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Performance or Processing? Effects of Levels of Processing and Divided Attention on Memory-Related Eye Movements

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PERFORMANCE OR PROCESSING? EFFECTS OF LEVELS OF PROCESSING AND DIVIDED ATTENTION ON MEMORY-RELATED EYE MOVEMENTS

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ABSTRACT

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Human memories are expressed either with or without consciousness, termed as explicit and implicit memories, respectively. Different encoding manipulations like levels of processing and divided attention have been shown to affect explicit memories but not implicit memories. These dissociations, however, were only found between explicit and implicit item memories. Whether explicit and implicit relational memories will exhibit similar dissociations is still unknown. In order to determine whether explicit and implicit relational memories dissociated in a similar way as explicit and implicit item memories, the levels of processing and divided attention were manipulated in the present study and participants' relational memories were tested either directly or indirectly while their eye movements were recorded simultaneously as an index of implicit relational memory suggested by previous studies. It was predicted that dissociations would be observed between explicit and implicit relational memories only if implicit relational memory behaved like implicit item memory. However, several pilot studies showed that there was no memory effect in the implicit relational memory. Therefore, the eye tracking experiments were modified and the effects of levels of processing and divided attention manipulations on human eye movements in direct relational memory tests were examined.

Participants' eye movements were affected by the levels of processing manipulation, although there was no main effect of the divided attention manipulation. Therefore, the different eye movements may be associated with the levels of processing specifically rather than levels of performance in general.

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CHAPTER 1

INTRODUCTION

Explicit and implicit memories

Early in the 1960s, researchers found that hippocampal lesions in the Medial Temporal Lobe (MTL) led to deficits in a conscious form of memory in amnesic patients but spared their memory for previous experience when conscious access to such experience was not required by the task (e.g., Warrington & Weiskrantz, 1968). These two kinds of memories have been called explicit and implicit memories respectively. Dissociations between explicit and implicit memories in normal, healthy participants have been found in terms of levels of processing, study-test modality changes, retention interval, influence of retroactive and proactive interference (Schacter, 1987), and divided attention manipulations (e.g., Jacoby, 1996; Jacoby et al., 1989; Jennings & Jacoby, 1993; Wolters & Prinsen, 1997). For example, Jacoby (1983) found that reading a single word aloud, reading it in a meaningful context, and generating it from a meaningful context have different effects on recognition memory (explicit test) and perceptual identification (implicit test) and similar dissociations between explicit and implicit tests in terms of reading and generating encoding conditions have been observed in other studies as well (e.g., Smith & Branscombe, 1988). In Jacoby's (1983) study, as the encoding level progressed from a shallow level (reading the word aloud) to a deeper level (generating a word from the context), explicit memory performance improved but the opposite trend was observed for implicit memory performance. Moreover, the picture superiority effect (which refers to the finding that concepts are usually better remembered when they are presented as pictures than as words) found in explicit memory tasks was reversed in an

implicit perceptual test (Weldon & Roediger, 1987). Although pictures elicited better memory performance than words on an explicit free recall test, words elicited better performance on an implicit word fragment completion test, which further suggested that explicit and implicit memories are quite different.

In addition to the dissociations observed in normal participants, double dissociations between explicit and implicit memory tests have been documented with normal participants and amnesic patients. For example, normal participants performed better than amnesic patients in explicit free recall and recognition tests but their performance in implicit word fragment identification and word stem completion tasks was similar (Warrington & Weiskrantz, 1970). Although implicit memories for single items (such as words) can be preserved in amnesic patients, whether implicit memories for associations of items (such as word pairs) are intact in amnesiac patients has been fiercely debated. Some studies have provided evidence indicating that amnesic patients can learn new word pair associations implicitly despite damage to the hippocampus (e.g., Graf & Schacter, 1985). Other studies, however, have found that amnesic patients could not learn new associations of word pairs as normal participants due to the damage to their hippocampus, which was consistent with the idea that learning associations between random items depends on intact hippocampus (e.g., Shimamura & Squire, 1989). For example, Graf and Schacter (1985) asked participants to study unrelated word pairs and then gave them a word completion task with either a studied word (same-context condition) or a new word (different-context condition) as the associative context. They found that the priming effects were larger in the same-context condition than in the different-context condition and this was true for both healthy college students and

amnesic patients. They interpreted this to mean that the implicit memory for new associations is preserved in amnesic patients. In a study conducted by Goshen-Gottstein, Moscovitch, and Melo (2000), both healthy control subjects and amnesic patients were instructed to study word pairs within a sentence. When tested, participants were given both an explicit speeded recognition test and an implicit lexical decision test on the studied words that were either in the intact pairs or in the recombined pairs. Both groups of participants exhibited faster and more accurate responses to the intact word pairs than to the recombined pairs in the implicit lexical-decision task, indicating intact implicit associative memory in both groups. However, Shimamura and Squire (1989) conducted a similar study to that of Graf and Schacter (1985) and found something different. They also asked control subjects and amnesic patients to study unrelated word pairs and later tested their memory for the studied words for either the same or recombined pairs in a word completion task. Contrary to the results in Graf and Schacter (1985), implicit memory was impaired for amnesic patients relative to healthy controls and amnesic patients' performance did not differ between the same-context and different-context conditions. Debate over whether learning new associations between items is implicit has been ongoing since the 1980s and lead to the research question in the present study.

Relational memory theory

It is now widely accepted that human memory is not a single unit but it consists of different systems or components. For example, human memory can be divided into two general systems: a declarative memory system and a nondeclarative memory system (Squire, 1992; 2004). Generally speaking, declarative memory refers to the conscious retrieval of facts or knowledge about the world as well as personal experiences or events.

In contrast, nondeclarative memory includes memories for skills, priming and perceptual learning, simple classical conditioning, and nonassociative learning (Squire, 2004). In other words, declarative memories can be considered as "knowing that" whereas nondeclarative memories can be considered as "knowing how" (Cohen & Squire, 1980). Declarative memory is considered explicit, relational, and dependent on MTL structures (especially the hippocampus), whereas most forms of nondeclarative memory do not depend on that structure (Squire, 1992). According to this division, the memory deficits observed in amnesic patients with damage to the MTL are likely due to selective impairments in their declarative memory system. Their nondeclarative memory system, however, should be intact because evidence indicates that they still have the ability to learn skills and perform procedures (e.g., Cohen & Squire, 1980).

Human memory can also be divided into item memory and relational memory. Item memory refers to memory for individual items (e.g., words, pictures, people) whereas relational memory refers to memory for relations among items. For example, remembering people's names or faces are item memories, whereas associating their names with their faces and remembering such name-face associations are relational memories. According to the relational memory theory (Cohen & Eichenbaum, 1993; Cohen et al., 1997) developed from declarative memory theory (Squire, 1992; 2004), declarative memory is hippocampus-dependent and its representations are fundamentally relational, flexible, and capable of being used in novel contexts. Procedural memory, however, is hippocampus-independent and its representations are nonrelational and inflexible. Although relational memory theory also emphasizes declarative memory and claims the role of the hippocampus in processing relational information, it is quite

different from the declarative memory theory proposed by Squire (1992) who claims that the relational processing relies on the entire MTL structure rather than just the hippocampus. Consistent with relational memory theory, amnesic patients with hippocampal lesions have been shown to exhibit deficits in relational memory tasks (e.g., Hannula et al., 2007; Ryan et al., 2000). In addition, such deficits have been found even at very short delays across both spatial and non-spatial relations (Hannula et al., 2006; see Ryan & Cohen, 2004 for the opposite findings where short-term retention of relational information is intact in amnesiacs). Although the hippocampus appears to be very important for processing spatial information, relational processing is not exclusively spatial and hippocampal neurons have been found to be active in many nonspatial tasks as well (Cohen & Eichenbaum, 1993). By comparing item and relational memories with the same materials, Konkel et al. (2008) found that lesions in the hippocampus of amnesic patients can cause impairments in all types of relational memory including spatial, associative (co-occurrence), and sequential (temporal) relations, even though these patients' item memories are relatively intact. Such results suggest again that the hippocampus is the neural substrate underlying relational memory. However, surrounding cortical structures (e.g., the perirhinal cortex) are sufficient for memories of single items.

