes (M=17.201, SE=1.559) compared to objects remove from scenes (M=3.622, SE=1.090). However, in contrast to results reported above, there was no main effect of test type and no interaction between AOI and test type, F's≤3.000, p's≥.090.

Exploratory Analyses examining Whole Scene Recognition. To examine whether there were differences in how effectively participants could distinguish new scenes from previously presented scenes, I calculated a 2 (AOI type: filled, empty) x 2 (test type: direct, indirect) repeated-measures ANOVA using corrected recognition scores (novel hits minus novel false alarms). I predicted that novel scenes would be more difficult to identify in the first (relative to the second) direct test because these "novel" scenes were also presented in the immediately preceding (indirect test) block. Therefore, participants would have to remember whether the picture they were viewing now *had been* new in the previous test block in order to identify it correctly. There was a significant main effect of test type, F(1,32)=27.865, p<.001, $\eta_p{}^2$=.465, where corrected recognition scores were greater for novel scenes in direct test 2 (M=77.188, SE=3.421), compared to the direct test 1 (M=49.516, SE=4.846). Thus, participants were better able to identify scenes as "new" when their memory was tested in a single block, rather than when they needed to consider the status of the scene in the preceding (indirect) test block (Figure 4B). There was also a main effect of AOI type, F(1,32)=7.875, p=.008, $\eta_p{}^2$=.198, where corrected recognition scores were greater for novel scenes with empty critical AOIs (M=67.298, SE=3.515) compared to novel scenes with filled critical AOIs (M=59.406, SE=3.612), but the interaction was not significant, F(1,32)=.015, p=.905.

The effect of AOI type on novel scene identification was unexpected. My working hypothesis for this finding was that that participants may have been more likely to false alarm (i.e., call a scene "new" in error) when the scene was manipulated and included a new object. In other words, the new object may have sent a signal that participants misattributed to the whole scene, so they called the scene "new" in error. If this was true, then I would not expect to see a difference based on AOI type when novel hits were considered alone (i.e., without subtracting out false alarms). To test this hypothesis, I calculated a 2 (AOI type: filled, empty) x 2 (test type: direct, indirect) repeated-measures ANOVA using the percentage of novel hits. As above, there were significant main effects of both test type, $F(1,32)=29.931$, $p<.001$, $\eta_p^2=.468$ and AOI type, $F(1,32)=10.116$, $p=.003$, $\eta_p^2=.229$. In contrast to my prediction, the percentage of correctly identified novel scenes was still greater when the critical region was empty (M=75.516, SE=3.374) versus filled (M=68.710, SE=3.395). Thus, it appears that the reduction in performance for novel scenes with filled (versus empty) critical regions was not being driven by an increased false alarm rate to manipulated scenes that included a new object. This effect is considered further in the discussion section.

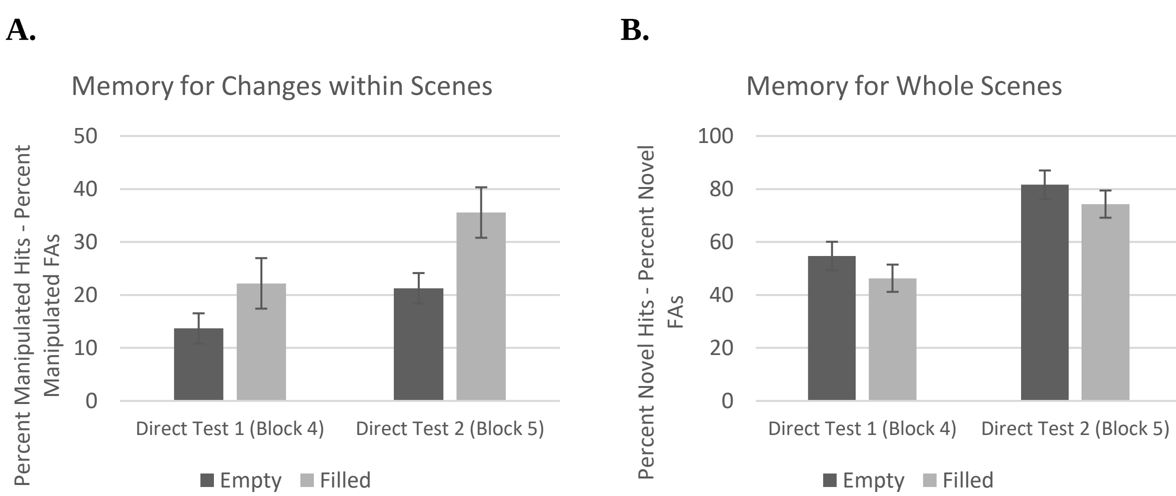


Figure 4. A) Corrected recognition scores for manipulated scenes (percent manipulated "hits" minus percent manipulated "false alarms") from blocks 4 and 5, with empty and filled AOIs. **B)** Corrected recognition scores for novel scenes (percent novel "hits" minus percent novel "false alarms") from blocks 4 and 5, with empty and filled AOIs.

Eye-Tracking Results

Viewing of Filled and Empty Regions (Novel and Repeated Scenes). To examine whether viewing distinguishes filled from empty AOIs, analyses were based strictly on viewing directed to these regions when scenes were novel or repeated (i.e., contents in the critical region had not been modified). First, I calculated a 2 (AOI type: filled, empty) x 2 (test type: direct, indirect) x 2 (condition: novel, repeated) repeated measures ANOVA on the proportion total viewing time in the critical AOI. There was a main effect of AOI type, F(1,32)=416.166 p<.001, $\eta_p{}^2$=.929, where proportion total viewing time was greater for filled critical AOIs (M=.134, SE =.005) compared to empty critical AOIs (M=.032, SE=.002) (Figure 5A). There was not a significant effect of condition or test type, and none of the interactions were significant, F's≤ 3.726, p's ≥ .062.

Results based on the duration of the first gaze into the critical AOI also produced a main effect of AOI type, F(1,32)=430.912, p<.001, $\eta_p{}^2$=.931, with greater first gaze duration in filled (M=312.657, SE=11.373) compared to empty critical regions (M=82.855, SE=4.848). Additionally, there was a main effect of test type, F(1,32)=5.693, p=.023, $\eta_p{}^2$=.151, where the duration of the first gaze into the critical AOI was greater in the indirect test (M=209.546, SE=7.949) than in the direct test (M=185.966, SE=8.787) (Figure 5B). There was not a main effect of condition, and none of the interactions were significant, F's≤3.146, p's≥.089.

Finally, looking at the number of eye movement transitions into the critical AOI, there was a main effect of AOI type, F(1,32)=574.469, p<.001, $\eta_p{}^2$=.947, where the number of transitions into the critical AOI was higher for scenes with filled critical AOIs (M=1.55, SE=.05) compared to scenes with empty critical AOIs (M=.45, SE=.02). There was also a main effect of test type, F(1,32)=11.106, p=.002, $\eta_p{}^2$=.258, where the number of transitions was greater in the direct test (M=1.09, SE=.04) than in the indirect test (M=.91, SE=.04). In contrast to results above, there was also a significant interaction between AOI type and test type, F(1,32)=4.341, p=.045, η_p^2=.119. The difference between AOI types was greater for direct test 2 (Block 5) than for the indirect test (Block 3), $t(32)=2.084$, p=.045, d=.363 Neither the main effect of condition nor any of the remaining interactions were significant, F’s≤1.298, p’s≥.263.

