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Relational Memory Expression Following Subliminal Presentations of Retrieval Cues

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RELATIONAL MEMORY EXPRESSION FOLLOWING SUBLIMINAL PRESENTATIONS OF RETRIEVAL CUES

by

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ABSTRACT
RELATIONAL MEMORY EXPRESSION FOLLOWING SUBLIMINAL PRESENTATIONS OF RETRIEVAL CUES

by

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Several investigations have provided compelling evidence for subliminal perception (Greenwald, Klinger, & Schuh, 1995; Snodgrass, Bernat, & Shevrin, 2004a, b; Pertzov, Zohary, & Avidan, 2009; Haase & Fisk, 2011). Although, questions about whether or not visual information can be processed in the absence of awareness have fostered substantial debate (Marcel, 1983; Cheesman & Merikle, 1984; Reingold & Merikle, 1988; Merikle, 1992; Klinger & Greenwald, 1995; Erdelyi, 2003; Holender & Duscherer, 2005). We were interested in whether or not processing of a subliminal cue might trigger implicit memory for previously studied relationships, and whether or not evidence for successful retrieval (following presentation of subliminal cues) could be documented in eye movement behavior. Previous work has shown that the influences of memory on eye movement behavior are evident early in viewing, found consistently even when viewing is counterproductive to the task requirements, and that eye movement measures are sensitive to memory for elements of prior experience even in the absence of conscious awareness (Hannula, Ryan, Tranel, & Cohen, 2007; Ryan, Hannula, & Cohen, 2007; Hannula & Ranganath, 2009; Hannula, Baym, Warren, Cohen, 2012). By using subliminal memory cues, we were able to investigate whether or not eye movements are sensitive to memory for studied relationships when participants do not “see”, and are therefore unaware of, the retrieval cues. While some of the predicted outcomes were not confirmed, two key results suggest that implicit processing of the scene cue influenced the expression of subsequent eye-movement-based relational memory effects. First, more viewing was directed to faces that were studied with the subliminal scene cues but not selected relative to other non-selected faces during an implicit task. Second, the emergence of disproportionate viewing to the correctly identified scene associate was later than predicted for the control group during a subsequent explicit task. Results from the post-test confirmed that subliminal scenes were in fact masked from awareness for the experimental group, which was critical to our interpretation of the implicit task data. Our results add to previous findings by suggesting that the effects of memory on eye movement behavior may occur in the absence of awareness of the retrieval cue.

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Questions about whether or not visual information can be processed in the absence of awareness have fostered substantial debate (Marcel, 1983; Cheesman & Merikle, 1984; Reingold & Merikle, 1988; Merikle, 1992; Klinger & Greenwald, 1995; Erdelyi, 2003; Holender & Duscherer, 2005), but several investigations have provided compelling evidence for subliminal perception (Greenwald, Klinger, & Schuh, 1995; Snodgrass, Bernat, & Shevrin, 2004a, b; Pertzov, Zohary, & Avidan, 2009; Haase & Fisk, 2011). For example, Pertzov, Zohary, and Avidan (2009) used eye movement measures to investigate the ways in which viewing patterns are influenced by the implicit perception of objects. Each trial in this set of experiments began with the presentation of an object that was masked from view. Thereafter, a change detection display was presented. Two scenes, identical with the exception of a critical object that was modified from one version to the next (e.g., a TV remote was rotated 180 degrees across scenes) were presented alternately, and participants were instructed to identify the change as quickly as possible. Critically, the subliminal object was either the target (i.e., the object that changed from one scene to the next) or a distractor that was also present in the scene. Results from two experiments indicated that less time was required to detect the change and that gaze was attracted more quickly to the location of the change when scenes were preceded by a subliminal presentation of the target (vs. the distractor). This suggests that implicit perception of an object can occur and yields faster and more accurate performance in a change detection task. Here, we were interested in whether or not processing of a subliminal cue might trigger implicit memory for previously studied relationships, and whether or not evidence for successful retrieval (following presentation of subliminal cues) could be documented in eye movement behavior.

As outlined in more detail below, previous work has shown that the influences of memory on eye movement behavior are evident early in viewing, are found consistently even when viewing is counterproductive to the task requirements, and that eye movement measures are sensitive to memory for elements of prior experience even in the absence of conscious awareness (Hayhoe, Bensinger, & Ballard, 1998; Hollingworth, Williams, & Henderson, 2001; Hollingworth, Richard, & Luck, 2008; Hollingworth & Henderson, 2002; Henderson & Hollingworth, 2003; Hannula, Ryan, Tranel, & Cohen, 2007; Ryan, Hannula, & Cohen, 2007; Hannula & Ranganath, 2009; Hannula, Baym, Warren, Cohen, 2012). However, this last finding has not always been replicated (See Smith, Hopkins, & Squire, 2006; Smith & Squire, 2008), and therefore does not necessarily provide iron clad evidence in support of the view that eye-movement-based memory effects can be documented without concomitant awareness of retrieved content. By using subliminal memory cues, we were able to investigate whether or not eye movements are sensitive to memory for studied relationships when participants do not "see", and are therefore unaware of, the retrieval cues.

Cognitive Processing: Insights from Eye Movement Behavior

The distribution of eye movements across the visual field is not random. Instead, eye movements are guided by salient stimulus characteristics and physical properties of the elements that are in view (Buswell, 1935; Mackworth & Morandi, 1967). For example, Buswell (1935) investigated the ways in which people look at visual stimuli by monitoring participants' eye movements as they viewed a series of pictures. While he was unable to quantify specific differences in eye movements between participants, he did conclude that observers exhibited two forms of eye movement behavior. Viewing sequences were characterized by either a general survey of the image, where a succession of brief pauses was distributed over the main features of the photograph, or by long fixations over smaller sub-regions of the image. In general, people made quick, global fixations early, switching to longer fixations (and shorter saccades) as viewing time increased. When fixation patterns were superimposed on the image, areas with a higher density of fixations often corresponded with perceptually salient regions (e.g., eyes in the context of a face). These results support the idea that eye movements are not random, and are influenced by the stimulus characteristics and physical features of the image being viewed. Likewise, Mackworth and Morandi (1967) analyzed eye movement patterns and verbal reports to two different pictures presented one after the other for 10 seconds to determine the general characteristics of the important regions of the images. Results indicated that a few areas within either picture received more fixations of longer duration. These areas were assessed subjectively by the participants and judged to be very recognizable. In other words, the participants viewed areas of the pictures that they felt were highly informative and would be highly recognizable during another viewing occasion. The remaining areas received few fixations. Visual fixation patterns and verbal reports indicated that informative perceptual characteristics (e.g. texture, unpredictable contours, unusual details) of pictures were the most likely to be fixated. The above research suggests that eye movements are influenced by perceptual characteristics (e.g. colors, textures, contours) that draw attention and provide information about the scene.

Influences of Semantic Memory on Viewing Patterns

The ways in which we evaluate and extract information from a visual stimulus are also influenced by semantic memory, or memory for facts, concept knowledge and general world knowledge (Tulving, 1972). When basic perceptual properties of a visual stimulus have been controlled, it is possible to identify effects of semantic memory on eye movement behavior. For example, Yarbus (1967) investigated patterns of eye movements evoked by a scene entitled “An Unexpected Visitor”. Under free-viewing conditions, it was found that the more prominent elements (i.e. faces and objects as compared to a uniform background or repetitive mosaic) that provide information were viewed disproportionately. When participants were asked to answer certain questions about the scene (e.g. How long has the unexpected visitor been gone?) viewing patterns changed, reflecting knowledge the viewer had about where in the scene the information necessary to answer the question might be located. The results of this study indicate that semantic knowledge can drive eye movement behavior such that regions that contain the most useful information are likely to receive more fixations.

Past work has also shown that general world knowledge about the context and location in which an object is expected to be can decrease the time it takes for the eyes to detect a target object (Loftus & Mackworth, 1978; Henderson, Weeks, & Hollingworth, 1999; Henderson, 2003; Brockmole & Henderson, 2008; Hollingworth, 2009). In one study, Loftus and Mackworth (1978) presented participants with scenes that contained either informative or non-informative objects. An informative object was defined as an object that has a low a priori probability of being in that scene (e.g. an octopus in a barnyard). A non-informative object was one that had a high a priori probability of being part of the scene (e.g. a tractor in a barnyard). Results indicated that informative objects were fixated faster and more often than non-informative objects. It was proposed that the extra time spent fixating the informative object represents the time it takes to incorporate that object into an existing schema (i.e., the framework representing some aspect of the world). The individuals in this study looked more at objects that conflicted with expectations, perhaps because of semantic memory for, or prior experience with, a certain situation. In another example, Brockmole and Henderson (2008) examined the influence of scene-object semantic consistency on viewing patterns. Participants were split into consistent or inconsistent groups where a target object was either semantically consistent or inconsistent with the context of the scene and either present for the entirety of viewing or added during a saccade. Results indicated that viewing was directed to the inconsistent object sooner than the consistent object for both the "always present" and "saccade" conditions. The results of these studies suggest that the semantic relationships of objects to scene contexts are considered when visual information is presented and that eye movements can be used to index general world knowledge.