According to relational memory theory all declarative memory could be relational in terms of the nature of the memory representations[1]. However, whether relational memories are necessarily conscious or explicit is of great interest. That is, is there any possibility that relational memory could be implicit as well? Relational memory theorists would likely claim that the hippocampus is necessary for relational memories and those

[1] Even for item memories, there could still be relational representations available. For example, the representations for individual items such as words can be associated with contextual information such as the room in which these words are encoded.

memories can be either explicit or implicit. Therefore according to relational memory theory, amnesic patients (with MTL damage) should perform poorly on relational memory tasks whether they are explicit or implicit. From an explicit/implicit perspective (specifically declarative memory theory), consciousness is the primary issue. Theorists taking this perceptive would likely claim that consciousness is a necessity for hippocampus-dependent memory (declarative memory). Therefore, amnesic patients should exhibit deficits only for tasks demanding explicit memory, no matter whether such memory is for relations or for items.

Evidence for implicit relational memory

Several studies have demonstrated that hippocampus-dependent relational memory can be separated from consciousness and these researchers suggest that relational memory can be implicit. For example, Chun and Phelps (1999) conducted a visual search task in which participants were asked to find a target letter "T" among a group of letter "L"s and some of the visual displays were repeated throughout the trials. They found that amnesic patients with hippocampal lesions did not benefit from the repetition of the contextual displays in the visual search task whereas normal control participants' performance was facilitated by them. This result was used to support a hippocampus-dependent relational memory effect. For normal participants who benefitted from the contextual memory of the spatial layouts, their performance of explicitly discriminating repeated displays from non-repeated displays was at chance, suggesting such hippocampus-dependent relational memory for the context display was implicit. Following Chun and Phelps's (1999) neuropsychological findings, Green, Gross, Elsinger, and Rao (2007) used the same context cueing task as in Chun and Phelps (1999)

with event-related functional Magnetic Resonance Imaging (fMRI) with normal participants. The behavioral results replicated the findings of Chun and Phelps (1999). In addition, even though participants failed to discriminate the repeated contexts from non-repeated contexts in a recognition test immediately after scanning, hippocampal activation was observed which appeared to differentiate repeated contexts from novel contexts. In another two fMRI studies, Henke, Treyer, Nagy, Kneifel, Dursteler, Nitsch, et al. (2003) and Henke, Mondadori, Treyer, Nitsch, Buck, and Hock (2003) found evidence that associative representations for masked human faces and accompanying professions could be expressed without their subjective awareness. Participants were exposed to a series of face-profession pairs that were visually masked during encoding. At test, they were shown the face and asked to guess the profession. Reaction time was significantly faster for correct guesses than for incorrect guesses and this difference was correlated with the neural activation in brain structures related to successful memory retrieval (i.e., the right perirhinal cortex and the left hippocampus). Because the materials were masked participants' memories for the pairs could be considered implicit, which provides further support for the separation between relational memory and consciousness.

By using a neuropharmacological approach with within-subjects design, Park et al. (2004) demonstrated that hippocampus-dependent relational memory could be implicit. After being injected with either midazolam (a Benzodiazepine that impairs hippocampal functions) or saline, participants were asked to perform a visual search task similar to the one used by Chun and Phelps (1999) in which some of the displays were repeated. In this study, the contextual-cuing effect (reduced reaction time for repeated visual displays compared to novel visual displays) was only observed under the saline injection condition.

Participants neither noticed display repetitions nor adopted any explicit strategies to help them complete the visual search task. These results may be interpreted to suggest the existence of an implicit hippocampus-dependent relational memory.

Another kind of evidence supporting the existence of implicit relational memory comes from studies measuring eye-movements. Ryan, Althoff, Whitlow, and Cohen (2000) presented a series of scenes to participants and measured their eye movements as an indirect index for memory across the scenes. Scene pictures were presented twice before a final viewing opportunity. During the final viewing, some scenes were repeated a third time, some were repeated but with a critical area of the scene changed, and some scenes were novel. Comparison of eye movements across the three trial types revealed that fixations and viewing time of the critical area increased only for trials that included a change. Moreover, this effect was only observed when participants failed to explicitly identify the changes in the manipulated scenes and was absent in amnesic groups, suggesting that it is an effect of implicit relational memory.

Hannula, Ryan, Tranel, and Cohen (2007) also investigated relational memory by measuring eye movements. They asked participants to study a series of scene-face pairs and later tested their memory for scene-face associations. In the study phase, a scene picture was first presented for 3 seconds followed by a face superimposed onto that scene and these face-scene pairs were presented for another 5 seconds. Participants were instructed to study the picture pairs. In the test phase, a previously studied scene was presented for 3 seconds before three faces were superimposed onto that scene, and this three face-scene display was presented for another 10 seconds. Participants were instructed to choose the face that matched the background from the study session. There

were three different types of trials in the test phase depending on the status of the faces. For *Matching* trials, all three faces were studied and one of them matched the background scene. For *Nonmatching* trials, all three faces were studied but none of them matched the background scene. For *Novel* trials, none of the three faces were studied previously. Results showed that, compared to the non-matching studied faces, participants spent significantly more time viewing the face that had been studied with the scene picture. As the time course analysis showed, this difference in viewing time emerged earlier than explicit behavioral responses. Such preferential viewing for studied-matching faces (compared to studied-nonmatching faces) was considered to index memory for the relationship between face-scene pairs and it was absent in amnesic patients. Moreover, in a subsequent study with the same paradigm using fMRI (Hannula & Ranganath, 2009), hippocampal activation during the preview phase of a scene cue (before the three faces and scene combination appeared) was significantly higher for trials where participants viewed the matching face for a longer time compared to trials where they viewed the non-matching face more, even when their explicit memory selections for the matching faces were incorrect.

Evidence against implicit relational memory

Although the existence of implicit relational memory seems very convincing based on the studies already described, there is also evidence against it. According to declarative memory theory, consciousness and hippocampus-dependent relational representations might not be separate from each other. For example, Clark and Squire (1998) found that amnesic patients failed to acquire trace conditioning. Normal participants could acquire trace conditioning but only if they became aware of the

relationship between the separated conditional stimuli (CS) and unconditional stimuli (US). Trace conditioning requires the involvement of the hippocampus, therefore these results indicate that consciousness is necessary for hippocampus-dependent memory and consciousness and hippocampus-dependent memory cannot be separated from each other. Therefore, as a form of hippocampus-dependent memory, relational memory might be necessarily conscious.

Using the same visual search task adopted by Chun and Phelps (1999), Manns and Squire (2001) found the exact opposite results: both amnesic patients with hippocampal lesions and normal control participants benefitted from the repetition of background displays and had faster reaction times to repeated (old) displays compared to non-repeated (new) displays. They interpreted the results to mean that such contextual memory effects were not hippocampus-dependent and, as a result, challenged the idea of implicit relational memory. According to the authors, however, the failure to observe the anticipated facilitation in amnesic patients (as found by Chun and Phelps, 1999) study might have been due to the presence of more extensive lesions in the amnesiac patients that included areas outside the hippocampus.