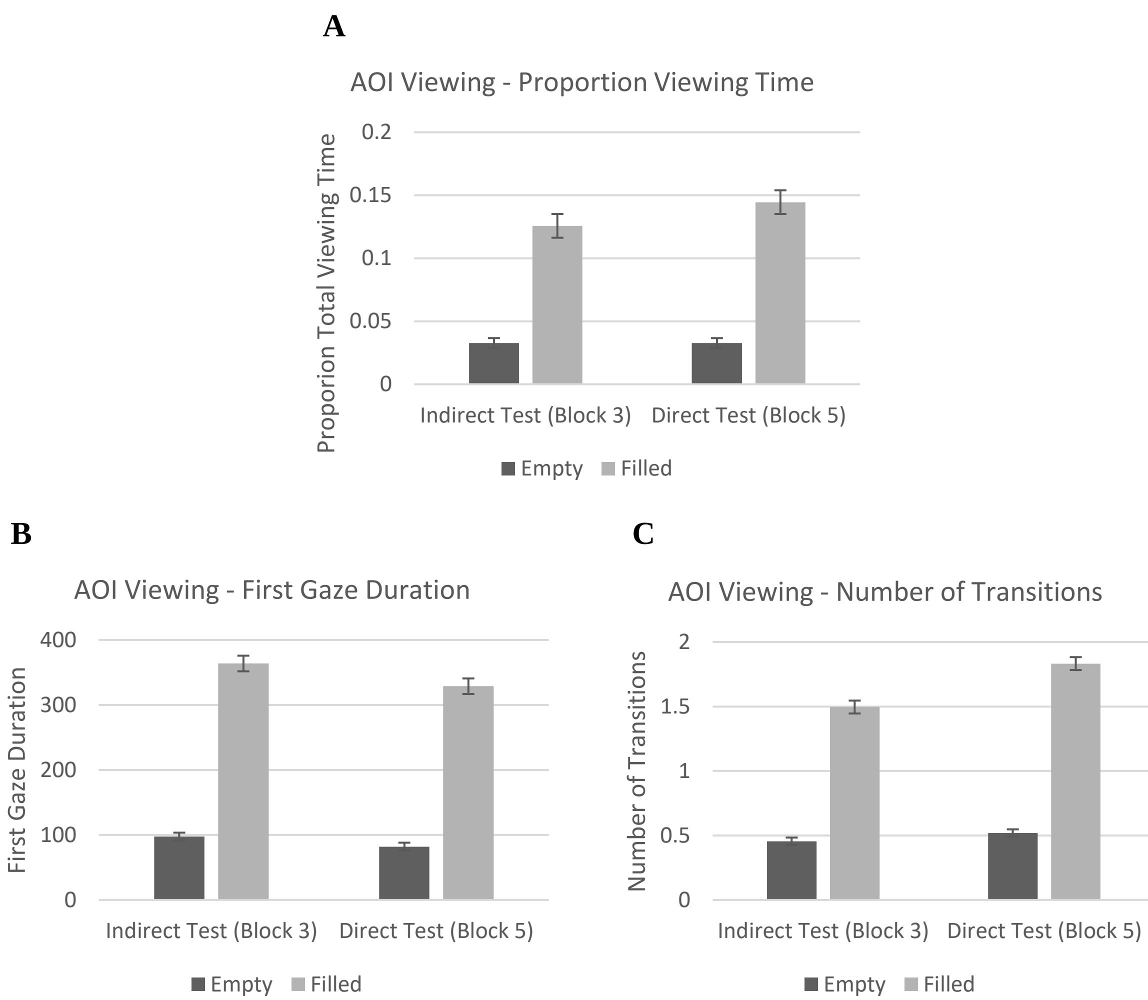


Figure 5. Collapsed across novel and repeated scene trials, eye movements recorded from blocks 3 and 5, for filled and empty AOIs**. A)** Proportion total viewing time spent in the critical AOI (viewing time in critical AOI/viewing time in whole scene AOI). **B)** Duration of first gaze into critical AOI (summation of all fixations within critical AOI in the first gaze made into the critical AOI). **C).** Number of transitions made into the critical AOI (each time gaze crossed into the critical AOI boundary).

Memory-Based Viewing of Critical Regions (Repeated and Manipulated Scenes). This last set of analyses was performed to determine whether memory-based viewing effects are evident with and without corresponding awareness, and whether unaware viewing effects depend on test type, manipulation type, or the rules that are used to categorize trials as aware or unaware. Memory-based viewing effects in these analyses are evident if participants look at the critical regions of manipulated scenes more than the critical regions of repeated scenes. Analyses were performed twice, once using a strict criterion for awareness, and again using a more liberal criterion for awareness.

<u>Strict Awareness</u>. In this first set of analyses, modified trials were considered *aware* if participants could identify the scene as changed *and* verbally describe the change that had occurred. Modified trials were considered *unaware* if both of these responses were incorrect. Sixteen participants were removed from analyses because they did not have any "aware" trials for scenes with empty AOIs (n=9), filled AOIs (n=1), or both of these AOIs (n=6). Three participants were removed because they did not have any "unaware" trials for scenes with empty AOIs (n=1) or filled AOIs (n=2). Finally, four participants were removed because they did not have any "aware" trials for scenes with empty AOIs and did not have any "unaware" trials for scenes with filled AOIs. Altogether, 23 participants were removed from the "strict awareness" analysis, which means that data from 10 participants were carried forward and included in analyses reported below. Data were analyzed using 3 different eye-tracking measures: proportion of total viewing time directed to the critical AOI, duration of the first gaze in the critical AOI, and the number of transitions into the critical AOI.

Proportion of Total Viewing Time. A repeated-measures ANOVA was calculated with the factors AOI type (filled, empty), test type (indirect, direct), and trial type (manipulated-aware, manipulated-unaware, repeated) based on the proportion of total viewing time directed to the critical AOI. Results indicated that there were main effects of AOI type and trial type, F's≥17.992, p's≤.001, η_p^2≥.667, but the main effect of test type was not significant, $F(1,9)=.489$, $p=.502$, $\eta_p^2=.052$. More time was spent looking at filled AOIs (M=.179, SE =.007) than empty AOIs (M=.046, SE=.008), and when the data were collapsed as a function of AOI type and test type, more time was spent viewing the critical regions of manipulated-aware trials than manipulated-unaware and repeated trials, *t*'s≥4.629, *p*'s≤.001, *d*'s≥1.464. There was not a significant viewing time difference to manipulated-unaware and repeated trials, $t(9)=-.980$, $p=.353$, $d=-.310$. This indicates that when AOI type (empty, filled) and test type (indirect, direct) were not considered, only an "aware" memory-based viewing effect is observed. In addition to the significant main effects of AOI type and trial type, there were significant interactions between AOI type and test type, AOI type and trial type, and a significant interaction of all three factors, F's≥=6.316, *p*'s≤.008, η_p^2≥.412. To unpack this 3-way interaction, repeated-measures ANOVAs with the factors AOI type (filled, empty) and trial type (manipulated-aware, manipulated-unaware, and repeated) were calculated separately for the *indirect test* and the *direct test.*