Eye Movement Behavior Distinguishes Studied from Novel Items

The research described thus far has focused on the influence of semantic knowledge on viewing behavior. In contrast, the research described next used pre-experimentally unfamiliar materials to address questions about whether or not patterns of viewing are sensitive to episodic memory for studied materials (e.g., objects, scenes). Further, the following studies attempted to determine what the constraints of these effects might be (e.g., whether they are influenced by instructional manipulations, or explicit recognition accuracy). Sensitivity of eye movements to memory for faces was examined by Althoff & Cohen, 1999. In several experiments, they found that fewer fixations were made to pre-experimentally familiar faces (i.e., famous individuals) and there was less constraint on the location of successive fixations to these faces than to novel, non-famous faces. Further, when pre-experimentally unfamiliar faces were presented repeatedly, the number of fixations decreased systematically as a function of the number of exposures to that face (Althoff, Cohen, McConkie et al., 1998; Althoff & Cohen, 1999; Heisz & Shore, 2008). This *repetition effect* occurred regardless of whether the participants were completing a recognition (Althoff & Cohen, 1999; Heisz & Shore, 2008), emotional labeling (Althoff & Cohen, 1999) or recall task (Heisz & Shore, 2008), and was therefore independent of task demands.

Researchers have also used a face recognition paradigm to examine whether memory exerts an effect on scanning behavior by analyzing fixation-by-fixation viewing patterns to familiar and novel faces. In the context of this paradigm, participants were asked to commit several faces to memory during a study phase and were tested with three-face displays. Using this paradigm, Ryan, Hannula, and Cohen (2007) explored the influence of various levels of exposure on eye movements directed to pre-experimentally familiar and novel faces that were presented in a three-face test display, and addressed questions about whether or not effects of memory on scanning behavior are obligatory by manipulating the task instructions. Eye-movement-based memory effects were seen in several experiments. Specifically, viewing was directed disproportionately to familiar faces (i.e., faces seen for the first time during an encoding phase and famous faces) when participants were given recognition instructions. Further, viewing was directed to famous faces, even when participants were explicitly instructed not to look at familiar faces.

In another set of studies, Hannula and colleagues (2012) investigated whether manipulations of visual similarity between faces and highly similar morphs of those faces would influence explicit recognition of studied faces or lead to incorrect endorsement of novel faces as studied. The researchers were also interested in whether or not eye movements distinguish studied faces from the faces incorrectly endorsed as studied. The test phase consisted of three-face displays that were target present, which contained a studied face and two faces that were visually similar to that face, or target-absent, which contained three faces that were visually similar to a studied face (i.e., the studied face was not presented). Participants were instructed to select a face on every trial (the studied face was to be selected if present) and they were subsequently asked to indicate whether or not the face they had selected was in fact studied. Eye movements were sensitive to past experience, and distinguished actually studied faces from selected faces that were not studied, even when those faces were incorrectly endorsed as have been seen during the encoding phase. So, even when behavioral responses were incorrect, eye movements provided a veridical index of past experience. In sum, the experiments described briefly above indicate that eye movement measures are sensitive to memory for studied items irrespective of instructional manipulations, and even when explicit recognition responses do not accurately reflect past experience.

Eye Movements are Sensitive to Memory for Inter-item and Item-Context Relationships

While the work described above was designed to address questions about whether or not eye movement behavior is sensitive to memory for individual items, other studies have investigated questions about memory for inter-item and item-context relationships. Some of these experiments assessed memory for spatial relationships among items embedded in the context of a scene (Ryan, Althoff, Whitlow, & Cohen, 2000; Ryan & Cohen, 2004a, b; Beck, Peterson, & Angelone, 2007), while others examined memory for arbitrarily paired items (e.g., scenes and faces; Hannula et al., 2007; Hannula & Ranganath, 2009; Chua, Hannula, & Ranganath, 2012). Research conducted by Ryan and colleagues (2000) used eye movements to explore memory for spatial relations between objects embedded in a scene. Following a study phase where several scenic images were encoded, participants were presented with novel, repeated, and manipulated scenes. Manipulated scenes were seen during the study phase, but now one of the objects embedded in the picture was either a new addition, had been deleted, or was moved from one location to another (e.g., the soap was moved from the right to the left of the sink in a kitchen picture). For trials where scenes were manipulated rather than repeated, regions where an object used to be or where an object moved to were found to receive more fixations. Most importantly, greater viewing was directed to "now empty" regions where objects were previously located in manipulated scenes compared to the same regions of repeated scenes when they were always empty. This is notable because eye movements tend to be attracted to objects and not empty regions; increased viewing of regions that became empty seems to imply memory for what used to be in that location.

Studies have also examined relational memory for pre-experimentally unfamiliar, randomly paired scenes and faces (Hannula et al., 2007; Hannula & Ranganath, 2009; Chua et al., 2012). In one example, Hannula and colleagues (2007) used a version of the face recognition paradigm described above and eye movement measures to examine the time course of participants' access to, and use of, memory for scene-face pairs in several experiments using different instructional manipulations. In the study phase, participants were presented with several scene-face pairs. Participants were tested with 3-face displays that were superimposed on previously studied scenes. Test trials were one of two types. "Match" displays consisted of three studied faces, one of which had been studied with the scene in the study phase. "Re-pair" displays consisted of three studied faces, but none of them were paired with the scene in the study phase. Participants were instructed to select the matching face when they felt it was present and to simply select one of the faces when they felt the associate was not present. Results indicated that a disproportionate amount of time was spent viewing the face that had been studied with the scene even in the presence of two equally familiar faces. This experiment differs from those reporting a novelty preference in that the three faces in each test display had been studied equally often, thus preventing differential viewing patterns from emerging based on differences in item memory. Instead, the differential viewing emerged as a result of memory for relations between items. In a second experiment participants were instructed to encode the relationships between all three faces and the background context in an effort to examine the eye movement patterns to these displays indirectly. It was shown that eye-movement-based relational memory effects were evident even when there were no explicit instructions to identify the face that had been studied with the scene. Further these effects were not tied to a particular spatial location, as the matching faces appeared unpredictably in all three of the possible locations across trials (see also Hannula & Ranganath, 2009). The results suggest that memory for specific face-scene pairs shaped the subsequent viewing of the test displays such that differential viewing occurred for the matching face and indicate that these eye-movement-based memory effects do not depend upon explicit instructions to recognize studied associates. The results of these studies speak to the sensitivity of eye movement measures to a variety of cognitive content and support the idea that memory for different aspects of experience, such as relationships between objects, can influence eye movement behavior.

Implicit Memory: Eye Movements as a Measure of Memory Without Awareness

It has been proposed that eye movements may reflect memory prior to conscious awareness or explicit recognition (cf. Hannula, Althoff, Warren et al., 2010). Parker (1978) was the first to note that the effects of memory on eye movements develop early in viewing. Specifically, the manipulated region of a studied scene was fixated more quickly following picture presentation than the same region when the picture remained unchanged. On average, viewing was directed to the changed region of the scene more than one fixation before any viewing was directed to the same region when the picture was not changed. Other individuals found that these rapid eye movements to remembered content are accompanied by an increase in fixation duration (Ryan & Cohen, 2004a, b; Ryan et al., 2007; Hannula et al., 2007; Hannula & Ranganath, 2009; Hannula et al., 2012) suggesting that eye movements help gather information that can inform later behavioral responses. Providing further support for the notion that early disproportionate viewing can occur prior to conscious awareness or explicit recognition, recent research indicates that participants look at fragmented target objects embedded in distractor displays several fixations before explicit identification. For example, Holm et al. (2008) had participants complete a fragmented object recognition task where they were asked to identify fragmented line drawings of animals embedded in a distractor display containing lines that served as distractors. Participants looked at the regions occupied by fragmented target objects as many as 25 fixations before explicit object recognition. Methodical and virtually exclusive investigation of the target region was apparent four fixations prior to explicit identification.

In other research, time-course and response-locked measures have been developed to determine when in time eye-movement-based memory effects emerge relative to stimulus onset and associated behavioral responses (Hannula et al., 2007; Ryan et al., 2007; Hannula & Ranganath, 2009; Hannula et al., 2012). Effects of relational memory on eye movement behavior have been documented 500-750 ms after onset of the test display and as much as 1-1.5 seconds before explicit recognition responses were made in the face recognition and face-scene experiments conducted by Hannula and colleagues (Hannula et al., 2007; Hannula & Ranganath, 2009; Hannula et al., 2012). The time-course of these effects was resistant to changes in the task instructions, becoming apparent 500-750 ms following stimulus presentation whether participants were told to identify the familiar or matching face or instructed to avoid viewing of this face when presented within a 3-face test display (Hannula et al., 2007; Ryan et al., 2007; Hannula & Ranganath, 2009; Hannula et al., 2012). Taken together, the results provide strong support for the automatic influence of memory on eye movement behavior, and suggest that these effects may precede and contribute to explicit recognition (Hannula & Ranganath, 2009; Hannula et al., 2012; see also Moscovitch, 2008). Further, the results of these experiments suggest that eye movements can be used as a temporally accurate measure of memory expression and, since they are able to reflect memory prior to conscious awareness, they may also reflect memory in the absence of conscious awareness and explicit recognition.

Evidence consistent with the proposal that eye movements are sensitive to memory despite an absence of explicit recognition has been reported in a handful of experiments. As indicated briefly above, participants look disproportionately at regions of scenes that have been systematically manipulated (Ryan et al., 2000; Ryan & Cohen, 2004a, b; Beck et al., 2007). Critically, the same effects have been found even when participants fail to report the changes explicitly or fail to recognize that anything has changed (Hayhoe et al., 1998; Hollingworth et al., 2001, 2008; Hollingworth & Henderson, 2002; Henderson & Hollingworth, 2003; Ryan & Cohen, 2004a; Ryan et al., 2007). Hollingworth and colleagues (2001) examined the influence of swapping an object with a different exemplar from the same category (e.g., a plate is swapped with a different plate on a table) on eye movement behavior. Participants spent more time viewing a target object that was replaced with a different exemplar, even when they failed to detect the change explicitly. Hayhoe (1998) also reported the sensitivity of eye movements to changes in visual materials in the context of a block-copying task. Here, the participants copied a pattern of colored blocks and the consequences of changing the color of the blocks during active eye movement were examined. Participants showed disproportionate viewing to the changed blocks, even when they were unable to reliably report the changes verbally. The results suggest that eye movement measures may be more sensitive indicators of memory representations than explicit recognition, providing further support for the use of eye movement measures to study memory. Taken together, the results described above suggest that eye-movement-based memory effects can be expressed even when explicit recognition has failed or is incorrect.