Preston and Gabrieli (2008) also conducted a modified version of the visual search task adopted by Chun and Phelps (1999) using fMRI scanning. Participants exhibited context-dependent memory indexed by reduced reaction time to repeated contexts relative to novel contexts, regardless of whether they could later explicitly recognize the repeated displays. However, the authors claimed that such memory was not relational but configural[2], a type of memory that depends on the perirhinal cortex rather

[2] Contrary to relational representations, configural representations are not flexible and cannot be used in novel contexts. Elements in configural representations are bound into a unitized memory trace (Preston &

than the hippocampus. Critically, a significant difference in hippocampal activity between recognized old displays and unrecognized old displays was only observed when participants could later explicitly identify those repeated displays, which also challenged the existence of implicit relational memory.

Challenges to implicit relational memory have also been found in studies including eye movement analysis. Smith, Hopkins, and Squire (2006) and Smith and Squire (2008) conducted studies with the eye movement paradigm adopted by Ryan et al. (2000) and they found that only participants who were subsequently aware of the manipulations viewed the critical regions (where change occurred) of manipulated pictures more than repeated and novel pictures. This finding was used to support the notion that relational memory for the elements within the scene pictures was not implicit but explicit. However, the way the eye movement data were analyzed was different between the Smith et al. (2006, 2008) and Hannula et al. (2007, 2009) studies and the different analysis methods might have contributed to the opposite results observed in these studies (Hannula et al., 2010). In the Smith et al. (2006, 2008) study, the proportion of viewing time was equal to the amount of time spent viewing the manipulated critical region divided by the entire trial duration, whereas in the Ryan et al. (2000) and Hannula et al. (2007) studies, the proportion of viewing time was equal to the amount of time spent viewing the manipulated critical region or the matching face divided by the actual amount of time directed to the stimuli.

Gabrieli, 2008) by the entorhinal/perirhinal cortex rather than the hippocampus. Therefore, configural representations can only be expressed in the repetitions of the initial learning situations. An example of relational representation can be the association between previously studied people's faces and names, no matter whether the faces are with the exact same expressions or whether the names are written in the same fonts as they were first studied. In contrast, a configural representation must be the exact faces and names as studied and it is just a repetition of the initial stimuli.

Proposed experiments

Some of the studies support the existence of implicit relational memory while others do not. However, two critical points should be noted. First, in the studies using a visual search task, interpretation of the data depends on our understanding of whether the representations of the stimuli are relational or configural. Relational representations are based on the relationship among the individual items and are flexible; whereas configural representations are based on the global configuration of the individual items and are inflexible. The ongoing debate about whether the representations in the contextual cueing task (the visual search task adopted by Chun and Phelps (1999)) are relational or configural make it unclear whether data from those tasks really address questions about relational memory. Second, for the studies using eye trackers, whether the memory of the relations among visual elements appears to be implicit or not seems to depend on the way the data is analyzed. During each trial, participants' gaze may not be always on the stimuli (e.g., gazing at something else on the computer monitor or just blinking). If the entire trial duration rather, than the actual amount of time participants spent on the stimuli, is taken as the denominator for calculating the proportion of viewing time, it is likely that the actual proportion of viewing time will be underestimated and a positive result might be concealed.

In addition, recall that the dissociations between explicit/implicit item memories have been well documented, but the evidence on potential dissociations between explicit/implicit relational memories is still unclear. Different encoding manipulations such as levels of processing and full/divided attention have been shown to affect explicit item memory but not implicit item memory. It is unclear whether similar differences exist

between explicit and implicit relational memories. Therefore, the aims of the present study were (1) to try to replicate prior findings of implicit relational memory; (2) to investigate whether the dissociation between explicit/implicit relational memories differs from the dissociation between explicit/implicit item memories in terms of levels of processing and full/divided attention manipulations. A paradigm similar to that in Hannula et al's (2007, 2009) was adopted. Participants were exposed to different encoding manipulations (such as levels of processing and full/divided attention) during the study of object-landscape picture pairs. Later they were tested on their memory of the association of the picture pairs either directly or indirectly while their eye movements were recorded[3]. Eye tracking has been considered as a very useful tool to investigate human memory (Hannula et al., 2010, 2012) and many studies have used participants' eye movements to reveal memory effects (e.g., Althoff & Cohen, 1999; Ryan et al., 2000, 2007; Hannula et al, 2007, 2009). Inclusion of eye movements were included in order to investigate whether there was a relational memory effect indexed by both behavioral and eye movement data, even when it was tested indirectly. Furthermore, the configuration of the current studies allowed consideration of how direct and indirect relational tests dissociated under different encoding manipulations.

If implicit relational memory has similar characteristics to implicit item memory as declarative memory theory would predict, the different encoding manipulations should only affect explicit relational/item memory but leave implicit relational/item memory

[3]In the field of explicit/implicit memory study, it is important to distinguish between "explicit/implicit" and "direct/indirect" (Kelly & Lindsay, 1996). According to Johnson and Hasher (1987), "direct/indirect" tests refer to tasks requiring responses with/without conscious expressions of previous experience and are used to describe the nature of the tasks. In contrast, "explicit/implicit" refers to the memory systems that are recruited to complete certain tasks. In the current study, "direct/indirect" distinction is used to describe the two kinds of tests and the corresponding memory performance on those tests.

untouched (see Table 1). It is possible, however, that relational memory operates by a single set of principles, regardless of whether it is explicit or implicit. If that is the case, relational memory will be affected by the levels of processing manipulations, regardless of how the memory is expressed later.

CHAPTER 2

BEHAVIORAL PILOT EXPERIMENTS

Before beginning the formal experiments with the eye tracker to test the hypothesis, four behavioral pilot tests were conducted (two are reported here in details) with the levels of processing manipulation and a paradigm similar to Hannula et al.'s (2007) to see whether the expected results on direct and indirect relational memory tests at the behavioral level could be achieved.

Pilot 1

The first pilot test addressed whether both explicit and implicit relational memories could be affected by the levels of processing manipulation. The procedure of this pilot was the same as the procedure of the later eye tracking study so that the effectiveness of the manipulations that would be used in the eye tracking study could be evaluated.

Methods

Participants

Fifty-four healthy college students from the University of Nevada, Las Vegas (UNLV) were recruited to participate in pilot 1. All participants had normal or corrected to normal vision and none of them had been diagnosed with any mental disorders that could potentially hurt their memory performance. Participants were compensated with course credits for their participation.

Materials and design

One hundred and eighty-four salient landscape pictures (such as mountains and deserts) and 184 object pictures (such as chairs and puppies) were used. Another 12

landscape pictures and 12 object pictures were used in the practice phase before the formal part of the experiment started. Landscape pictures were 500 × 400 pixel landscape wallpapers collected from online sources. Two hundred and sixty object pictures were 200 × 140 pixel Snodgrrass and Vanderwort-like object drawing from the Tarr's lab[4] (Rossion & Pourtois, 2004) and the rest were similar object drawings with the same size found online. All pictures were presented with Eprime 1.2 software on a computer screen.

The present pilot was a 2 (deep/shallow) × 2 (direct/indirect) between subject experimental design. These two independent variables were the deep/shallow encoding manipulations and the direct/indirect retrieval manipulations respectively. Participants were randomly assigned into each condition.

Procedure

The experiment was separated into two phases: a study phase and a test phase. Before the formal study phase started, participants completed a short keyboard task to practice with the four response keys which were used in the test phase.

At the study phase, a landscape picture was first shown on the screen for 2 seconds. Immediately after that, an object picture was superimposed onto the center of the landscape picture. These two pictures were then shown together for another 4 seconds. The interval between two successive trials was 1.5 seconds, during which there was a fixation presented on the center of the screen (see Figure 1). Participants were divided into two different encoding condition groups: deep and shallow levels of encoding. In the deep encoding condition, participants were asked to judge whether they thought the object-background picture pair (e.g., a nose and a forest) was pleasant or not by pressing one of two buttons for a "yes" response and the other one for a "no" response. In the

[4] The website link for the stimuli of Tarr's lab is: http://stims.cnbc.cmu.edu/Image%20Databases/TarrLab/

shallow encoding condition participants were asked to judge whether they thought the major color of the object matched the major color of the background landscape picture or not by giving a "yes" or a "no" response by depressing the respective keyboard buttons. For both encoding conditions, participants were informed that there were no correct answers to the judgment and they were encouraged to respond on their own criteria.