When data from the *indirect test* were examined, there were main effects of AOI type and trial type, F's≥6.722, *p's*≤.020, η_p^2≥.428, ε=.629. More time was spent looking at filled AOIs (M=.161, SE=.012) than empty AOIs (M=.056, SE=.014) and, as above, more time was spent looking at the critical region when participants were aware of the change (i.e., manipulated-aware) than when they were unaware or when scenes were repeated, *t*'s≥ 2.299, *p*'s≤.047, *d's*≥.772. There was not an AOI type by trial type interaction, but because my primary objective was to determine whether memory-based viewing effects are evident without awareness, planned comparisons were performed across trial types separately for the empty and filled critical regions. When the critical region was *empty*, the proportion of total viewing time to that region was greater for manipulated-aware trials than for manipulated-unaware trials, $t(9)=2.232$, $p=.045$, $d=.734$, and there was a trend for greater empty AOI viewing when participants were aware of the change versus when scenes were repeated, $t(9)=2.185$, $p=.057$, $d=.691$. There was not a significant viewing time difference between modified-unaware and repeated trials, $t(9)=.214$, $p=.835$, $d=.086$. When the critical region was *filled*, more time was spent looking at that location when participants were aware of the change than when the scene was repeated, $t(9)=3.458$, $p=.007$, $d=1.093$. In addition, and in contrast to results from the empty region, there was also a marginal difference between manipulated-unaware and repeated trials, $t(9)=2.079$, $p=.067$, $d=.658$, with more time spent in the critical region when a change had been made even though participants failed to report that change (see Figure 6A). There was not a significant difference between manipulated-aware trials and manipulated-unaware trials, $t(9)=1.545$, $p=.157$, $d=.489$.

When data from the *direct test* were examined, main effects of AOI type and trial type were observed again, F's≥17.923, p's≤.001, $\eta_p^2 \geq .666$. As above, more time was spent looking at filled AOIs (M=.198, SE=.010) than empty AOIs (M=.037, SE=.008), and more time was spent looking at the critical region when participants were aware of the change that had been made than when they were unaware or the scenes had been repeated, t's≥3.957, p's≤.003, d's≥1.251. In addition, there was a marginal difference between manipulated-unaware and repeated trials, $t(9)=2.079$, $p=.067$, $d=.658$, but now the effect went in the opposite direction. Marginally more time was spent looking at the critical region of repeated scenes than the critical region of manipulated scenes when participants were unaware. In addition to the significant main effects, there was a significant interaction between AOI type and trial type, F(2,18)=13.827, p<.001, η_p^2 = .606. Planned comparisons based on data from trials with *empty* AOIs indicated that there were no differences in proportion of total viewing time to manipulated-aware, manipulated-unaware, or repeated trials, t's≤.500, p's≥.650. When the critical AOI was *filled*, there were differences in proportion of total viewing time to the critical region across trial types. More time was directed to this region for manipulated-aware trials than for manipulated-unaware and repeated trials, t's≥3.899, p's≤.004, d's≥1.282. There was not a difference between manipulated-unaware and repeated trials, t(9)=1.675, p=.128, d=.530 (see Figure 6B).

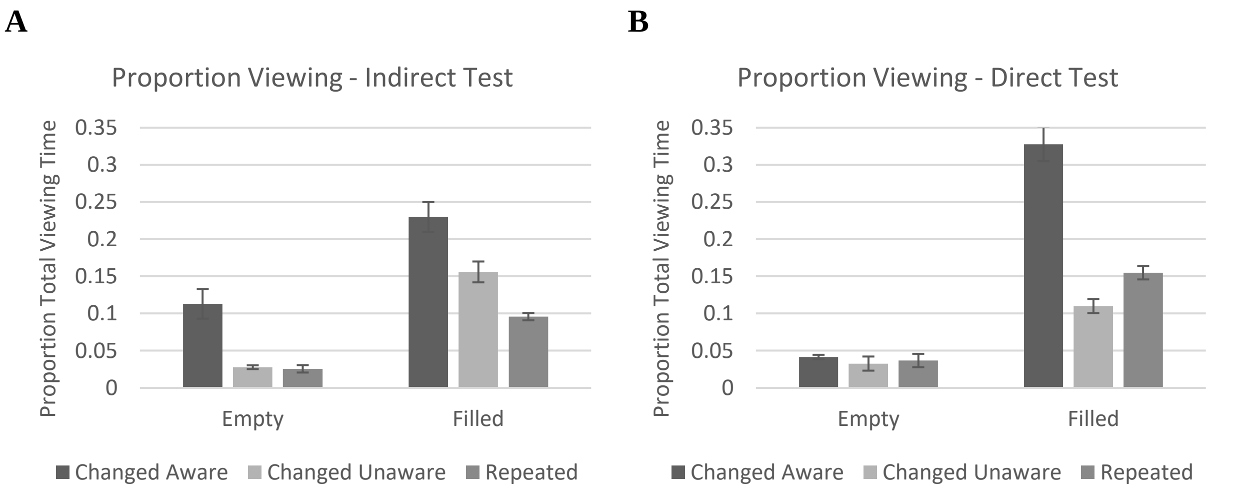


Figure 6. *Memory-based viewing with strict thresholding of awareness*. **A)** Proportion total viewing time directed into the critical region during the indirect test (block 3). **B)** Proportion total viewing time directed into the critical region during the direct test (block 5).

First Gaze. To examine whether there were differences in the duration of the first gaze to the critical region across conditions of interest, I conducted a repeated-measures ANOVA with the factors AOI type (filled, empty), test type (indirect, direct), and trial type (manipulated-aware, manipulated-unaware, repeated). There were main effects of AOI type and trial type, F's≥7.475, p's≤.004, η_p^2≥.454, but there was not a main effect of test type and none of the interactions were significant, F's≤2.231 p's≥.136. As above, for the proportion of total viewing time, the first gaze into the critical region was longer for filled AOIs (M=364.75, SE=29.18) than for empty AOIs (M=106.05, SE=20.44), and collapsed across AOI type and test type, gaze was longer for manipulated-aware trials than for manipulated-unaware and repeated trials, *t*'s≥3.798, *p's*≤.004, *d*'s≥1.201. There was not a significant difference between manipulated-unaware and repeated trials, *t*(9)=1.200, *p*=.261, *d*=.379. Additional, exploratory analyses were performed separately by test type for empty and filled regions to determine whether there were any unaware effects of memory on first gaze duration. When memory was tested *indirectly*, there was no difference in first gaze duration to empty AOIs between manipulated-aware, manipulated-unaware, and repeated trials, *t*'s≤1.551, *p*'s≥.155 (see Figure 7A). Similarly, when first gaze to filled AOIs was evaluated, there was no difference in viewing as a function of trial type, *t*'s≤1.370, *p*'s≥.204. When memory was tested *directly*, there were no differences in the duration of the first gaze to empty AOIs as a function of trial type, *t*'s≤.147, *p*'s≥.886, but when the critical AOI was filled, the duration of the first gaze was longer for manipulated-aware trials than for manipulated-unaware and repeated trials, *t*'s≥2.948, *p*'s≤.016, *d*'s≥.932, which did not differ from each other, *t*(9)=.918, *p*=.383 (see Figure 7B).