The influences of different types of memory have been revealed through eye movement behaviors using a variety of materials and instructional manipulations. This has allowed researchers to ask specific questions about distinct memory systems. Disproportionate viewing of items and relations that were studied previously may precede and contribute to the development of awareness, as suggested by Hannula et al. (2007). In other words, conscious awareness may occur as a result of changes in our eye movements, rather than eye movements resulting from conscious awareness. Based on results like those described briefly above, it has been proposed that eye-movement-based memory effects occur automatically, shortly after stimulus presentation, and may be evident long before, or even without, conscious awareness of successfully recovered content. However, it is possible that some of these effects reflect the tendency for participants to adopt a conservative response criterion – that is, they may not report a change, despite a suspicion that one has occurred. Furthermore, some studies have failed to document influences of memory on eye movement behavior in the absence of awareness, and have instead linked these effects to high confidence recognition responses (e.g., Smith, Hopkins, & Squire, 2006; Smith and Squire, 2008). Here, we were interested in investigating whether or not successful relational memory retrieval can be documented in eye movement behavior even when retrieval cues are presented subliminally. The combined use of subliminal masking procedures and eye movement methods to investigate relational memory was novel, and this approach was intended to help resolve current debates about whether or not memory can be documented in eye movement behavior in the absence of awareness.

Subliminal Stimulus Presentation: Evidence of Memory for Information Masked from Awareness

Recent studies conducted by Henke and colleagues (Henke, Mondadori, Treyer, et al., 2003a; Henke, Treyer, Turi Nagy et al. 2003b; Degonda, Mondadori, Bosshardt, et al., 2005; Duss, Oggier, Reber, & Henke, 2011; Reber & Henke, 2011; Reber & Henke, 2012; Reber, Henke, & Duss, 2013) have examined whether or not evidence for memory can be documented without conscious awareness (implicit memory) using subliminal stimulus masking procedures, but none of these investigations have used eye movement measures. In one of these experiments, used here to describe the general approach, Henke and colleagues (2003a) used subliminal stimulus masking techniques to present combinations of faces and written professions to an experimental group or just faces to a control group so that participants were unaware of them. Here, faces and written professions were presented very quickly between two pattern masks repeatedly such that the stimuli were presented six times in 3 seconds for encoding. During a subsequent retrieval phase, the faces were presented for conscious inspection, and participants were asked to guess the category of the associated profession. Accuracy for the retrieval phase was not significantly different from chance for either the experimental or control groups. However, reaction times for the correctly guessed professional categories were significantly shorter than incorrectly guessed categories for participants in the experimental group; the same results were not evident in the response times of control participants (see also Duss et al., 2011). These results suggest that associations between the faces and professions were successfully encoded despite the fact that they were not accessible to awareness. However, without significant differences in accuracy between groups, the results are rather equivocal. We hoped to shed light on this matter by including eye movement measures in our analyses, which had the possibility of showing group differences in viewing patterns in conjunction with reaction time differences and in spite of the lack of difference in accuracy.

Current Investigation

The following study was designed to address questions about whether or not processing of a subliminal cue might trigger implicit memory for previously studied relationships, and whether or not evidence for successful retrieval (following presentation of subliminal cues) can be documented in eye movement behavior. Participants studied several (visible) scene-face pairs and were asked to commit these pairs to memory. During a corresponding test phase, each trial began with the presentation of a studied scene cue that was presented subliminally (i.e., masked from awareness). Following the subliminal scene cue, a 3-face display was presented; for half of the participants, one of the faces was the studied associate of the scene cue. Participants were instructed to select the face they thought was the associate of a visible scene to be presented after the 3-face display, and were told that this task was a measure of foresight; eye movements were recorded. This implicit test of memory permits examination of eye-movement-based and behavioral measures of memory. Subsequent to the implicit test, the same 3-face display was presented again, but now it was preceded by the visible scene. In this case, the associated face was present regardless of group assignment. Participants were instructed to select the face that had been paired with the scene in the encoding phase and eye movements were recorded. This explicit test of memory also permits examination of eye-movement-based and behavioral measures of memory.

As reported by Hannula and colleagues (Ryan & Cohen, 2004a, b; Hannula et al., 2007; Ryan et al., 2007; Hannula & Ranganath, 2009; Hannula et al., 2012), we expected that eye movements would be sensitive to memory for the face that was associated with a specific scene context, but here these viewing effects were expected even when scene cues, meant to trigger memory for studied relationships, were presented subliminally. Consistent with results reported by Henke and colleagues (Henke et al., 2003a, b; Degonda et al., 2005; Duss et al., 2011), it was predicted that participants assigned to the experimental group would respond more quickly when associates were identified correctly (vs. not) following subliminal scene cues. This outcome would provide additional evidence for memory in spite of the absence of awareness of the retrieval cue. Before providing a detailed description of the methods used to conduct the primary experiment, a norming study that was designed to assess the effectiveness of the subliminal masking procedure will be described.

METHODS: NORMING EXPERIMENT

It was critical, in the context of the current investigation, that scene cues were successfully masked from awareness. Therefore, a method was developed to systematically degrade each scene, and a norming experiment was performed to eliminate visible scene exemplars from the set that would be carried forward for use in the study. During the norming task, scenes were presented in a masking sequence, which was followed by a 2-alternative forced-choice test. Participants attempted to identify the masked scene, guessing if necessary, and were then asked to describe any perceptual information they had noticed when the masking sequence was in view. This procedure was meant to increase the likelihood that scene cues would not be perceived explicitly in the investigation, and is described in more detail below; detailed methods for the primary investigation are provided in a subsequent section.

Participants

Sixty-seven undergraduate students participated in the norming experiment and were compensated with course credit. Informed consent was obtained from each participant prior to initiating the experiment in a manner approved by the Institutional Review Board at the University of Wisconsin-Milwaukee.

Materials

One-hundred sixty-eight pictures were chosen from a database or found online (see Hannula & Ranganath, 2009). Half of these pictures were indoor scenes (e.g, dentist office) and the remainders were outdoor scenes (e.g, Millennium Park). For norming purposes, each scene was degraded systematically using Adobe Photoshop in a process that yielded a set of nine

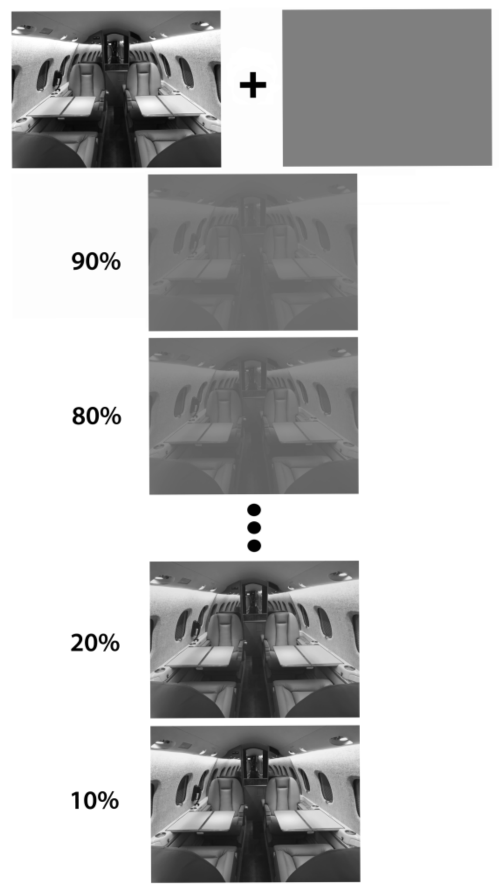

Figure 1. Scene Degradation Method: A gray layer was superimposed over each scene. The opacity was adjusted by 10% and the scene was saved to create 10 exemplars for each scene (0-90%).

additional exemplars of each original scene. To produce each set, a gray layer (R: 115, B: 113, G: 113) was superimposed on top of the original scene. The opacity of this gray layer was then repeatedly reduced by 10% so that the picture underneath was made increasingly visible (e.g., picture + gray scale layer at 90% opacity, picture + gray scale layer at 80% opacity). Following each reduction in the opacity of the gray overlay, the resulting image was flattened and saved (See Figure 1).

Forty-two black and white visual noise images were used as masks during subliminal scene presentation; these masks have been described elsewhere (e.g., Henke et al., 2003a). Scenes and masks were presented at 600 x 450 pixel resolution, in the center of the screen. Scenes presented were presented at 225 x 300 pixel resolution for the forced-choice task.

Design and Procedure

After giving informed consent, participants were seated at a distance approximately 25” from the computer screen and task instructions were provided. A practice block was also administered to ensure that the participants understood the instructions. Participants who volunteered for this experiment were told that a series of visual noise images would be presented very rapidly on the computer screen in front of them. Because the goal here was to identify and eliminate scenes that were visible when subliminal masking sequences were presented, participants were also told that a scenic picture would be embedded among the visual noise images, and that they would be asked to identify that picture at the end of each trial. To eliminate potential differences in the distribution of attention across trials and participants, a visual attention task was performed as the masking sequence was presented. Successful performance on this task required that participants direct their attention to a fixation cross in the center of the computer screen. They were told that the fixation cross would either be replaced with a horizontally oriented line segment or a vertically oriented line segment at some point during the trial and that they should press a button as soon as they noticed the change. Finally, following the subliminal masking sequence, a two alternative forced-choice test was presented and participants were asked to identify the scene that had been presented in the subliminal sequence by making a button press. Following their response, participants were asked if they had seen the picture or any component thereof (e.g., shapes, shadows, contours, or flashes that were not consistent with the masking pattern). Responses were recorded by the experimenter and provided a subjective measure of scene perception.