At the test phase, a studied landscape picture was first presented for 2 seconds. Immediately after that, three object pictures were superimposed in a triangle pattern in the center of a studied landscape picture and presented for another 10 seconds (see Figure 1). The interval between two successive trials was also 1.5 seconds. There were three types of trials in the test phase: 1) 20 *Matching* trials in which all of the three objects had been studied and one of the three objects matched the background landscape picture in the previous study phase; 2) 20 *Nonmatching* trials in which all of the three objects had been studied but none of them matched the background picture; and 3) 20 *Novel* trials in which all the three objects were new. All background landscapes were old. For *Matching* trials, the position of the actual matching object was randomized among the three locations within the display.

Participants were also assigned into either a direct or indirect condition. In the direct condition, participants were asked to identify which of the three objects (left, right, or bottom) was paired with the background landscape picture in the previous study phase by pressing one of three buttons corresponding to the three objects on the screen. In the indirect condition, participants were asked to select which one of the three objects (left, right, or bottom) they thought was most related to the background picture by pressing one of three buttons representing the objects' location. They were instructed to press a forth

button to indicate "none of them" if they did not think any of the three object pictures met the task requirements. For both test condition groups, participants were asked to respond as soon as they made their decisions. The entire test phase was grouped into 4 blocks with a short break between two successive blocks.

Results

For data analysis, participants' performance was indicated by *d'* for the *Matching* trials and false alarm rate for the *Nonmatching* and *Novel* trials in both direct and indirect tests. According to the Signal Detection Theory (SDT), the *d'* parameter is used to indicate participants' sensitivity and it is calculated by the formula *d'* = Z(hit rate) - Z(false alarm rate). Because the matching objects that had a relationship with the old backgrounds only existed in the *Matching* trials and participants were given three response keys to select any of the three objects plus an additional response key to choose "none of them", the hit rate in this formula was defined as the probability of selecting the matching object as the target in the total 20 *Matching* trials, whereas the false alarm rate was defined as the probability of selecting a nonmatching object as the target in the *Matching* trials, regardless of whether the test was direct or indirect. Similarly, for *Nonmatching* and *Novel* trials, the false alarm rate was defined as the probability of selecting a nonmatching or a novel object as the target respectively.

For the *Matching* trials (see Figure 2 and Table 2), a 2 (deep/shallow) × 2 (direct/indirect) ANOVA on the *d'* parameter showed that there was a significant main effect of levels of processing manipulation, $F(1, 50)=6.379$, $p=0.015$, partial $\eta^2=0.113$, suggesting that participants generally exhibited higher sensitivity in the deep condition compared to the shallow condition. In addition, there was a significant main effect of task

type, $F(1, 50)=4.162$, $p=0.047$, partial $\eta^2=0.077$, suggesting that participants' *d'* was generally higher in the direct condition than indirect condition. The interaction of LOP and task type was not significant, $F(1, 50)=0.341$, $p=0.562$, partial $\eta^2=0.007$. Planned independent t-tests between deep and shallow conditions on each level of task type further showed that the greater *d'* in deep than in shallow condition only existed in the direct tests, $t(21)=2.010$, $p=0.057$, but not in the indirect tests, $t(26)=1.650$, $p=0.111$[5]. However, the overall performance was very low in all four conditions. Another two 2 (deep/shallow) × 2 (direct/indirect) ANOVAs conducted on the false alarm rates of *Nonmatching* and *Novel* trials showed that there were no main effect of levels of processing manipulation for either type of trials, $F(1, 50)=0.383$, $p=0.539$, partial $\eta^2=0.008$; $F(1, 50)=0.396$, $p=0.532$, partial $\eta^2=0.008$, respectively. The main effect of task type was significant for both type of trials, $F(1, 50)=5.130$, $p=0.028$, partial $\eta^2=0.093$; $F(1, 50)=4.397$, $p=0.041$, partial $\eta^2=0.081$, respectively. There were no interactions of LOP and task type for either type of trials, $F(1, 50)=0.821$, $p=0.369$, partial $\eta^2=0.016$; $F(1, 50)=0.273$, $p=0.604$, partial $\eta^2=0.005$, respectively.

Discussion

In Pilot 1, there seemed to be a levels of processing (LOP) effect on participants' sensitivity only in the *Matching* trials in the direct test where they were required to directly use their relational memories for the object-scene pairs but not in the indirect test. Participants in the deep condition exhibited greater sensitivity towards the object-scene

[5]There were 25 participants in the deep condition and 29 participants in the shallow condition. Because the *d'* reported here was calculated by using the formula *d'* = Z(Hit rate) - Z(False Alarm rate), two participants in the deep condition whose False Alarm rates were 0 and one participant in the shallow condition whose Hit rate was 0 were not included for these two comparisons between *d'*s respectively. Therefore, the degrees of freedom for these two independent t-tests were 21 and 26 respectively (instead of 23 and 27).

pairs than those in the shallow condition. For the indirect test, however, there was no difference in terms of sensitivity between deep and shallow conditions. These results appeared to demonstrate the dissociation between direct and indirect relational memories under the manipulation of levels of processing. However, one problem was that participants' overall performance was so low that *d'* was not different than the 0 chance level in three out of four conditions (deep direct condition, shallow direct condition, and deep indirect condition), *p*s>0.144, suggesting that prior exposure to these object-scene pairs had no memory effect in one of the direct tests and no influence on participants' selections in the indirect tests. Therefore, the null effect of levels of processing in the indirect test might have been due to the floor performance in both the deep and shallow conditions. Because there were only 20 *Matching* trials, a very small variation in the number of correct trials could have a big effect on both the hit rate and the false alarm rate. For example, if a participant got 11 out 20 *Matching* trials correct, the corresponding *d'* was 0.25. However, if he/she got 10 out of 20 *Matching* trials correct, the corresponding *d'* was 0.

In addition to floor performance issues, there are several other possible explanations for the null effect of levels of processing in the indirect test. First, the object-landscape relatedness task might not be very effective in terms of measuring participants' indirect relational memories. It is possible that the judgment of the relatedness of the objects and their backgrounds primarily depended on the natural semantic or perceptual relationship between the picture pairs rather than the prior exposure of the pairing. For example, a picture of a fork, a picture of a football, and a picture of a boat were presented together on a background of a river in the test session.

The fork was paired with the river in the study session, but when asked to select which one of the three was most related to the background, participants might just select the boat as the target instead of the fork, even if they were aware of the previous pairing of the fork and the river. Similarly, participants might select a nontarget object as most related to the background because of the similar perceptual features (e.g., color or shape) the nontarget shared with the background. In these cases, participants' selections could not be used as an indirect measurement of their relational memories of the picture pairs. Perhaps the LOP effect would have been observed if a more effective indirect task was adopted. Unfortunately, there are no existing implicit memory tests for relational memory using images in the literature[6]. In developing the indirect task, the relational judgment seemed to be the most promising task, but it is not clear what other judgments might be influenced by relational memories of these images.

A second potential reason for a null effect might be a true absence of the LOP effect. It is possible that there would have been no LOP effect even if the task does measure implicit relational memory. Prior exposure to the pairs at different levels simply may not bias participants' selections in an indirect task. Another possibility was that there was no indirect (or implicit) relational memory in the first place. Just as the declarative memory theory argued, it may be that the human brain (especially the hippocampus) could not deal with relational representations without the involvement of consciousness.