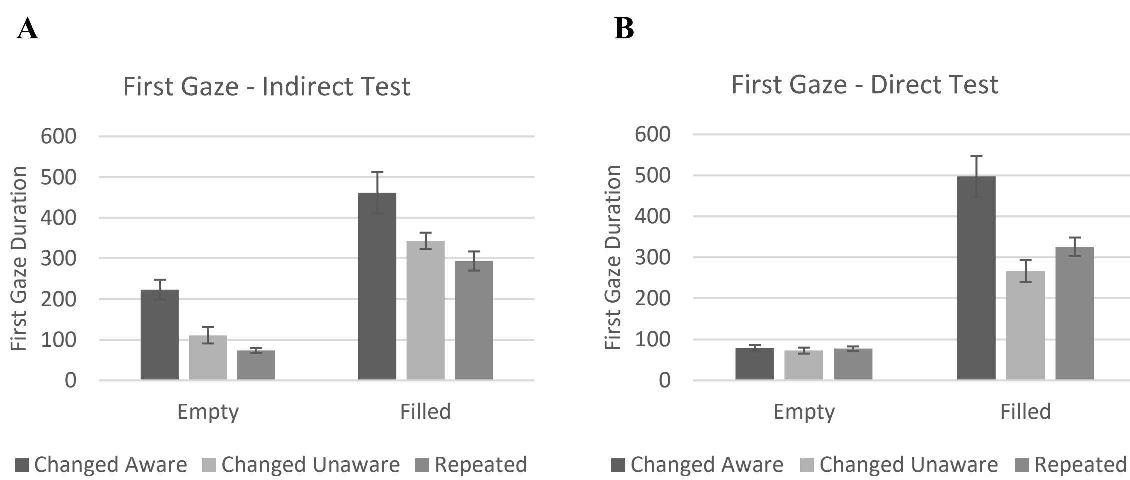


Figure 7. *Memory-based viewing with strict thresholding of awareness*. **A)** Duration of the first gaze into the critical region in the indirect test. **B)** Duration of the first gaze into the critical region in the direct test.

Transitions into the Critical AOI. The number of transitions into the critical region was the final measure that was used to examine questions about memory-based viewing when the strict awareness threshold was applied. Results from the repeated-measures ANOVA indicated that there were main effects of AOI type and trial type, F's≥17.069, *p*'s≤.001, η_p^2 ≥.655. More transitions were made into filled AOIs (M=1.861, SE=.102) than empty AOIs (M=.580, SE=.093), and more transitions were made into the critical AOIs when participants were aware of the change than when they were unaware of the change or scenes were repeated, *t's*≥4.862, *p's*≤.001, *d's*≥1.537. There was not a difference between manipulated-unaware trials and repeated trials, *t*(9)=2.220, *p*=.254, *d*=.386. In addition to the main effects, there were significant interactions between AOI type and test type, and between AOI type and trial type, F's≥4.276, *p's*≤.030, η_p^2≥.322. There was not a significant test type by trial type interaction, nor was there a significant 3-way interaction, F's≤2.674, *p*'s≥.096. Planned comparisons were performed to examine viewing time data separated as a function of test type and AOI type.

Results from the *indirect* test indicated that for the *empty* AOI there were marginal differences between manipulated-aware and manipulated-unaware trials, t(9)=2.042, p=.071, d=.646, and between manipulated-aware and repeated trials, t(9)=1.886, p=.092, d=.596. There was no difference in the number of transitions to *empty* AOIs between manipulated-unaware and repeated trials, t(9)=.237, p=.818. For the *filled* region, more transitions were made into the critical AOI of manipulated-aware trials than to repeated trials, *t*(9)=2.947, *p*=.016, *d*=.932. There were no differences between manipulated-aware and manipulated-unaware trials or between manipulated-unaware and repeated trials, *t*'s≤1.550, *p*'s≥.150 (see Figure 8A). When memory was tested *directly*, there was no difference in the number of transitions to *empty* AOIs as a function of trial type, *t*'s≤.630, *p*'s≥.530. When the AOI was *filled*, there were more transitions into the AOI for manipulated-aware trials than for manipulated-unaware and repeated trials, *t*'s≥3.595, *p's*≤.006, *d*'s≥1.137. There was no difference between manipulated-unaware and repeated trials, *t*(9)=-.623, *p*=.549, *d*=-.197 (see Figure 8B).

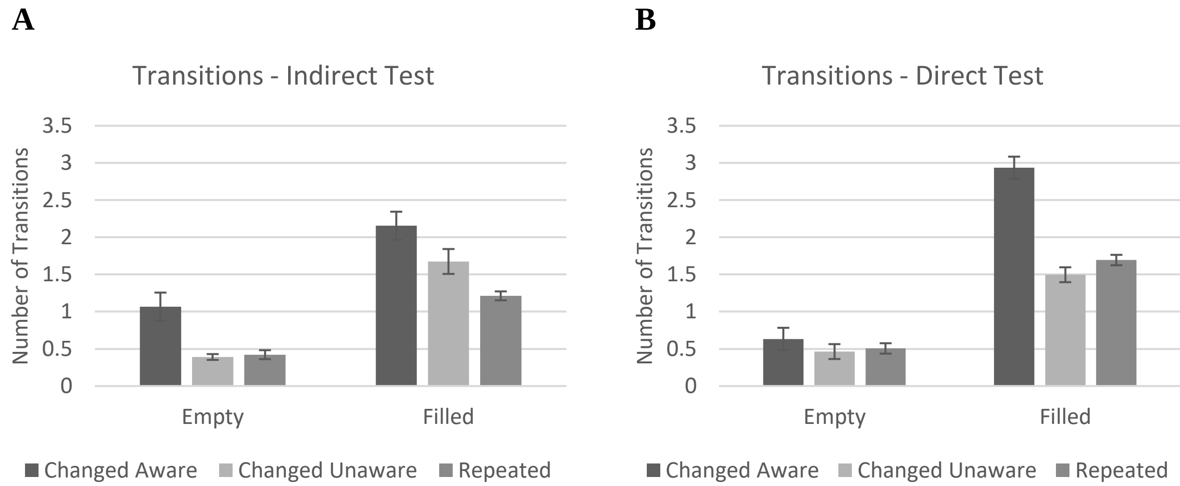


Figure 8. *Memory-based viewing with strict thresholding of awareness*. **A)** Number of transitions made into the critical region in the indirect test. **B)** Number of transitions made into the critical region in the direct test.

Liberal Awareness. In this second set of analyses, modified trials were considered *aware* if participants could identify the scene as changed *or* verbally describe the change that had occurred, or both. The classification scheme remained the same for *unaware* trials. Four participants were removed because they did not have any "aware" trials for scenes with empty AOIs. Six participants were removed because they did not have any "unaware" trials for scenes with empty AOIs (n=1) or filled AOIs (n=5). Finally, one participant was removed because they did not have any "aware" trials for scenes with empty AOIs and did not have any "unaware" trials for scene with filled AOIs. Altogether, 11 participants were removed from the "strict awareness" analysis, which means that data from 22 participants were carried forward and included in analyses reported below. As above, data were analyzed using 3 different eye-tracking measures: proportion of total viewing time directed to the critical AOI, duration of the first gaze in the critical AOI, and the number of transitions into the critical AOI.