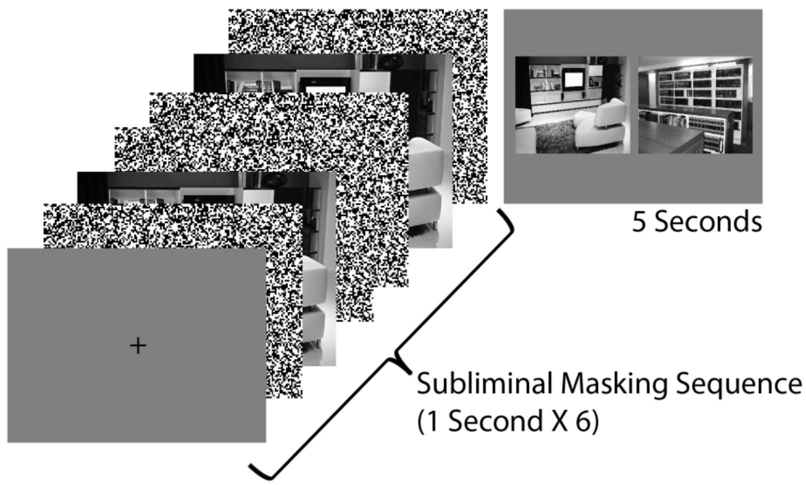

Figure 2. Example norming trial: The masking sequence and forced-choice presentation.

The masking technique developed by Henke et al. (2003a) was used to present scenes subliminally on each trial. The scenes were flanked by visual noise masks and presented twelve times in 6 seconds. Presentation durations were 17 msec for scenes (S), 183 msec for masks (M), and 233 msec for fixation crosses/bars (F). The presentation of one scene was given in the following sequence F-M-S-M-M-S-M-F-M-S-M-M-S-M-F-M-S-M-M-S-M-F-M-S-M-M-S-M-F-M-S-M-M-S-M-F-M-S-M-M-S-M (see Figure 2). As described above, the fixation cross was replaced randomly with a horizontal or vertical bar once per trial. Following the subliminal presentation of the scene, a two-alternative forced-choice display was presented for 5 seconds (see Figure 2).

Scenes were randomly assigned to one of 12 blocks, each consisting of 14 trials. Each scene was used once as a target and once as a foil on the 2-alterntive forced-choice test, and the targets and foils appeared equally often on the left and the right across trials. The initial round of testing (N=20) was done with the original grayscale scenes. Subsequent testing (N=47), conducted only for the subset of scenes that were reliably detected on the 2-alternative forced-choice test, was performed with increasingly degraded versions of those pictures (e.g., the original image + gray layer at 10% opacity) and was repeated until an appropriate level of masking was identified for each scene. The highest level of degradation required for sufficient masking of a given scene was 70%. More than half of the scenes (N=96) were found to be successfully masked from awareness without degradation.

RESULTS: NORMING

The number of times a scene was successfully identified was calculated for each scene to be used in the main experiment and a global mean was calculated across scenes. On average scenes were successfully identified 53.3% of the time (SD=11.4%) and performance was reliably greater than chance ($t(161) = 3.67$, $p < 0.0001$). Binomial tests, performed for each picture individually indicated that performance was not better than chance for 120 scenes. Performance was reliably below chance for 9 of scenes and above chance for the remainders (i.e., for 39scenes). Because participants did not report any subjective awareness of scene features, even in cases of above chance performance on the objective 2-alternative forced-choice task, it was determined that scenes had been masked from awareness.

METHODS: PRIMARY EXPERIMENT

The primary experiment was designed to investigate whether or not subliminal scene cues can support successful relational memory retrieval. Participants encoded several scene-face pairs, and were tested with 3-face displays. On a given test trial, the 3-face display was presented twice. The first presentation was preceded by a subliminal (i.e., masked) scene cue, and the second presentation was preceded by a visible scene cue. The first exposure permitted us to examine implicit memory for studied scene-face relationships, and the second exposure permitted us to examine explicit memory for the same pairs. Evidence for memory was examined using eye movements and behavioral responses.

Participants

Forty undergraduate students were recruited to participate in this experiment and were compensated with course credit. Each participant was randomly assigned to either the control group (N=20) or to the experimental group (N=20). Informed consent was obtained from each participant prior to initiating the experiment in a manner approved by the Institutional Review Board at the University of Wisconsin-Milwaukee. One participant assigned to the experimental group was dropped from reported analyses because explicit recognition performance was more than two standard deviations below the group mean, and was at chance (33.33% correct).

Materials

One hundred sixty-eight gray-scale scenes were selected based on the outcome of the norming experiment described above. In addition, one hundred sixty-eight gray-scale faces (half female; half male) were selected from an established faces database (see Hannula et al., 2007; Hannula & Ranganath, 2009).

Forty-two black and white visual noise images were used as masks during the subliminal scene presentation (e.g., Henke, Mondadori, Treyer et al., 2003). Scenes and masks were presented at 600 x 450 pixel resolution, in the center of the screen. Faces were presented at 210 x 210 pixel resolution, and superimposed on top of a 225 x 225 pixel gray background.

Apparatus

Eye position was recorded every 17 msec (i.e., 60 Hz) with an Applied Science Laboratories D6 remote eye tracker (Applied Science Laboratories, Bedford, MA). This eye tracking system operates by illuminating the eye with infrared light and recording changes in the angle between the pupil and the corneal reflection as the eyes move. Movement of the head in all three dimensions was recorded using a head tracking system and head position was integrated with eye position to permit reliable acquisition of data that reflects gaze coordinates.

Design and Procedure

After providing their informed consent, participants were seated at a distance approximately 25 inches from the computer screen and task instructions were provided. Following a brief practice session, participants had an opportunity to ask any remaining questions. The experiment began after eye position was calibrated using a 3 x 3 spatial array, a process that was repeated prior to each experimental block. Individual trials were only initiated when participants were fixating a centrally located black circle.

Participants were presented with 3 interleaved encoding and test blocks. Novel scenes and faces were used for each of the corresponding encoding and test block pairs. Upon completion of the experiment, participants were debriefed about the true nature of the masking sequence and completed a short post-test questionnaire. Then, they completed an objective awareness test in 3 blocks.

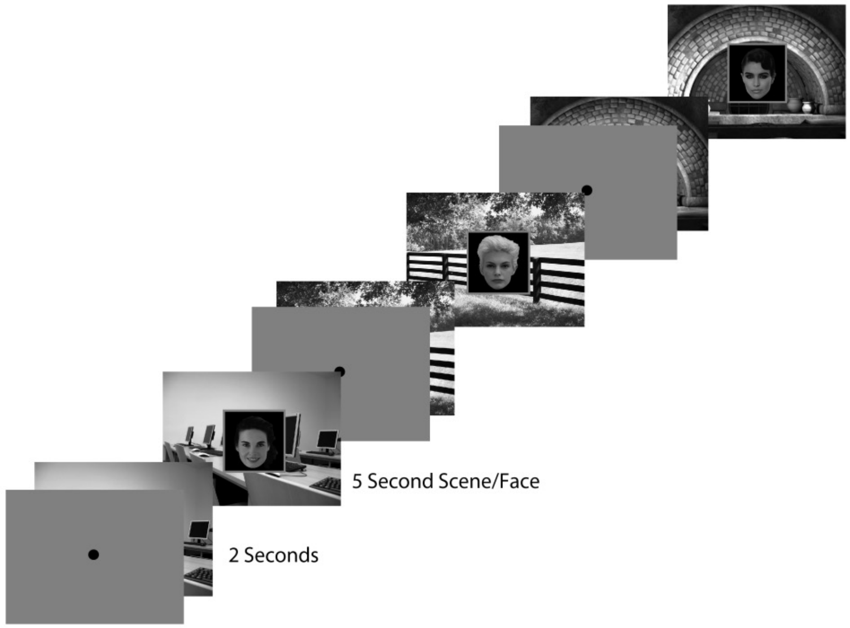

Figure 3. Example encoding trials: 2s scene presentation, 5s scene and face presentation

Prior to the first encoding phase, participants were instructed that they should commit 56 scene-face pairs to memory. Scenes were presented for 2 seconds, and were followed by a 5 second presentation of the same scene with a face superimposed on top (see Figure 3). Following the presentation of the pair, participants indicated whether or not they thought there was a good fit between the person and the place depicted in the scene by making a button press (e.g. How well does the scene fit the face? 1 = Terrible Fit, 2 = Poor Fit, 3 = Good Fit, 4 = Excellent Fit); a time limit was not applied to this judgment, which was meant to encourage deep encoding of each pair.

Each trial in the retrieval phase began with the subliminal presentation of a studied scene followed by a visible 3-face display for implicit retrieval of the face-scene associations. Next, a visible scene was presented followed by a 3-face display superimposed on the same scene for explicit retrieval of the face-scene associations. Participants were not told about the presence of the scene in the subliminal sequence; instead, they were instructed to perform the attention task described earlier. Participants were told that a fixation cross, presented among visual noise masks, would either be replaced with a horizontally oriented line segment or a vertically oriented line segment at some point during the noise sequence and that they should press a button as soon as they noticed the change. To conceal the purpose of the scene masking sequence, participants were told that the task measured attention alone. Following the subliminal masking sequence, the 3-face test display was presented for 5 seconds for the implicit retrieval of previously formed associations. All three faces in this display were seen during the encoding phase. Participants were asked to select the face from this display that they expected would be the associate of the upcoming visible scene cue; participants were told this is a measure of foresight, and this cover story permitted us to obtain behavioral responses for 3-face displays that were preceded by subliminal scene cues (i.e., a behavioral measure of implicit memory).