In the next pilot, the procedure was modified by removing the "none of them" response choice and forcing participants to make a selection from among the objects even if they did not think there was a target. The forced choice requirement was also consistent

[6]Another route might have been to speed participants' responses. However, it was not possible to incorporate with the eye tracker because of the time frame over which eye movements were examined.

with the original procedure in Hannula et al. (2007). The goal was to improve the overall performance. This change was in response to the notion that it was possible that the LOP effect was not found in the indirect tests because of the low performance and it might be observed once the overall performance was improved.

Pilot 2

The intention of the second pilot test was to investigate whether the LOP effect existed in the indirect object-landscape relatedness task.

Methods

Participants

Twenty-five college students from UNLV were recruited with the same standards as in pilot test 1 to participate in pilot test 2.

Materials and design

The same set of materials was used in pilot test 2, and the experimental design of pilot test 2 was the same as in pilot test 1 except that there were only indirect tests and participants were forced to make a selection on each trial.

Procedure

The general procedure of pilot test 2 was similar to that of pilot test 1, except that the fourth response choice of "none of them" was discontinued which forced participants to make a selection for each trial even if they did not think there was a target. Furthermore, all participants were tested under the indirect condition only. After participants successfully finished the object-landscape relatedness task, a post-test questionnaire (see Appendix 2) was also given to participants to investigate their awareness of the relationship between the object and landscape scenes in the indirect tests.

Results

For the *Matching* trials (see Figure 3 and Table 3), an independent t-test on the *d'* of the indirect tests between deep and shallow conditions revealed that there was no main effect of levels of processing, $t(23)=0.646$, $p=0.525$, suggesting that there was no difference in participants' sensitivity between deep and shallow encoding conditions. Moreover, the *d'*s in both deep and shallow encoding conditions were not different than the 0 chance level, ps>0.113. Again, it seemed that the prior exposure of the object-scene pairs had no effect on participants' selections in the indirect tests even if they were forced to make a selection for each trial. For both the *Nonmatching* and *Novel* trials, because the "none of them" key was removed and participants were forced to make a selection, their false alarm rate was 1.00 for both deep and shallow encoding conditions.

For the awareness questionnaires, participants' responses to the last two questions were of primary interest: 1) "Did you notice any relations between the landscapes and objects while you were doing this task?" and 2) "Did you intentionally use your memory of the landscape-object pairs to complete this task or not?". Ten out of 12 participants (83%) in the deep condition reported that they did notice the relationship between the objects and the backgrounds, and three out of the 12 (25%) reported they did intentionally use their memories of the picture pairs to complete the object-landscape relatedness judgment task. For participants in the shallow encoding condition, 12 out of 13 (92%) reported they noticed the relationship, and four out of 13 (31%) reported they intentionally used their memories to fulfill the task. It seemed that most of the participants were able to notice the relationship between the matching objects and their

backgrounds, even though they might not use such relationship to help them fulfill the task.

Discussion

In pilot test 2, participants in the indirect test where they were required to select which one of the three objects they thought was mostly related to the given background were considered. Again, the levels of processing manipulation did not influence participants' selection in this task and their performance was the same in the deep and shallow encoding conditions. However, sensitivity indexed by the *d'* parameter was at chance level for both conditions. Therefore, it was not possible to rule out floor performance as a reason for the absence of an LOP effect.

As discussed in pilot test 1, the null effect of the levels of processing manipulation might be explained in different ways. In addition to the pilots reported above, two other pilots using the same paradigm as pilot test 1 and 2 were also conducted and they also failed to reveal an influence of memory on the relatedness judgment[7]. Thus, these pilot studies indicated that the indirect task was not effective in terms of measuring implicit relational memories, either because the judgment itself does not reflect a memory influence or because there is no memory to influence in the first place. As a result it might not be worth using this task in the eye tracking experiments.

Modification of proposed experiments

Based on the floor performance and null results of the behavioral pilots and after careful consideration, significant changes were made to the proposed experiments. Given the failure to find any indirect test that would work in the current paradigm to measure

[7]The general procedures of these two earlier pilots were the same as those of Pilot 1 except for several minor changes, e.g., shorter study duration (2s) and no keyboard practice. Given that the same patterns of results were found in these two pilots as in Pilot 1, they are not reported here in this paper.

implicit relational memory, the indirect tests were removed and focus was shifted to the effects of levels of processing and divided attention on the direct relational memories, particularly on how these manipulations could affect participants' eye movements at retrieval. Although human eye movements have become very good indexes of memory effects (Hannula, 2010), there have been no studies examining the effects of common and popular manipulations like levels of processing and divided attention on participants' eye movements. Given that both levels of processing and divided attention manipulations have shown robust effects at the behavioral level in previous studies, it would be interesting and informative to determine whether those memory effects are also reflected at the eye movement level.

Over the past few decades, levels of processing theory has been influential in explaining better memory performance under conditions where materials are encoded at a deeper level (e.g., judging the pleasantness of the materials) compared to conditions where materials are encoded at a mover shallow level (e.g., judging the perceptual features of the materials) (Craik & Lockhart, 1972; Craik, 2002). It would appear that there have been no studies directly addressing the effect of levels of processing on memory dependent eye movements, and several studies indirectly connected the eye tracking methodology with the levels of processing framework. For example, by conducting a series of four experiments using eye tracking, Reingold (2002) demonstrated that participants' recognition memory performance for pictures was better when the viewing modes towards these pictures matched between encoding and retrieval compared to when their viewing modes mismatched (viewing modes were defined by the length of saccades required to align gaze point with certain areas of interest within the

picture and the direction of saccades across the image). Moreover, this perceptual specificity effect was only observed under high overlap in perceptual processing (e.g., repeated pictures) between encoding and retrieval rather than under high overlap in semantic processing (e.g., semantically related but visually different pictures), and was larger for non-verbal materials than verbal materials, suggesting the influence of perceptual factors on memory performance. These results were discussed with the levels of processing theory which is considered more robust with verbal materials than with non-verbal materials. In addition to the traditional perceptual and semantic processing levels proposed by Craik and Lockhart (1972), Velichkovsky (2002) expanded the original framework into a multilevel hierarchy with extra processing levels "below" perceptual (form-oriented) processing and levels "above" semantic (metacognitive) processing. Velichkovsky (2002) used eye tracking methodology in a virtual driving task to monitor participants' perception and reaction to sudden affective visual events (e.g., abrupt change of traffic light from green to red; a pedestrian jumping onto the road), and participants' eye tracking data revealed two levels of visual processing. First was a relatively lower level of ambient visual processing manifested by fixations with shorter duration and saccades with larger amplitude, which was considered pre-attentional. The other was a relatively higher level of focal visual processing manifested by fixations with longer duration and saccades with smaller amplitude, which was considered attentional and could facilitate detailed perceptual processing and corresponding behavioral reactions (e.g., braking the car). These results suggested that different eye movements could be used to index different levels of processing in visual perception.

In the present study participants' eye movements were only recorded at retrieval rather than encoding. Intuitively these different eye movements should be associated with different levels of memory performance under the levels of processing and divided attention manipulations. That is, memory dependent eye movements at retrieval might reflect the overall memory strength caused by the manipulations in general. If so, different eye movements (e.g., different amount of fixations and viewing time) under both LOP and DA manipulations corresponding to different levels of memory performance at the behavioral level were expected. Alternatively, given that different eye movements during perceptual tasks could be associated with different levels of processing in visual perception as mentioned earlier, it is also possible that the memory dependent eye movements could be associated with different levels of processing in memory encoding rather than just the levels of performance. If so, different eye movements would be observed only under the LOP manipulation but not under the DA manipulation. Such dissociation would indicate that eye movements at retrieval could be specific and reflect different levels of processing at encoding.