Proportion of Total Viewing Time. A repeated-measures ANOVA was calculated with the factors AOI type (filled, empty), test type (indirect, direct), and trial type (manipulated-aware, manipulated-unaware, repeated) using the proportion of total viewing time directed to the critical AOI. As for the strict awareness criterion, there were main effects of AOI type, $F(1,21)=297.096$, $p<.001$, $\eta_p^2= .934$, and trial type, $F(1.377,28.927)=15.490$, $p<.001$, $\eta_p^2= .424$, $\varepsilon=.690$, but the main effect of test type was not significant, $F(1,21)=.521$, $p=.459$, $\eta_p^2=.060$. More time was spent looking at filled AOIs (M=.153, SE=.008) than empty AOIs (M=.041, SE=.004), and when the data were collapsed as a function of AOI type and test type, more time was spent viewing the critical regions of manipulated-aware trials than manipulated-unaware and repeated trials, t's$\geq$5.410, p's$\leq$.001, d's$\geq$1.153. There was also greater viewing for repeated compared to manipulated-unaware trials, $t(21)=2.231$, $p=.037$, $d=.476$. Thus, once again, when AOI type (empty, filled) and test type (indirect, direct) were not considered, only an “aware” memory-based viewing effect is observed.

In addition to the main effects, there were significant interactions between test type and trial type, and a significant 3-way interaction, F's$\geq$=4.440, p‘s$\leq$.018, $\eta_p^2\geq.340$. To unpack the 3-way interaction, repeated-measures ANOVAs with the factors AOI type (filled, empty) and trial type (manipulated-aware, manipulated-unaware, and repeated) were calculated separately for the *indirect test* and the *direct test.* When data from the *indirect test* were examined, there were main effects of AOI type and trial type, F's$\geq$4.622, p's$\leq$.015, $\eta_p^2\geq.180$, $\varepsilon= .716$, and there was a marginal AOI type by trial type interaction, $F(2,42)=2.712$, $p=.078$, $\eta_p^2= .114$. As above, follow-up comparisons were performed across trial types separately for the empty and filled critical regions. When the critical region was *empty*, there was no difference in proportion of viewing time between aware, unaware, and repeated trials, t's≤1.160, p's≥.260. When the critical region was *filled*, more time was spent looking at that location when participants were aware of the change than when they were unaware or when the scene was repeated, *t*'s≥2.449, *p*'s≤.029, *d*'s≥.499. There was no difference between unaware and repeated trials, $t(21)=1.257$, $p=.223$, $d=.268$ (Figure 9A).

When data from the *direct test* were examined, main effects of AOI type and trial type, and an interaction between AOI type and trial type were observed, F's≥22.468, *p's*≤.001, $\eta_p^2 \geq .517$. Planned comparisons based on data from trials with *empty* AOIs indicated that there were no differences in proportion of total viewing time to manipulated-aware, manipulated-unaware, or repeated trials, t's≤.680, p's≥.500. When the critical AOI was *filled*, more time was spent looking at that region for manipulated-aware trials than for manipulated-unaware and repeated trials, *t*'s≥5.448, *p's*≤.001, *d's*≥1.162. More time was also directed to that region for repeated trials than for manipulated-unaware trials, $t(21)=3.406$, $p=.003$, $d=.726$ (see Figure 9B).

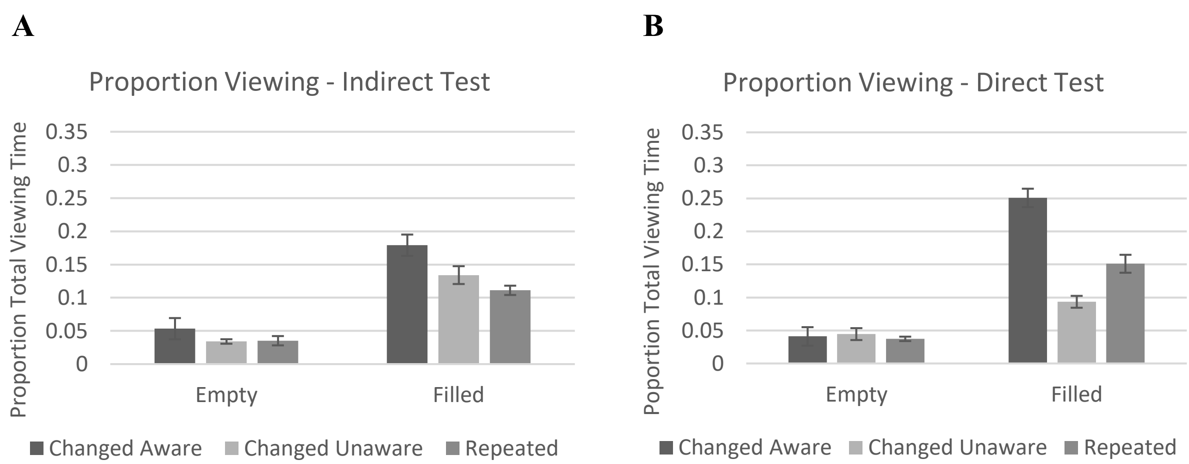


Figure 9. *Memory-based viewing with liberal thresholding of awareness*. **A)** Proportion total viewing time in the critical region in the indirect test. **B)** Proportion total viewing time in the critical region in the direct test.

First Gaze. When first gaze was the dependent measure, results from the omnibus repeated-measures ANOVA indicated that there were main effects of AOI type and trial type, as well as a significant interaction between AOI type and trial type, and a three-way interaction, F's≥8.440, *p*'s≤.003, η_p^2≥.290, ε=.751. The main effect of test type, and the remaining interactions were not significant, F's≤1.168, *p's*≥.292, η_p^2.≤053.

Because there was a three-way interaction, I followed up with 2 (AOI type: empty, filled) x 3 (trial type: manipulated-aware, manipulated-unaware, repeated) ANOVAs for the indirect and direct tests separately. When data from the *indirect* test were considered, there was a main effect of AOI type, F(1,21)=88.355, p<.001, η_p^2= .808, where first gaze duration was greater within filled AOIs (M=358,534, SE=21.975) compared to empty AOIs (M=107.052, SE=18.623), but there was not a main effect of trial type or an interaction between AOI type and trial type, F's≤3.000, *p*'s≥.060). Planned comparisons based on data from trials with *empty* AOIs indicated that there was no difference in first gaze as a function of trial type, t's≤.1.199, p's≥.244. For *filled* AOIs, there was greater first gaze duration toward the critical region for aware compared to repeated trials, *t*(21)=2.242, *p*=.036, *d*=.478, there was a marginal difference between aware and unaware trials, *t*(21)=1.953, *p*=.064, *d*=.416, and there was no difference between unaware and repeated trials, *t*(21)=.606, *p*=.551 (Figure 10A).

In the *direct* test, there were main effects of AOI type and trial type, as well as a significant interaction of these factors, F's≥10.052, p's≤.001, η_p^2≥.342. There were no differences in first gaze duration between manipulated-aware, manipulated-unaware, and repeated trials for *empty* AOIs, *t'*s≤1.350, *p'*s≥.190. For *filled* AOIs, first gaze duration was greater for manipulated-aware trials compared to manipulated-unaware trials and repeated trials, *t's*≥5.745,

p's≤.001, d's≥1.225. There was no difference between repeated and manipulated-unaware trials, $t(21)=1.862$, $p=.077$, $d=.397$ (Figure 10B).