Following the first 3-face display, a visible scene was presented for 2 seconds, followed by the same 3-face test display, now superimposed on top of the scene, which remained in view for 5 seconds. Participants were instructed to indicate which face had been paired with this scene during the encoding phase (i.e., a behavioral measure of explicit memory). Finally, participants were asked to indicate how confident they were in the accuracy of their explicit recognition response (1=high confidence, 2=low confidence, 3=guess).

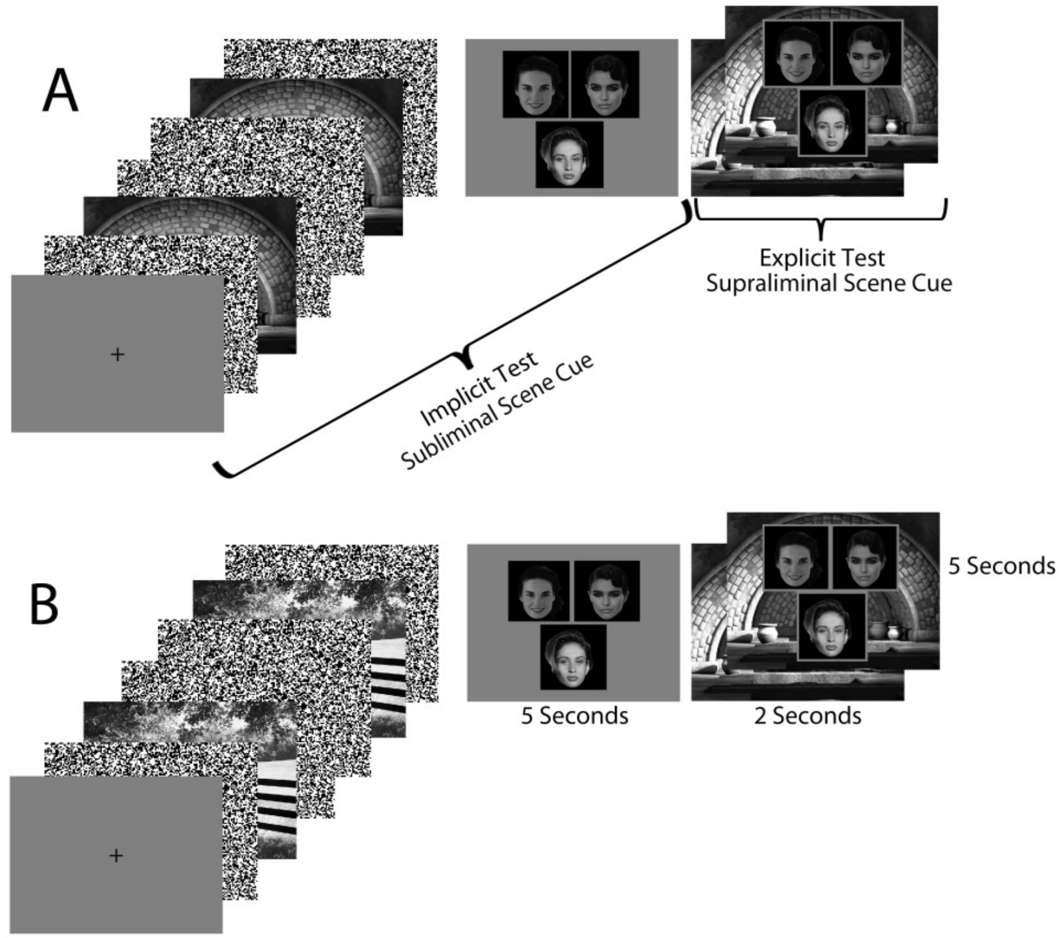

Figure 4. Example test trials: A: Experimental group, B: complementary control group sequence.

As indicated above, participants were randomly assigned to either the experimental group or the control group prior to testing. For participants in the experimental group, the subliminal scene was the studied associate of one of the faces in the 3-face display (see Figure 4a). Participants assigned to the control group were presented with the same 3-face displays but none of the faces had been studied with the subliminal scene cue (see Figure 4b). For participants in both groups, the visible scene cue was the studied associate of one of the faces in the 3-face display (see Figure 4a and b). All of the faces used in the 3-face displays, for both groups, were studied in the encoding phase. The experimental group was presented with 14 scenes (both subliminally and supraliminally) and the control group was presented with 28 scenes (14 subliminally; 14 supraliminally) in each test block. The critical face (i.e. the matching face for the experimental group, and the same face absent the match for the control group) appeared equally often in each spatial location (i.e., left, right, or bottom) across trials. Altogether, participants completed 42 test trials in this experiment.

Following the final retrieval block, a 2-part post-test designed to assess awareness was administered. Up to this point, the participants were not informed about the subliminal stimulus presentations or the purpose of the experiment. During the first part of the post-test, participants were asked several questions about the masking sequence. Responses to these questions provided a subjective measure of scene perception and recognition. The participants were then told that subliminal scene cues were presented in the visual noise prior to the first 3-face display and several more questions were asked (see Appendix). During the second part of the post-test, a more objective test of awareness was administered. The testing procedure described above (see norming experiment) was used to obtain scene visibility estimates for each participant. Participants were told that a masking sequence, identical to the ones used previously, would be presented, but now they had been informed that a scene would be present in each sequence. With this in mind, they were asked to identify that scene when a 2-alternative force-choice display was presented immediately after the masking sequence ended. The awareness test was broken up into three blocks of 14 trials (42 trials in total) as in the retrieval phase. Scenes from pairs that were encoded, but were not used as cues during the test phase, were used for the post-test. Use of encoded scenes was important because it is possible that scenes embedded among visual noise masks are more easily identified when they have been studied. Scenes that were used in the awareness test were presented in reverse order relative to when they had been encoded (scenes encoded more recently were presented first, those encoded more remotely were presented last). This approach meant that we could examine whether or not any successful detection of subliminally presented scenes was affected by the amount of time that had passed since encoding. Targets and foils appeared equally often in all spatial locations (i.e. left, right) across trials.

Counterbalancing

For counterbalancing purposes, each of the individual scenes were randomly assigned to one of 12 lists (14 scenes per list), each with equal numbers of indoor and outdoor scenes. Faces were also assigned to one of 12 lists (14 faces per list), each with an equal number of male and female faces. For each participant, a given list of scenes was then paired with a given list of faces. Individual scenes and faces from corresponding lists were presented as pairs during the encoding phase. One-quarter of the scenes and three quarters of the faces were used to construct the retrieval trials for the experimental group. Half of the scenes and three quarters of the faces were used to construct the retrieval trials for the control group. The remaining half of the scenes, those that were not used in the retrieval trials for either group, was used to construct the post-test awareness trials. Counterbalancing ensured that across participants each list of faces was presented equally often with each list of scenes across blocks and experimental conditions.

Eye Movement Analyses

Evidence of retrieval and use of memory for face-scene relationships was taken from time course measures, which provide information about how viewing unfolds over the course of a test trial. One of the faces in each 3-face display was designated a *critical* *face*, and viewing time directed to that face was evaluated. For participants assigned to the experimental group, the *critical face* was the studied associate of the subliminally presented scene cue (implicit test trials) and was also the studied associate of the visible scene cue (explicit test trials). Control group participants saw the same 3-face displays, but here, the *critical face* was not the studied associate of the subliminal scene cue (implicit test trials); the associate was not present in the 3-face display. Following visible scene cues, the studied associate was present, and was the *critical face* (explicit test trials).

Previous studies have shown that overall viewing measures (i.e., proportion of viewing time) collapsed across an entire trial do not always reveal effects of memory (cf. Hannula et al. 2007). Time-course measures will permit us to determine whether and when disproportionate viewing of the critical face occurred, after 3-face displays were presented. Starting with the onset of the 3-face displays, eye movement data was binned into consecutive 250ms time bins and the proportion of total viewing time directed to the critical faces was evaluated.

Statistical Contrasts

Repeated measures ANOVAs were performed with corrections using the Greenhouse-Geisser adjustment to reported p-values when there was more than 1 degree of freedom in the numerator. This correction was applied because the Greenhouse-Geisser epsilon values deviated substantially from 1.0 for several of the ANOVAs that were calculated. Because this can indicate violations of sphericity, the more conservative p-values are reported. All of the reported post-hoc comparisons were Bonferroni corrected.

RESULTS

Behavioral Performance: Accuracy and Response Times

<u>Attention Task</u>

Compliance with attention task instructions was generally good – participants failed to make responses on just 5.19% (SD=12.24) of the trials. For the remaining trials, successful detection/identification of horizontal or vertical line segments embedded in the subliminal masking sequence was well-matched across groups (experimental group: 82.61% correct, sd=16.60; control group: 82.09% correct, sd=22.32; $t(37)=.08$, $p>.05$).

<u>Implicit Memory for Scene-Face Relationships</u>

Consistent with previous work (Henke et al., 2003; Duss et al., 2011), participants were not expected to show better than chance performance on the test of subliminal memory for studied scene-face relationships. In other words, participants assigned to the experimental group were not expected to select the *critical* face more often than the remaining two faces in the 3-face display despite the fact that the subliminal scene cue had been paired with that face during the study phase. In addition, selection of the critical face was expected to be well-matched across groups. However, group differences were expected when response times were evaluated. Specifically, the experimental group was expected to respond more quickly when the critical face was selected versus not; no differences in response time were expected for the control group.