Therefore, in the modified eye tracking experiments, the focus was shifted from the dissociation between direct/indirect relational memories under the levels of processing and divided attention manipulations to the effects of these two manipulations on memory dependent eye movements in the direct relational memory tests. In addition, whether the eye movements recorded at retrieval would reflect different levels of memory performance in general or levels of processing was considered.

CHAPTER 3

EXPERIMENT 1

In Experiment 1, the effect of levels of processing manipulation on participants' direct relational memory performance at both the behavioral and the eye tracking levels was tested. The overall procedure was similar to what was done in the previous pilot studies, but several important changes were made. Generally speaking, better memory performance was expected indexed by behavioral responses in the deep encoding condition than in the shallow encoding condition. In addition, a stronger memory effect was expected indexed by eye movements from the participants in the deep encoding group than in the shallow encoding group, regardless of whether eye movements reflect different levels of memory performance in general or different levels of processing more specifically.

Methods

Participants

Ninety healthy college students from UNLV were recruited to participate in Experiment 1. All participants had normal or corrected to normal vision and none of them had been diagnosed with any mental disorders that could potentially hurt their memory performance. Participants were compensated with course credits for their participation. Twenty-three participants were excluded from final data analysis due to one or several of the following reasons: calibration failure [8], bad memory performance (e.g., negative or

[8]Calibration is a procedure conducted before formal eye tracking recording is started. It ensures that the machine is accurately recording the location of the subjects' gaze by comparing the actual location of a stimulus (e.g., a cursor) on the screen to the detected location of the subjects' gaze (see the Procedure for detailed information on calibration). Calibration failure occurs when the detected location of subjects' gaze does not match the actual location of the cursor on the screen so that the cursor stops moving across the different locations on the screen and calibration process is stuck with that location. For

chance level *d'*s)[9], or missing too many behavioral responses (e.g., no response in an entire block).

Materials and design

One hundred and eighty-four landscape pictures (such as mountains and deserts) and 184 object pictures (such as chairs and puppies) were used in the formal part of the present study. Another 12 landscape pictures and 12 object pictures were used in the practice phase before the formal part of the experiment started. Landscape pictures were 800 × 600 pixel landscape wallpapers collected from online sources. Two hundred and sixty object pictures were 300 × 300 pixel Snodgrrass and Vanderwort-like object drawing from the Tarr's lab (Rossion & Pourtois, 2004) and the rest were similar object drawings with the same size found online. All pictures were presented with Eprime 1.2 software on a computer screen.

Procedure

The experiment was separated into two phases: a study phase and a test phase. The measurement of eye movement only occurred in the test phase. Before the formal study phase started, participants completed a short task to practice on the keyboard with the three response keys which were used for the formal tasks in the test phase[10].

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example, if participants were wearing heavy make-ups, the eye tracker would consider the dark eye lashes as the pupil to compare with the location of the cursor on the screen so the calibration would fail.

[9]Four participants with 0 *d'*s were kept for analysis because their apparent lack of memory could have been due to the small number of the total *Matching* trials. Given that there were only 20 *Matching* trials, a small variation in the number of correct trials would change the *d'* value dramatically. For example, if a participant got 11 out 20 *Matching* trials correct, the corresponding *d*' was 0.25. However, if he/she got 10 out of 20*Matching* trials correct, the corresponding *d'* was 0. Thus, this criterion was set to include those participants with 0 *d'*s in order to be conservative because our measure of memory was not very sensitive to memory variation at the high or low end of the scale.

[10]Because participants had to have their heads fixed in the column of the eye tracker during the entire test phase, they would not be able to see those response keys. The keyboard practice was to help them become familiar with the keys so that they could make responses without seeing them during the experiment.

In the study phase, a landscape picture was first shown on the screen for 2 seconds. Immediately after that, an object picture was superimposed onto the center of the landscape picture. These two pictures were then shown together for another 4 seconds. The interval between two successive trials was 1.5 seconds, during which there was a fixation presented on the center of the screen (see Figure 1). Participants were divided into two different encoding condition groups: deep and shallow levels of encoding. In the deep encoding condition, participants were asked to judge whether they thought the object-background picture pair (e.g., a nose and a forest) was pleasant or not by pressing one of two buttons for a "yes" response and the other one for a "no" response. They were encouraged to use their imaginations (e.g., imagining themselves in the scenes with the objects) to think about why these two pictures were related and whether the relationship was pleasant or not. In the shallow encoding condition, the task was different from that in the behavioral pilots. Instead of judging the colors of the pairs, participants were asked to judge whether they thought they could find the materials or basic elements of the object in the background scene or not by giving a "yes" or a "no" response (e.g., a "yes" response could be made if a wooden chair was paired with a forest because the material-wood-could be found in the forest). The reason for the change to the shallow task was because it seemed as though the old shallow encoding task-color judgment-might have been too shallow for participants to form memory trace for the pairings and the negative or chance level *d'*s observed in the behavioral pilots might disappear if the processing level was a little bit deeper. For both encoding conditions, participants were informed that there were no "correct" answers to the judgment and they were encouraged to respond on their own criteria.

In the test phase, a thirteen-point calibration procedure with corner correction of the gaze point was conducted before each test block started. During the calibration participants moved their gaze across 13 points on the screen following the movement of a small cursor while the eye tracker monitored the eye and validated the calibration as successful if the computer's estimated eye position was close to the known position of the cursor on the screen. After participants were successfully calibrated with the eye tracker, a studied landscape picture was first presented for 2 seconds. Immediately after that, three object pictures were superimposed in a triangle pattern in the center of a studied landscape picture and presented for another 10 seconds (see Figure 1). The interval between two successive trials was also 1.5 seconds. There were three types of trials in the test phase: 1) 20 *Matching* trials in which all of the three objects had been studied and one of the three objects was paired with the background landscape picture in the previous study phase; 2) 20 *Nonmatching* trials in which all of the three objects had been studied but none of them were paired with the background picture; and 3) 20 *Novel* trials in which all the three objects were new. All background landscapes were old. For the *Matching* trials, the position of the actual matching object was randomized among the three locations within the display. Participants were asked to identify which of the three objects (left, right, or bottom) was paired with the background landscape picture in the previous study phase by pressing one of three buttons corresponding to the three objects on the screen. Participants were instructed to make a selection even though they did not think there was a target among the three objects and were asked to respond as soon as they made their decisions[11]. The entire test phase was grouped into 4 blocks with a short break between two successive blocks.

[11]The reason that the "forced choice" part of Pilot 2 was retained was to minimize the number of trials

Throughout the four test blocks, participants' eye movements were recorded by the SensoMotoric Instruments (SMI) iView X Hi-speed eye tracker at a sampling rate of 240 Hz. The monocular recording approach was adopted through which participants' left eye was sampled[12]. During the experiment, participants sat comfortably in a chair and put their chin on top of the chin rest of the eye tracker column. They were also required to stare at the fixation before the pictures appeared and could start free viewing after the onset of the landscape pictures. During each trial in the test phase, participants were supposed to keep their heads still on the chin rest and not to blink too much. The distance between participants' eyes and the computer monitor for presenting stimuli was approximately 500 mm.

Data analysis

Only trials in which participants made a response (e.g., behaviorally selecting an object as the target) were used in the following analyses, regardless of whether the response was correct. Behavioral responses were made on 99.4% of all the trials across all subjects, and the trials without behavioral responses were excluded from the analyses reported here. For the behavioral data, participants' *d'*s in the *Matching* trials and False Alarm rates in both *Nonmatching* and *Novel* trials between deep and shallow conditions were compared.

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with no behavioral responses. Connections between memory effect and eye movements have to be built up upon participants' behavioral responses. Therefore, eye movements in trials without behavioral responses could not be considered to reflect any memory effect and could not be compared with eye movements in trials with behavioral responses. This is consistent with the methods used in prior studies.