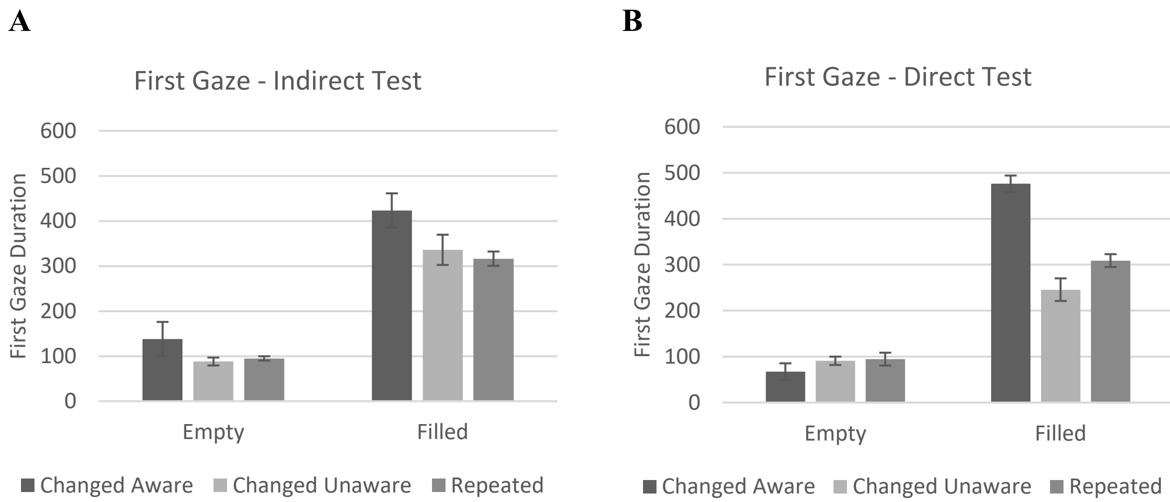


Figure 10. *Memory-based viewing with liberal thresholding of awareness*. **A)** Summed duration of the first gaze in the critical region in the indirect test. **B)** Summed duration of the first gaze in the critical region in the direct test.

Transitions into the Critical AOI. The final analysis examined the number of transitions into the critical region when the liberal awareness criterion had been applied to the data. Results from the repeated-measures ANOVA indicated that there were main effects of AOI type, test type, and trial type, F's≥6163, p's≤.006, $\eta_p^2 \geq .304$. More transitions were made into filled AOIs (M= 1.620, SE=.069) than empty AOIs (M=.530, SE=.046), and the number of transitions into critical AOI was greater in the direct test (M= 1.182, SE=.054) than in the indirect test (M=.960, SE=.067). There were a greater number of transitions directed toward the critical region for aware trials compared to unaware and repeated, t's≥3.130, p≥.002, d≥.648. There were also significant interactions between AOI type and test type, between AOI type and trial type, as well as a 3-way interaction between these factors, F's≥4.140, p's≤.023, $\eta_p^2 \geq .168$.

Because there was a three-way interaction, I followed up with 2 (AOI type: empty, filled) x 3 (trial type: manipulated-aware, manipulated-unaware, repeated) repeated-measures ANOVAs for the indirect test and the direct test separately. For the *indirect* test, there was a main effect of AOI type, $F(1,21)=186.254$, $p<.001$, $\eta_p^2= .899$, where first gaze duration was greater within filled AOIs ($M=1.450$, $SE=.096$) compared to empty AOIs ($M=.474$, $SE=.055$). There was not a main effect of trial type, or an interaction between AOI and trial type, F's≤ 2.150, p's$\geq .130$ (Figure 11A). Planned comparisons based on data from trials with *empty* AOIs indicated that there was no difference in the number of transitions as a function of trial type, t's$\leq .403$, p's$\geq .691$. For *filled* AOIs, there was a greater number of transitions for aware compared to repeated trials, $t(21)=2.416$, $p=.025$, $d=.515$. Neither of the other comparisons were significant, t's≤ 1.168, p's$\geq .256$.

In the *direct* test, there were main effects of AOI type and trial type, as well as an interaction between AOI and trial type, F's≥ 6.458, p's$\leq .004$, $\eta_p^2 \geq .235$. There were no differences in the number of transitions to *empty* AOIs between trial types, t's$\leq .830$, p's$\geq .410$. There was a greater number of transitions made to *filled* AOIs for manipulated-aware trials compared to manipulated-unaware trials and repeated trials, t's≥ 3.452, p's$\leq .002$, d's$\geq .736$. Marginally more transitions were made to *filled* AOIs for repeated trials compared to manipulated-unaware trials $t(21)=2.026$, $p=.056$, $d=.432$ (Figure 11B).

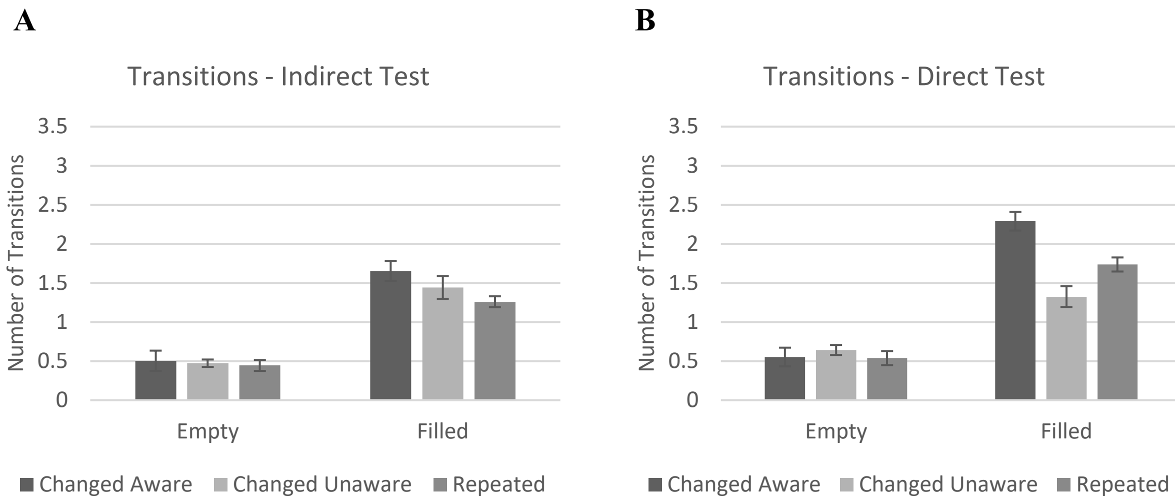


Figure 11. *Memory-based viewing with liberal thresholding of awareness*. **A)** Number of transitions made into the critical region in the indirect test. **B)** Number of transitions made into the critical region in the direct test.