Following the presentation of subliminal scene cues, participants failed to make responses on 3.11% (SD=5.81) of the trials when 3-face displays were presented. Reported results are based on the subset of remaining trials in which participants did respond.

To test the first hypothesis, the percentage of selected critical faces was calculated for the experimental group and for the control group. As predicted, the critical face was selected equally often by both groups (experimental group: mean= 34.77%, sd=5.99; control group: mean=34.80%, sd= 7.35; $t(37) = 0.01$, $p > 0.05$), and neither group selected critical faces more often than would be expected by chance (experimental group: $t(18)=1.29$, $p>0.05$; control group: $t(19)=1.09$, $p>0.05$).

To determine whether or not there were reaction time differences between groups associated with selection of the critical face, a between-groups repeated-measures ANOVA was calculated with the factors *group* (experimental vs. control) and *trial type* (critical face selected vs. critical face not selected). In contrast to the predicted outcome, the experimental group did not make faster responses than controls when the critical face was selected (non-significant group x selection interaction ($F(1,37) = 0.59$, $p>0.05$). Instead, response times were well-matched across groups and trial types, the numerical difference was not statistically reliable (F's(1,37) ≤ 2.65, p's>.05; see Table 1). Therefore, results reported by Henke and colleagues (Henke et al., 2003; Duss et al., 2011) were not replicated in this experiment.

TABLE 1: Response time means and standard deviations (in parentheses) on the implicit test of memory.

	Critical Face Selected	**Critical Face Not Selected**
Experimental Group	2466.03 (731.77)	2490.88 (810.75)
Control Group	2838.81 (618.82)	2799.86 (468.84)

Explicit Memory for Scene-Face Relationships

For the explicit task, the visible scene cue was the associate of one of the faces in the 3-face display for participants assigned to both groups. Here, participants were instructed to identify that face from among the three alternatives and it was predicted that there would be no difference between groups in accuracy or reaction time.

Participants failed to make responses on 3.72 % (sd =6.25) of the explicit task trials. The results reported below are based on the subset of remaining trials in which participants did respond.

To test the predictions outlined above, the percentage of correctly identified associates for both groups was calculated. As predicted, the associate was correctly identified equally often by participants assigned to the experimental (mean= 75.92%, sd=16.14) and control groups (mean=83.11% , sd= 10.57; $t(37) = 1.65$, $p > 0.05$), and recognition performance was well above chance levels for both groups (experimental group: $t(18) = 11.59$, $p < 0.05$; control group: $t(19) = 21.2$, $p < 0.05$).

To examine reaction time differences, a repeated-measures ANOVA with factors *group* (Experimental vs. Control) and *accuracy* (associate correctly identified vs. associate not identified) was computed. Results indicated that response times were well matched across groups ($F(1,30) = 0.79$, $p >.05$), but were significantly faster when the face that had been paired with the *visible* scene cue was successfully identified ($F(1,30) = 117.271$, $p >.05$). The *group* by *accuracy* interaction was not statistically reliable ($F(1,30) = 0.516$, $p > 0.05$; response times are reported in Table 2).

TABLE 2: Response time means and standard deviations (in parentheses) on the explicit test of memory.

	Critical Face Selected	**Critical Face Not Selected**
Experimental Group	2114.00 (484.43)	2900.26 (686.19)
Control Group	2232.04 (405.64)	3109.19 (500.26)

Subsequent Memory Analyses

To account for the possibility that participants may not have successfully encoded some of the studied pairs, implicit behavioral data were back-sorted as a function of response accuracy on the explicit recognition test. Here, data analysis was limited to the subset of implicit trials for which participants successfully identified the associate when the corresponding explicit test was administered. We expected that implicit effects might be evident when explicit memory for studied scene-face relationships was accurate. A repeated measures ANOVA with the factors *group* (Experimental vs. Control) and *trial type* (critical face selected, critical face not selected) was calculated for the subset of implicit trials that were associated with correct explicit responses. Even when the pairs had been successfully encoded and explicitly retrieved, there was no evidence for the predicted response time differences in the implicit data. The slight numerical difference in responses times were not statistically reliable – there was not a main effect of group or trial type, nor was there a statistically significant interaction (F's(1,36) $\leq$ 2.27, p's>0.05; see Table 3).

TABLE 3: Response time means and standard deviations (in parentheses) on the back-sorted implicit test data

	Critical Face Selected	**Critical Face Not Selected**
Experimental Group	2440.37 (679.20)	2488.90 (801.07)
Control Group	2812.90 (604.22)	2760.10 (481.19)

Eye Movements

Implicit Memory for Scene-Face Relationships

Past work has shown that participants spend more time viewing materials (e.g., face, objects) that are *selected and studied* than materials that are *selected, but were not studied* – an eye-movement-based memory effect (Hannula et al., 2007; Hannula & Ranganath, 2009; Hannula et al., 2012). Here, for participants assigned to the experimental group, one of the faces in the 3-face display (i.e., the *critical* face) was the studied associate of the scene cue. Based on previous findings, it was predicted that experimental group participants might spend more time viewing *selected critical faces* than other faces that happened to be selected, but were not studied associates of the subliminal scene cue. This outcome, if it was documented, would reflect implicit memory for scene-face relationships. The same effect was not expected for control participants because the critical face had not been presented with the subliminal scene cue during encoding (thus, selected critical faces were no different from other selected faces).

It has also been shown that when participants fail to identify studied items, eye movements may be drawn to those items disproportionately relative to other non-selected (and non-studied) items in the same display (Hannula & Ranganath, 2009). This suggests that even when experimental group participants fail to select the critical face, they may spend more time viewing it than the other non-selected face in the same display. Again, control group participants would not be expected to show this memory-based viewing effect because the subliminal scene cue was not the associate of the critical face.

Time-course measures were used to evaluate these predictions. For the analyses that follow, data from the first 2 seconds following 3-face display onsets were considered. Analyses were limited to early viewing because this is the time frame in which other relational memory effects have been documented previously (Hannula et al., 2007; Hannula & Ranganath, 2009; Hannula et al., 2010; Ryan et al., 2007). Broadly speaking, individual trials were separated into two categories – trials on which the critical face was selected, and trials on which the critical face was not selected. From these two trial types, there were four faces of interest: 1) selected critical faces; 2) critical faces that were not selected; 3) faces that were selected in error; 4) non-selected faces. Note that the last three face types all come from the same display (from trials on which participants did not select the critical face).

A between-groups repeated-measures ANOVA with the factors *group* (experimental, control), *face type* (critical face selected, critical face not selected, selected face, non-selected face) and *time bin* (0-250, 250-500, etc.) was calculated. Proportion of viewing was well matched across groups ($F(1,37) = .273$, $p > 0.05$) and no interactions between group and time bin ($F(6,222) = 0.80$, >0.05) or group and face type ($F(3,111) = .47$, $p > 0.05$) were found. There were significant differences in the proportion of viewing based on face type ($F(3,111) = 72.453$, $p < 0.05$) because more time was spent viewing faces that were selected. There was also an effect of time bin ($F(6,222) = 4.571$, $p < 0.05$) such that viewing changed across the duration of the trial. A significant interaction between face type and time bin was found ($F(18,666) = 3.07$, $p < 0.05$) suggesting an effect of selection on eye movement behaviors across time. The most important finding was an interaction between face type, time bin, and group ($F(18,666) = 3.289$, $p < 0.05$). This result suggests the presence of eye-movement-based memory effects for previously studied face-scene pairs. To determine what was driving this interaction, post-hoc comparisons were calculated.

Post-hoc comparisons were performed to examine whether or not disproportionate viewing occurs for the selected critical faces relative to the selected faces and also whether disproportionate viewing is directed to the non-selected critical faces relative to non-selected faces. Disproportionate viewing was directed to the selected face relative to the selected critical face between 250-500ms for the experimental group ($t(36) = 3.37$, $p < 0.05$). Further, disproportionate viewing was directed to the non-selected critical faces relative to non-selected faces between 1500-2000 ms ($ts(36) \geq 2.85$, $p < 0.05$; see Figure 5.). This is an important finding, as it reflects memory for the face-scene pairing despite the subliminal presentation of the scene cue. Therefore, it provides evidence of implicit memory for studied scene-face relationships. When the same comparisons were made for the control participants, no differences in viewing directed to the selected critical face relative to selected faces ($ts(38) \leq 1.10$, $ps > 0.05$) or the non-selected critical face relative to the non-selected faces ($ts(38) \leq 2.31$, $ps > 0.05$) were found.