[12]Monocular recording is standard for most psychological research unless a comparison between the left and right eyes needs to be conducted. Monocular recording of the left eye was also consistent with previous studies (e.g., Smith et al., 2006; Smith & Squire, 2008)

Participants' eye movement data were analyzed with the Begaze 3.4 software by means of Area of Interest (AOI) analysis and Time Bin Analysis[13]. The regions of the three object pictures within the display were defined as left, right, and bottom AOIs respectively, and the region of the entire landscape background (including the three object areas) were defined as the total AOI.

Dependent variables

There were four main dependent variables for the eye movement data:1) the total number of fixations in the total AOI (i.e., the entire screen); 2) the total number of entries into the total AOI; 3) the proportion of fixations to each object AOI;4) and the proportion of viewing time to each object AOI. The total number of fixations indicated how many discrete pauses participants' eye made for the total AOI during the 10 seconds of the four picture displays. The total number of entries indicated how many times participants' gaze entered and left the total AOI. The proportion of fixations was the ratio of the number of fixations participants spent in a single object AOI (e.g., the matching object AOI) and the total number of fixations they spent in all three object AOIs. The proportion of viewing time was the ratio of the actual time participants spent viewing a single object AOI (e.g., the matching object AOI) and the actual time they spent viewing all three objects AOIs. These four eye movement indexes indicate participants' sampling of the visual displays in terms of the viewing time and region and have been consistently used as the measures for memory of previously encountered visual stimuli in previous studies (e.g., Ryan et al., 2000, 2007; Hannula et al., 2007, 2009; Smith et al., 2006, 2008).

[13]An AOI analysis allows comparison of eye movements amongst specific pre-defined areas of the screen; in the current study, the AOIs included the three areas where the objects were presented as well as the entire screen (i.e., the complete viewing area). The Time Bin Analysis refers to analysis of eye movement measurements (e.g., proportion of viewing time) over certain periods of recording duration.

Types of analysis

Three different types of analysis were conducted for the eye movement data: 1) a between-display comparison; 2) a within-display comparison; and 3) a time course analysis[14]. For the between-display comparison, the total number of fixations and total number of entries into the total AOI throughout the entire 10 second viewing period were compared between *Matching* and *Nonmatching* displays to examine the eye movements associated with the relational memory. *Nonmatching* and *Novel* displays were also compared in order to obtain the item memory effect for the objects because there were no original landscape-object relations in either of the displays. Thus, between-display comparisons are expected to reveal a relational memory effect (the matching-nonmatching comparison) as well as an item memory effect (the nonmatching-novel comparison). For the matching-nonmatching comparison, fewer fixations and fewer entries into the *Matching* AOIs than the *Nonmatching* AOIs were expected if participants showed relational memory for the pairings, which is consistent with the results from Hannula et al. (2007). The logic is similar to that in the infancy habituation studies where habituation refers to the phenomenon that infants' attention (i.e., viewing time) to a visual stimulus will decrease as this stimulus is repeated and they tend to spend more time viewing novel stimuli (Thomas & Gilmore, 2004). Similarly, for the nonmatching-novel comparison, there should be fewer fixations and entries into the *Nonmatching* AOIs than the *Novel* AOIs.

The within-display comparison was conducted for the *Matching* trials only. The proportion of fixations and viewing time for selected objects with the 33% chance level was compared to determine whether disproportional viewing was spent on the selected

[14] These different types of analysis originated from Hannula et al. (2007).

objects. In order to examine participants' relational memory for the pairings on the *Matching* displays, the proportion of fixations and viewing time between the correct and incorrect selections was compared. A greater number of proportion of fixations and proportion of viewing time was expected for the correct selections compared to the incorrect selections. Because behavioral responses were made in both the correct and incorrect *Matching* trials, the effect of making selections on eye movements should be controlled in the comparison between these two types of trials.

The time course analysis was conducted for both the entire 10 seconds and the first 2 seconds of the picture combination presentation duration. The proportion of viewing time towards the matching object in the *Matching* trials was compared with the proportion of viewing time towards the objects participants selected in the *Nonmatching* trials between the deep and shallow encoding conditions. This comparison revealed the relational memory effect over the 10 seconds (or first 2 seconds) time course because all objects were old in both the *Matching* and the *Nonmatching* trials but the object-scene pairings only existed in the *Matching* trials. The proportion of viewing time towards the correctly selected objects and the incorrectly selected objects in the *Matching* trials only was also compared to see the relational memory effect over the 10 seconds or (first 2 seconds) time course.

Although eye movement behaviors have been shown to be very reliable indexes for memory effect (Hannula et al., 2010), the direction of the comparison in terms of participants' viewing pattern (such as the number of fixation and the viewing time) is considered to depend on the task demands. It has been demonstrated that task demands influence participants' viewing preference towards familiar versus novel stimuli (Ryan et

al., 2007). When asked to make recognition judgment directly, participants tend to view the familiar stimuli more than the novel stimuli. In contrast, when asked to freely view the stimuli, participants tend to view the novel stimuli more than the familiar stimuli. The nature of the between-display comparison and the nature of the within-display comparison might be different and thus demand different processing. Because the within-display comparison was based on the three object AOIs within the *Matching* display only and participants had to make a selection among the three objects directly using their memories for the pairings, larger numbers in the corresponding measurements of the matching objects compared to the nonmatching objects would be expected. The between-display comparison, however, was based on the total AOI (the entire screen) between the *Matching*, *Nonmatching*, and *Novel* displays, and participants were forced to make selections for all three types of displays. It is likely that the general viewing patterns towards these total AOIs are similar to the free viewing patterns after the effect of memory based selections has been controlled. Therefore, smaller numbers in the corresponding measurements of the *Matching* displays compared to the *Nonmatching* or *Novel* displays would be expected.

Results

Behavioral data

For the *Matching* trials, there was a LOP effect, where participants exhibited significantly greater *d'* in the deep condition than in the shallow condition, $t(64)=2.902$, $p=0.005$[15] (see Figure 4 and Table 4). Because participants were forced to make a

[15]Because the *d'* reported here was calculated by using the formula *d'*=Z(Hit rate)-Z(False Alarm rate), one of the participants in the deep condition who had perfect performance (his False Alarm rate was 0) was not included for this comparison between *d'*s. Therefore, the degree of freedom for this independent t-test was 64 instead of 65.

selection on each trial as in pilot test 2, all responses in both *Nonmatching* and *Novel* trials were false alarms and no LOP effect on these false alarms[16] was expected.

Between-display data

For the number of entries into the entire display (see Figure 5 and Table 5), a 2 (LOP: deep/shallow) × 3 (trial type: Matching/Nonmatching/Novel) repeated-measures ANOVA was conducted, with LOP as a between-subject variable and trial type as a within-subject variable. The sphericity assumption for trial type was not violated, Mauchly's W=0.921, p=0.071. The analysis revealed that there was no main effect of LOP, $F(1, 65)=0.017$, p=0.895, partial $\eta^2=0.000$. There was a significant main effect of trial type, $F(2, 130)=4.407$, p=0.014, partial $\eta^2=0.063$. Planned paired sample t-tests between each two of the three displays revealed that participants made fewer entries into the *Matching* displays than the *Novel* displays, regardless of deep or shallow encoding, $t(66)=3.142$, p=0.003. There was no interaction between LOP and trial type, $F(2, 130)=0.797$, p=0.453. Overall, there was no LOP effect in the number of entries into the total display but there was a memory effect indicated by the main effect of trial type.