Discussion

The overall aim of this investigation was to determine whether recognition performance, eye-movement behavior, and eye-movement-based memory effects are influenced by test type (i.e., instructional manipulations) and AOI type (i.e., whether a critical scene region is filled or empty). Results indicated that recognition performance was better when the critical regions of modified scenes were filled and when the direct test did not follow a corresponding indirect test of memory, that eye movements are attracted disproportionately to filled scene locations, and that eye-movement-based memory effects are evident across test types, but are particularly strong when a new item has been added to (versus removed from) a scene. In addition, one result hints at the possibility that eye movements are sensitive to scene changes without awareness, but because performance was so variable, and several participants were dropped from analyses due to awareness thresholding, this outcome was marginal and likely underpowered. Each of these observations will be discussed in more detail below.

Modified scenes were more often recognized correctly as “changed” and new scenes were more often identified as “new” on the second direct test of memory. Performance on the first direct test of memory may have been compromised because there was potential for source confusion. All of the pictures had been seen already in the indirect test, so decisions about whether a scene was “new” or “changed” had to be made based on its status in the preceding (indirect) test block. This repeated exposure to new and modified scenes may have resulted in interference and source memory errors (i.e., an increase in the likelihood that novel scenes and manipulated scenes would be called “repeated” in error). Identification of manipulated scenes as “changed” might also have been better in direct test 2 because of differences in task instruction. In the second direct test, participants knew that they would be asked to identify each scene as identical, changed, or new immediately after it was presented. Additionally, they now knew that they would also be asked to identify the change if the scene had in fact been manipulated, which meant that they would actively look for, and pay close attention to, potential changes, thus making it more likely that they would be able to report them. That this is so is indicated by the increase in the number of gaze transitions into the critical region in the second, relative to the first, direct test of memory.

In addition to differences in recognition performance across tests, participants were better able to identify scenes as changed, and to report the change, when the critical scene location was “now filled” (i.e., there was a new object in the scene). Change specification performance was best when participants had correctly identified the scenes as changed, and was especially strong in the second direct test. This may be the case because due to knowledge about the task requirements (i.e., that they would have to indicate exactly what had changed if scenes were manipulated), participants intentionally committed any changes they found to memory. Change specification was also correct more often if the critical region was now-filled when scenes had not been identified correctly as changed. It may be the case here, that if participants were told there was a change, and they did not know what the change was, they would be more likely to say that something was added to the scene than to say that something was deleted. Because the scene was visible while they were making this response, they might then go on to choose the correct item, by chance, some of the time, a strategy that was unavailable when an object had been removed from the scene. If this is correct, and participants were guessing, it is not surprising that there was no effect of test type in this case. Alternatively, it is possible that participants really were more accurate for filled regions because when they learned that an error was made (i.e., they had not identified the scene correctly as “changed”), they could compare visible objects in the scene to memory; this may have been more difficult to do when an object was removed because there was no basis for comparison in the scene itself. Exactly what is driving this difference is something to investigate in future work (e.g., perhaps by collecting confidence judgements). Nevertheless, these recognition results were in line with my hypothesis that changes would be reported more often when they involved the addition of a new object than when they involved the removal of an object. While this may seem intuitive, previous studies like mine have not examined the effects of object presence on awareness. Here, results suggest that awareness can be confounded with manipulation type.

As indicated briefly above, participants distinguished new from old (i.e., repeated and manipulated) scenes more effectively when the scenes had not been presented previously in an indirect test block. This has been reported before (Smith and Squire, 2017), and is likely due to the fact discussed above in which re-presenting a block of scenes for the purpose of collecting recognition responses effectively tested participants’ source memory, which is generally associated with lower performance than item memory (Yonelinas, 1999; Guo et al. 2021). In addition to being better able to distinguish new from old scenes in direct test 2, participants performed better when there were fewer objects in the scene (i.e., the critical region was empty rather than filled). I had proposed that this effect of AOI type on novel scene discrimination may have been driven by an elevated false alarm rate to manipulated scenes with new objects. However, separate examination of the hit rate indicated that this could not explain the pattern. Why exactly an extra object in a novel scene makes recognition more difficult is not clear, although (interestingly) the same pattern is evident for repeated hits. Participants are more likely to identify repeated scenes correctly when the critical region is empty versus filled. So, there may be a general processing cost associated with the number of items in the scene. This turns into a benefit when participants are attempting to determine whether something in a scene has changed (i.e., the pattern reverses, so that performance is better when an additional, new object is present in the scene). This result may also be explained, to some extent, by memory load. During encoding, there are fewer objects to encode in scenes that will have an object added to them at test. The differential effects of object additions versus deletions on scene memory is something to investigate in future work.

In addition to the effects of AOI and test type on recognition memory, I was interested in how these factors influence general patterns of viewing. Observations indicating that instructions affect viewing patterns were made very early on in the eye-tracking literature by Yarbus (1967). Since this time, studies have indicated that eye-movement behavior is affected by what participants have been instructed to do during encoding and at test (Buswell, 1935; Castelhano et al., 2009). Here, I used two different types of tests, with different instructional manipulations while eye movements were recorded. In the indirect test, participants were instructed to "commit each scene to memory, paying close attention to the objects and their locations within each scene", whereas in the direct test after the presentation of each scene participants were asked to identify the scene as “new”, “identical” or “changed” and if it was changed, to verbally describe the change that occurred and click on the location of the change. As in past studies, these instructions affected eye-movement behavior. There was an interesting difference based on the type of testing instruction for first gaze duration and the total number of transitions into the critical region. First gaze duration to the critical region was longer in the indirect test than in the direct test, likely because participants were actively searching for a change in the direct test, and so their gaze moved away more quickly from a given object in service of that objective, especially at the start of the trial (e.g., there was no effect of test type on the overall proportion of viewing time). In contrast, more transitions were made in the direct test than in the indirect test. Again, this may be a consequence of active search for a change in the direct test when participants knew (or suspected that) a scene was old. The number of transitions into the critical region in the direct test was even greater when an object was present in that location, likely because sampling the objects was more informative than sampling empty space. This outcome maps onto recognition performance, which indicates that changes were detected more often when the critical region of manipulated scenes was now-filled. It would be interesting to see whether changes in instruction, encouraging participants to pay attention not only to the objects but to the empty spaces, affect this outcome and drive performance up when the critical region of manipulated scenes is empty.

By all measures (i.e., proportion viewing time, first gaze duration, number of transitions), and across test types, viewing was directed disproportionately to filled over empty regions. This finding is in line with previous work showing that preferential viewing is observed for objects over background (Buswell, 1935; Henderson, 2003; Yarbus, 1967). Demonstration of preferential viewing toward critical regions filled with objects is important because there is now clear evidence from my work that critical regions filled with an object are associated with both better change recognition, and greater critical region viewing (in the absence of a change – i.e., when scenes are novel or repeated). Therefore, manipulation type (i.e., object additions, deletions), awareness, and viewing effects are associated and may have been confounded in previous studies that have collapsed across AOI type. Consequently, taking manipulation type into account is a necessary step for the analysis of memory-based viewing as a function of awareness.