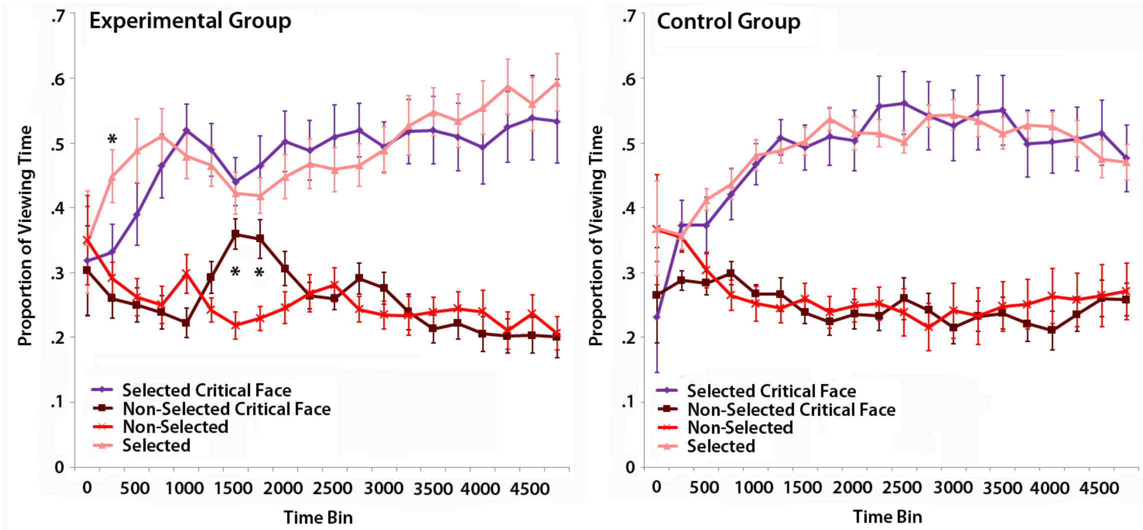

Figure 5. Time course for implicit task by group.

Explicit Memory for Scene-Face Relationships

For the explicit task, the visible scene cue matched (was the associate of) the critical face in the 3-face display for participants assigned to both groups. On the explicit test, participants were instructed to identify the critical face from among the three alternatives. In this case, trials were one of two types and there were two faces of interest: 1) correct trials: correctly identified associates; 2) incorrect trials: faces selected in error.

Disproportionate viewing of the correctly identified associates relative to faces selected in error was expected for participants assigned to both groups, an effect that would reflect memory for scene-face relationships.

As described above, and consistent with past work, disproportionate viewing of the correctly identified associate was expected to be evident early in the trial (i.e., between 500-750ms) for the both groups. A between-groups repeated-measures ANOVA with the factors *group* (Experimental vs. Control), *face type* (correctly identified associate, faces selected in error), and *time bin* (0-250, 250-500, etc.) was calculated.

Proportions of viewing were matched between groups (F(1,36) = 0.19, p > 0.05). Significant differences were found in the time course data as a function of face type (F(1,36) = 39.465, p <0.05) such that correctly identified associates were viewed disproportionately relative to faces selected in error. No other significant main effects or interactions were found (Fs < 1.52, ps > 0.05).

Planned comparisons indicated that there was significantly more viewing directed to the correctly identified associates as compared to faces selected in error for the experimental group starting at 500-750 ms (t(36) = 3.23, ps <0.05). The same comparisons made for the control group indicated that disproportionate viewing to correctly identified associates emerged later in time (750-1000 ms time bin: t(37) = 4.04, p < 0.05; See Figure 6). This is notable because we would expect that participants in both groups would have very similar viewing patterns as they are completing the same task.

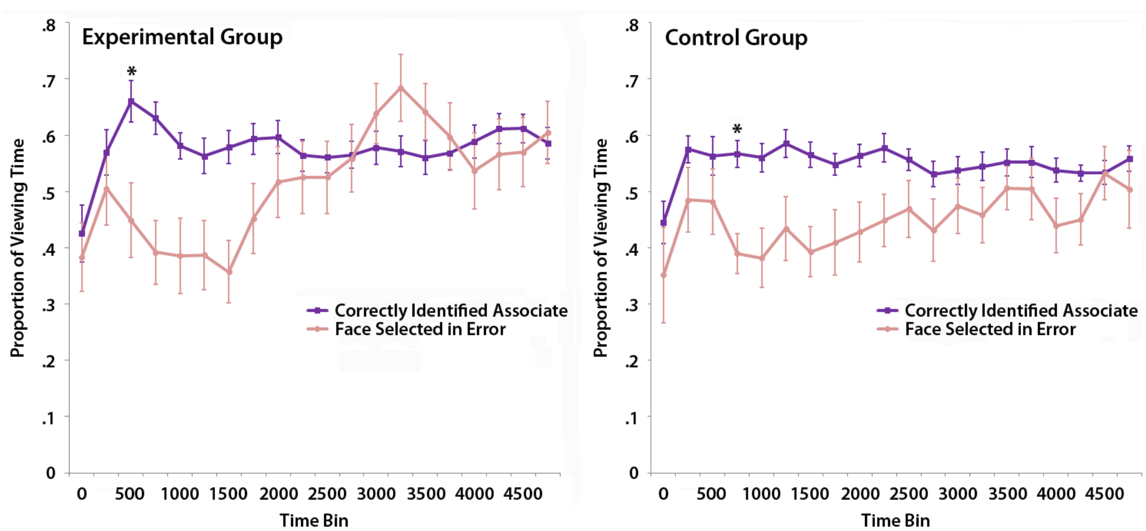

Figure 6. Time course for explicit task by group.

Post-Test: Assessment of Awareness

<u>Attention Task</u>

Similar to the retrieval phase, successful detection/identification of horizontal or vertical line segments embedded in the subliminal masking sequence was well-matched across groups (experimental group: 83.30% correct, sd=20.01; control group: 89.58% correct, sd=11.77, $t(37)=1.02$, $p>.05$). In addition, compliance with attention task instructions was generally good – participants failed to make responses on just 4.40% (sd = 6.26) of the trials. This was important because it ensured that the participants had generally complied with instructions to orient attention to the center of the screen during subliminal scene presentation.

<u>Subjective Awareness</u>

As was the case in the norming experiment, participants were not expected to indicate that they were aware of the subliminal presentation of the scene when the post-test questionnaire was administered, and in fact, very few participants suspected the presence of subliminal stimulus presentation (four from the experimental group; five from the control group). These participants reported that they thought they saw flashes or glimpses of something occasionally, but did not guess that scenes were embedded in the visual noise sequence. After being told about the presence of the scenes, none of the participants who reported some awareness of the subliminally presented stimuli were able to reliably report scene content, size, or screen location.

<u>Objective Awareness</u>

Subjective measures of awareness indicated that participants were not aware of the presence of the scene, but to confirm that this was indeed the case a more objective test was conducted. It was expected that participants would not perform better than chance when they were asked to explicitly identify a subliminally presented scene on 2-alternative forced-choice test trials.

Collapsed across groups, participants failed to make a response on 0.55 % (SD=1.39) of the forced-choice post-test trials. Reported results are based on the subset of remaining trials in which participants did respond.

Identification of subliminally presented scenes was not better than chance for the experimental group (mean= 51.80, SD=6.84; $t(18) = 1.15$, $p > 0.05$), but was reliably greater than chance for the control group (mean=57.33, SD=9.89; $t(19) = 3.313$, $p < 0.05$). The absence of above-chance performance among experimental group participants is critical, and suggests that the disproportionate viewing directed to critical faces that were not selected on the implicit test is unlikely to have been a consequence of conscious awareness of the masked scene cue.

Post-test accuracy by block

Scenes in the awareness phase blocks were presented in reverse order (scenes encoded more recently were presented first, those encoded more remotely were presented last) from the encoding phase blocks to permit us to examine whether or not awareness of subliminally presented scenes was affected by the amount of time that had passed since encoding. To test whether or not this was the case, average accuracy for each block (Post-test block 1: encoded most recently; Post-test block 2; Post-test block 3: encoded most remotely) for each participant was calculated. A repeated-measures ANOVA with factors *group* (Experimental vs. Control) and *block* (Post-test block 1, 2, 3) was calculated. As might be expected based on the patterns of post-test performance described above, there was a marginal between-groups difference, such that the control participants were more successful at identifying the subliminal scene on average ($F(1,37)$

= 4.132, $p = 0.049$). However, performance was not influenced by how recently scenes were encoded, and there was not a group by block interaction ($F's(2,74) \leq 0.295$, $p's > 0.05$). These results are informative, and suggest that pictures that were seen more recently are not better detected than pictures that were seen early in the experiment.

DISCUSSION

The current experiment was designed to address questions about whether or not the successful retrieval of relational memory could be expressed and documented in the absence of awareness. The combined use of subliminal masking procedures and eye movement measures to investigate relational memory was novel and represents a substantial departure from past work. While some of the predicted outcomes were not confirmed, two key results suggest that implicit processing of the scene cue influenced the expression of subsequent eye-movement-based relational memory effects. First, more viewing was directed to faces that were studied with the subliminal scene cues but not selected relative to other non-selected faces during the implicit task. Second, the emergence of disproportionate viewing to the correctly identified scene associate was later than predicted for the control group during the explicit task. Results from the post-test confirmed that subliminal scenes were in fact masked from awareness for the experimental group, which was critical to our interpretation of the implicit task data. These results will be subject to further discussion in the paragraphs that follow.

Before turning to the key findings mentioned briefly above, some of the predicted outcomes that were not confirmed will be described. As outlined in the introduction, past studies (Henke et al., 2003; Duss et al., 2011), have indicated that responses are made more quickly when participants correctly guess professions that were presented subliminally with faces than when they guessed incorrectly. The same results were not evident in the response times of control participants. The results from these studies suggest that associations were successfully encoded despite the fact that they were not accessible to awareness. In line with these studies, it was predicted here that there would be differences in reaction times for implicit task trials where the face that had been paired with the subliminal scene cue was selected relative to trials where other faces were selected. Evaluation of reaction time data did not confirm this prediction. Specifically, response times were not faster when participants assigned to the experimental group happened to select the associate of the subliminal scene cue. Although slightly numerically different, response times were well matched across groups and trial types. Therefore, the reaction time differences reported by Henke and colleagues (Henke et al., 2003; Duss et al., 2011) were not replicated in this experiment. However, these analyses have not always been performed in studies investigating implicit associative or relational memory (e.g., Degonda et al., 2005; Reber & Henke, 2011; Henke et al., 2003). Consequently, it is possible that the effect is subject to specific testing conditions, which makes it difficult to replicate. Future experiments will need to investigate when and under what circumstances these response time differences occur.

While the behavioral evidence for relational memory in the absence of awareness was not evident here, several documented effects have been found in the patterns of eye movements directed to stimuli in the absence of awareness, and so it was possible that eye movements would be sensitive to memory in the current investigation. For example, previous work has shown that the influences of memory on eye movement behavior are evident early in viewing, are found consistently even when viewing is counterproductive to the task requirements, and that eye movement measures are sensitive to memory for elements of prior experience even in the absence of conscious awareness (Hayhoe et al., 1998; Hollingworth et al., 2001, 2008 Hollingworth & Henderson, 2002; Henderson & Hollingworth, 2003; Hannula et al., 2007; Ryan et al., 2007; Hannula & Ranganath, 2009; Hannula, et al. 2012). Further, similar effects of memory on eye movements have been documented even when participants are not explicitly instructed to identify the associate or when they make incorrect behavioral responses (e.g, Hannula et al., 2012; Hayhoe et al., 1998; Hollingworth et al., 2001, 2008; Hollingworth & Henderson, 2002; Henderson & Hollingworth, 2003; Ryan & Cohen, 2004a; Ryan et al., 2007). For example, past work has shown that participants look disproportionately at the region of a scene that used to contain an object, even when they fail to explicitly report subsequent manipulations.

While previous work has demonstrated that prior knowledge maintained in memory may influence what areas within a display are fixated and for how long even when participants are unable to reliably report a change (Ryan et al., 2000; Ryan & Cohen, 2004a,b), it may have been the case that participants were aware and just not confident enough to report their awareness subjectively (Hannula & Greene, 2012; Hannula, Simons, & Cohen, 2005). Further, the results of these studies have not been replicated consistently in the absence of awareness (e.g., Smith, Hopkins, & Squire, 2006; Smith and Squire, 2008) and therefore do not provide concrete evidence for relational memory in the absence of awareness. The current work addressed these issues by combining subliminal stimulus presentation with eye movement measures of memory. Most importantly, subjective and objective post-tests were conducted to ensure that the reported results weren't an effect of low level awareness or awareness of the subliminal scenes that participants were not confident to report.

Based on past work, which has demonstrated the sensitivity of eye movements to relational memory for previously studied scene-face pairs (Hannula et al., 2007; Hannula & Ranganath, 2009), we had predicted for the implicit task that participants assigned to the experimental group would look disproportionately at selected faces following subliminal scene cues when that face happened to be the associate. While there was not any evidence for disproportionate viewing directed to selected scene associates, evaluation of the eye movement data did reveal that participants in the experimental group spent more time viewing faces that had been associated with scene cues, but were not selected, as compared to other non-selected faces. This effect was statistically reliable between 1500 and 2000ms after the onset of the 3-face display that followed the subliminal scene cue. Disproportionate viewing to the non-selected critical face reflects relational memory for the face-scene pair because the associate is no more familiar than the other faces and was not located in a particular spatial location. Relational memory effects, evident within 1500-2000 ms of display onset have also been documented in past work. In that experiment, face-scene pairs were encoding at study and at study the 3-face display was presented simultaneously with the scene (i.e., no scene preview; Hannula et al., 2007). Disproportionate viewing to the face that was associated with the scene emerged around 1500-1750 ms and was delayed relative to experiments where participants received a scene cue. It may be the case, in the current experiment, that in the absence of a visible scene cue, effects of selection dominate early viewing, and memory effects emerge subsequently following the selection process (i.e., without the visible cue, effects of memory emerge more slowly). When the same comparisons were made for the control participants, no differences in viewing directed to the non-selected critical face relative to the other non-selected faces were found. This outcome makes sense as critical face had not been the studied associate of the subliminal scene cue for this group. Together, these qualitatively different outcomes suggest that the difference seen for the experimental group likely reflects implicit relational memory for the face-scene pairing.

Skeptics might argue that disproportionate viewing effects outlined above for the implicit task were a consequence of residual awareness of the scene cue. However, subjective and objective measures of awareness indicate that this was not the case. Results from the post-test questionnaire indicated that very few participants suspected the presence of subliminal stimulus presentation. When suspicions were raised, participants did not guess that scenes were embedded in the visual noise sequence. Even after being told about the presence of the scene, none of the participants who reported some awareness of the subliminally presented stimuli were able to reliably report scene content, size, or location on the screen. Because subjective measures are subject to reporting biases, and may reflect uncertainty or low confidence rather than a lack of awareness (Hannula & Greene, 2012; Hannula, Simons, & Cohen, 2005), an objective test of awareness was administered as well. Critically, results indicated that identification of subliminally presented scenes was not better than chance for the experimental group. This suggests that disproportionate viewing directed to the non-selected critical face for the implicit task was not a consequence of residual conscious processing of the masked scene cue.

Previous work has demonstrated the sensitivity of eye movements to relational memory for previously studied pairs (Hannula et al., 2007; Hannula & Ranganath, 2009). Therefore, it was predicted for the explicit task that trials where the associates were correctly identified would have more viewing directed to selected scene associates for both groups. As predicted, results from eye movement analyses for the explicit task indicated that there was disproportionate viewing directed to the face that had been studied with the scene and selected, relative to faces selected in error for both groups. However, the time course was different between the groups. Participants in the experimental group directed significantly more viewing to the correctly identified associate as compared to faces selected in error beginning at 500-750 ms. This finding replicates previous results where eye movements were drawn disproportionately to faces at test that matched the scene at study emerging between 500-750 ms following 3-face display onset and persisting for the rest of the trial (Hannula et al., 2007). The same comparisons made for the control group indicated that disproportionate viewing emerged later in time and was initially evident in the 750-1000 ms time bin. This is later than predicted and notable because we would expect that participants in both groups would have very similar viewing patterns as they are completing the same task, and had the same encoding experience. Indeed, the only difference between groups was whether or not the subliminal scene cue was the associate of one of the faces in the 3-face displays. There are at least two potential explanations for this effect – 1) facilitation: priming experienced by the experimental group to view the associate due to the congruent subliminal cue prior to the explicit task, or 2) interference: the control group recieved an incongruent cue prior to the initial 3-face display which interfered with subsequent viewing of the associate during the explicit task. Because results from the experimental group were as predicted, it seems unlikely that the difference is due to facilitation in that group, but instead is a result of interference experienced by the control group.

That the effect described above may be a consequence of interference caused by the subliminal scene cue is suggested by past work that examined influences of an incongruent subliminal prime, presented prior to a comparison task, on subsequent explicit behavioral responses (Naccache & Dehaene, 2001). In this experiment, participants were briefly presented masked numbers. Following the masked presentation of the number, participants were presented with visible numbers and asked to make a button press indicating whether the visible number was greater than or less than the number five. Critically, the masked number was either congruent with the visible number (e.g., both the masked number and the visible number were greater/less than five) or incongruent (the masked number was greater than five and the visible number was less than five or vice versa). Results from this study indicated that when the masked number and the visible number were incongruent, reaction times were much slower than for baseline trials (the masked stimuli was a series of $'s). The researchers suggested that the masked number primed the participants to make one response or another and when the visible number was incongruent interference is introduced. The participants have prepared responses based on the subliminal cue and when the visible cue is incongruent, it takes time to switch gears to make the correct response. It may be the case in the current experiment that the incongruent subliminal scene cue interferes with the subsequent expression of eye movement based memory effects following the congruent scene cue in the explicit task for the control group. Future work could address questions about whether and how conflicting implicit information interferes with subsequent eye movement based associative memory effects during an explicit task.

In sum, our results add to previous findings by suggesting that the effects of memory on eye movement behavior may occur in the absence of awareness of the retrieval cue. Subliminal cueing appears to influence eye movement behavior such that changes in eye movements occur despite an absence of awareness. The results from this study complement past work that suggests that memory can be successfully documented in the absence of awareness (see Hannula & Greene, 2012; Hannula et al., 2010 for reviews), and strengthen these claims by addressing potential confounds (e.g., low level awareness) that may have contributed to outcomes reported previously. The reported results make contact with and expand upon classic and recent work on picture processing and eye movements, which have suggested memory can be documented reliably in the absence of awareness.

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Appendix

Post-experimental interview

During the experiment you were shown several pictures that looked like noise on a television set and you were asked to perform the alertness test. Did you notice anything in the noise or did you see any regularity in the noise while you were performing the alertness test?

If participant responds 'yes' to the above question, then the experimenter will ask and record responses to the following questions:

Describe what you saw:

Did you see it clearly?

How big was it?

Where on the screen did you see it?

Did you always see it or just sometimes?

In case you saw it only sporadically, when and how often did you see it?

We have asked whether you saw anything in the noise because when you were performing the alertness task, a picture – one of the studied scenes – was being presented very quickly in between the displays of black and white dot patterns. The picture was being presented so quickly that you were unlikely to have noticed it or to have noticed anything out of the ordinary. Now that we have told you about the presence of the scene, do you feel that you may have been aware of this on some of the trials? If so, where exactly do you feel the scenes were located and how big do you feel they were?

Questions and information for all participants:

Did you potentially see contours of letters, words, faces, or objects?

Indoor and outdoor scenes were presented very briefly – for 17ms – in the visual noise. Now that you know this, do you think that you sometimes had a hunch of a scene?

If yes, where exactly did you see scenes? How large were they?

In fact, we presented the scenes in the middle of the screen. The size of the scene was equivalent to the size of the pattern mask. The fixation cross was located at a point that corresponded to the center of the scenes. Now that you know this, do you think you could see any aspects of scenes? Edges? Curves? Changes in contrast? Objects?