Several studies have shown that eye movements are sensitive to memory for item-scene relationships, even without awareness of these relationships (Hannula and Ranganath, 2009; Nickel et al., 2015; Ryan et al., 2000). However, other findings have indicated that these viewing effects are expressed exclusively with awareness (Smith et al., 2006; Smith and Squire, 2008; 2018). I have systematically addressed the relationship between testing instructions, manipulation type, and different definitions of awareness to adjudicate between these conflicting accounts. Measuring memory-based viewing directed to the critical region of manipulated scenes (compared to repeated scenes) showed several interesting eye movement behaviors. By all measures, viewing was directed disproportionately to filled over empty critical scene regions. In addition, by all measures, aware trials received greater viewing to the critical region than unaware and repeated trials when data were collapsed by test type and AOI type. In other words, there was no evidence for unaware memory-based viewing effects in the collapsed analyses, as has been reported by Smith et al. (2006; 2008; 2018).

When data were subdivided by AOI type, and the critical region was empty, there were frequently no differences in viewing across trial types, although there were exceptions to this rule. For instance, when memory was tested indirectly, greater viewing toward the empty critical region for aware scenes than for unaware or repeated scenes was evident in some measures. It is possible that uncertainty about changes that entailed the *removal* of an object resulted in additional exploration of the objects that *were present* in scenes when memory was tested directly. When the memory test was indirect, there was no reason to engage in this active checking behavior. The absence of unaware effects on viewing behavior may be a consequence of the encoding demands of this particular experiment (participants needed to encode 144 scenes over the course of the experiment). Some of the trials categorized as "unaware" may never have been encoded. Examining viewing during encoding may help, as this will permit me to distinguish scenes where the critical (i.e., to-be-removed) object was never viewed or viewed for relatively short periods of time from those where the critical object was viewed for longer periods of time. Memory-based viewing differences directed to now-empty critical regions may then emerge in the indirect test for trials with higher levels of critical object viewing during encoding. A final potential factor that may contribute to the lack of memory-based viewing without awareness for empty critical regions under the indirect testing condition was our experimental task instructions at encoding and in the indirect test. Participants were told to "pay close attention to the objects and their locations within the scene." These instructions were used to improve memory performance, which was extremely low in pilot testing when participants were simply instructed to "pay full attention to each scene while it is one the screen." While the modified instructions did improve recognition performance, they also would have biased participants to look at the objects, perhaps at the expense of viewing locations that were now-empty in the indirect test. Thus, instructions may have led to a reduced "aware" memory effect on the indirect test and the absence of an "unaware" memory effect. It would be worthwhile to conduct a follow-up study with fewer to-be-encoded scenes with instructions that emphasize free viewing to see whether this makes a difference.

Examining the number of transitions made into the critical region of a scene, previous results showed a memory-based viewing effect for unaware trials, at a higher rate than for aware trials when memory was tested indirectly (Ryan et al., 2000). I did not find a similar memory-based viewing effect for unaware trials for the number of transitions made into the critical region of a scene. One possibility is that this difference reflects how "unaware" trials were defined. In my experiment, trials were only called "unaware" when the scene was not correctly identified as "changed" *and* the participants could not describe the change. In the study conducted by Ryan et al., trials in which participants got either the scene identification or the change description incorrect (and the other answer correct) were defined as "unaware" trials. Therefore, it is possible that some residual (or low-level) awareness was contributing to "unaware" viewing effects. That said, this difference across studies could also be due to the types of manipulations that were used. Ryan et al., included left-right position changes in addition to object additions and deletions. This may have driven exploration between the location where the object had been previously, and the object's new location after the change up, resulting in a greater number of transitions across the critical region boundary, even when participants ultimately failed to identify or report the change.

In my study, there was a marginal effect of unaware memory on the proportion of total viewing time directed to the critical region when that region was filled, and memory was tested indirectly. In addition, there were numerical trends in this direction for other measures. Because strict awareness thresholding reduced the sample size to 10 participants, and liberal awareness thresholding reduced the sample size to 22 participants, these analyses are currently underpowered. It is possible that with more power, this marginal effect (and other numerical trends in the data) will become significant. If so, then this finding will provide important evidence that eye movements can reveal memory for changes within scenes without awareness, replicating previous claims for these effects (Ryan et al., 2000). This would also further confirm how important it is to subdivide data by manipulation type when efforts are being made to examine the relationship between memory-based viewing effects and awareness (Smith et al., 2006; Smith and Squire, 2008; 2018).

Under direct testing instructions, a different pattern of memory-based viewing emerged. For instance, there were no memory-based viewing effects when critical regions were empty. One possibility is that when participants knew they would need to identify the scene, and describe (or attempt to describe) the change if scenes were modified, they continued to search for a change. If this kind of strategy was in play, it would bias viewing away from empty critical regions, and toward the objects that were present, even when participants went on to correctly identify the change (i.e., the object that had been removed). The interaction between AOI type and test type, where a greater number of transitions were made to filled AOIs in the direct test compared to the indirect test may support this view.

Differences as a function of test type that I have observed here are consistent with what has been reported previously in a study that examined the repetition effect (Smith and Squire, 2017). In that experiment, the repetition effect was observed without awareness when memory was tested indirectly (participants were unaware their memory was being tested), but when memory was tested directly, the repetition effect was only observed for scenes that were correctly identified as “repeated”. My work suggests that the same outcome may apply to the identification of scene changes, although as discussed above, results are currently marginal and the analyses are underpowered. If these effects are significant when more participants are tested, results would be consistent with claims that eye movements are sensitive to changes in the relationships amongst scene elements without awareness. Because these viewing effects depend on the integrity of the hippocampus (Ryan et al., 2000; Smith et al., 2006; Smith and Squire, 2018), this outcome would also be consistent with claims that the role of the hippocampus has more to do with relational memory processing and representation than awareness (Cohen and Eichenbaum, 1993; Eichenbaum, 2004; Henke, 2010).

There are several limitations associated with my study. First and foremost, results that examine awareness are underpowered because so many participants needed to be removed from analyses based on awareness thresholding criteria. This is an important issue, as there were numerical differences in several eye-tracking measures between unaware and repeated trials (especially when memory was tested indirectly, and the critical region was filled). In addition, the task may have been too difficult, especially when critical scene regions were manipulated and now-empty. This was predicted, but I had not anticipated that so many participants would fail to identify any of these changes. Importantly, a major difference between my study and previous investigations was the number of scenes that were used; this was a necessary aspect of my design, so that there would be at least 9 trials in each condition of interest, but when data were subdivided by awareness, the number of trials in each bin was further reduced. In the future, the design may need to be further modified (e.g., a between-subjects design, with test type as a between-subjects factor, avoiding the use of novel scenes during encoding) to make the task easier. Future studies might also use different instructions at encoding and for the indirect test to encourage free-viewing behavior. In this case, participants might not be as biased to look specifically at the objects in scenes. Finally, it would be worthwhile to include left-right position shifts in the paradigm to see whether this kind of change is contributing to some of the differences in viewing behavior that have been reported in previous studies.

CONCLUSION

The present study used a scene viewing paradigm to examine potential influences of manipulation type and testing instruction on the observation of memory-based viewing behavior, with and without awareness. My results showed that recognition of scene changes was better when objects were added to scenes, compared with when objects were removed from scenes, and that greater viewing was directed toward objects than toward empty space within a scene. Finally, my results showed that when memory was tested indirectly, and the critical region was now-filled, there was a trend for unaware memory-based viewing effects. These results indicate that manipulation type and testing instructions are important factors that should be considered separately in studies that are designed to examine unaware memory-based viewing effects.

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