Similarly, for the number of fixations into the entire display (see Figure 5 and Table 5), a 2 (LOP: deep/shallow) × 3 (trial type: Matching/Nonmatching/Novel) repeated-measures ANOVA was conducted, with LOP as a between-subject variable and trial type as a within-subject variable. The sphericity assumption for trial type was not violated, Mauchly's M=0.963, p=0.297. The analysis revealed that there was no main effect of LOP, $F(1, 65)=0.069$, p=0.793, partial $\eta^2=0.001$. There was a significant main effect of trial type, $F(2, 130)=14.893$, p=0.000, partial $\eta^2=0.186$. Planned paired sample t-

[16]Therefore, the behavioral results of *Nonmatching* and *Novel* trials were not of interest and not reported in either Experiment 1 or Experiment 2.

tests between each two of the three displays revealed that participants made fewer fixations into the *Matching* displays than the *Nonmatching* and *Novel* displays regardless of deep or shallow encoding, $t(66)=5.474$, $p=0.000$, and $t(66)=2.639$, $p=0.010$, respectively. There was no interaction between LOP and trial type, $F(2, 130)=0.113$, $p=0.893$, partial $\eta^2=0.002$. Overall, there was no LOP effect in the number of fixations into the total display but there was a relational memory effect indicated by the main effect of trial type.

The between-display comparison generally showed no effect of LOP on either the number of entries or the number of fixations into the entire display, although there was robust effect of relational memories on these two eye movement measurements.

Within-display data

Within-display comparison was conducted for the *Matching* trials only (see Figure 6 and Table 6). Participants' proportion of fixations towards both the correctly selected matching objects and the incorrectly selected nonmatching objects was greater than the 33% chance level in the deep condition, $t(32)=10.980$, $p=0.000$ and $t(32)=3.174$, $p=0.003$, respectively. And it was the same in the shallow condition, $t(33)=8.681$, $p=0.000$, and $t(33)=5.032$, $p=0.000$, respectively. A 2 (LOP: deep/shallow) × 2 (accuracy: correct/incorrect) repeated-measures ANOVA was conducted, with LOP as a between-subject variable and accuracy as a within-subject variable with two levels. The analysis revealed that there was no main effect of LOP, $F(1, 65)=1.939$, $p=0.169$, partial $\eta^2=0.029$. There was a significant main effect of accuracy, $F(1, 65)=15.200$, $p=0.000$, partial $\eta^2=0.190$. Participants spent a higher proportion of fixations on the correctly selected objects than the incorrectly selected objects, regardless of the LOP. There was also a

significant interaction between LOP and accuracy, $F(1, 65)=4.562$, $p=0.036$, partial $\eta^2=0.066$. Planned independent t-tests between deep and shallow conditions on each level of accuracy revealed that for correctly selected objects, participants made more fixations in the deep condition than in the shallow condition, $t(65)=3.020$, $p=0.004$. There was no LOP effect for the incorrectly selected objects, $t(65)=0.205$, $p=0.838$. Thus, in terms of the proportion of fixations, there was a LOP effect for the correctly selected object and there was a relational memory effect indicated by the main effect of accuracy.

Similar analyses were conducted for the proportion of viewing time (see Figure 6 and Table 6). Participants' proportion of viewing time towards both the correctly selected matching objects and the incorrectly selected nonmatching objects was greater than the 33% chance level in the deep condition, $t(32)=10.857$, $p=0.000$ and $t(32)=3.036$, $p=0.005$, respectively. And it was the same in the shallow condition, $t(33)=8.001$, $p=0.000$ and $t(33)=4.803$, $p=0.000$, respectively. A 2 (LOP: deep/shallow) × 2 (accuracy: correct/incorrect) repeated-measures ANOVA was conducted, with LOP as a between-subject variable and accuracy as a within-subject variable. The analysis revealed that there was no main effect of LOP, $F(1, 65)=1.673$, $p=0.200$, partial $\eta^2=0.025$. There was a significant main effect of accuracy, $F(1, 65)=20.116$, $p=0.000$, partial $\eta^2=0.236$. Participants spent a higher proportion of viewing time on the correctly selected objects than the incorrectly selected objects, regardless of the LOP. There was also a significant interaction between LOP and accuracy, $F(1, 65)=4.735$, $p=0.033$, partial $\eta^2=0.068$. Planned independent t-tests were conducted to examine the LOP effect on each level of accuracy. When the correct object was selected, deep encoding led to greater proportion of viewing towards that object than did shallow encoding, $t(65)=2.786$, $p=0.007$. There

was no difference between deep and shallow groups on the incorrectly selected objects, $t(65)=0.165$, $p=0.869$. Thus, the LOP effect was observed for the correctly selected objects in terms of the proportion of viewing time. And there was a relational memory effect indicated by the main effect of accuracy.

Overall, the within-display comparison revealed a LOP effect only for the trials with relational memory (trials with correct selections) but not for trials without memory (trials with incorrect selections), and there was a relational memory effect in general across both the deep and shallow groups (i.e., greater proportion of fixations and viewing time were spent on the correctly selected objects than the incorrectly selected objects).

Time course analysis data

Participants' proportion of viewing time towards the correctly selected matching objects in the *Matching* trials as well as the incorrectly selected nonmatching objects in the *Nonmatching* trials was examined across the entire 10 seconds of the duration of the picture combination (see Figure 7 and Table 7). The 10 seconds were segmented into10 time bins with each time bin comprised of1000ms.Because the relational memory effect revealed by the comparison between the *Matching* and *Nonmatching* trials was of interest, only these types of trials were included (the *Novel* trials were excluded here). If behavioral performance was reflected in viewing time over the time course of a trial, greater viewing time towards the correctly selected objects in the deep condition than in the shallow condition would be expected. A 2 (LOP: deep/shallow) × 2 (trial type: Matching/Nonmatching) × 10 (time bin: 0-1000ms, 1000-2000ms, ...9000-10000ms) repeated-measures ANOVA was conducted, with LOP as a between-subject variable, and trial type and time bin as within-subject variables. The sphericity assumption for time bin

was violated, Mauchly's W=0.056, p=0.000. The sphericity assumption for the interaction of trial type and time bin was also violated, Mauchly's W=0.165, p=0.000. Therefore, Greenhouse-Geisser correction was adopted for all the repeated-measures analysis. The analysis revealed a significant main effect of LOP, F(1, 65)=4.201, p=0.044, partial η^2=0.061. Participants in the deep condition spent higher proportion of viewing time towards the selected objects compared to participants in the shallow condition, regardless of whether the selection was correct[17]. There was also a significant main effect of trial type, F(1, 65)=36.452, p=0.000, partial η^2=0.359, and a significant main effect of time bin, F=(5.148, 334.650)=20.147, p=0.000, partial η^2=0.237. The interaction of time bin and LOP was not significant, F(5.148, 334.650)=0.891, p=0.490, partial η^2=0.014. There was a significant interaction between LOP and trial type, F(1, 65)=6.354, p=0.014, partial η^2=0.089. The interaction of trial type and time bin was not significant, F(6.548, 425.624)=1.389, p=0.212, partial η^2=0.021. The interaction of trial type, time bin, and LOP was not significant, F(6.548, 425.624)=1.126, p=0.346, partial η^2=0.017. Then, planned 2 (LOP: deep/shallow) × 10 (time bin: 0-1000ms, 1000-2000ms, ...9000-10000ms) repeated-measures ANOVAs were conducted for *Matching* and *Nonmatching* trials separately. The sphericity assumption for time bin was violated in both analyses, Mauchly's W=0.080, p=0.000; Mauchly's W=0.126, p=0.000, respectively. Therefore, Greenhouse-Geisser correction was adopted for both analyses. The analyses revealed a LOP effect on viewing time (greater viewing time in the deep condition than in the shallow condition) over the 10 seconds only for the correctly selected matching objects in the *Matching* trials, F(1, 65)=6.229, p=0.015, partial η^2=0.087. There was no LOP effect

[17]All selections in the *Matching* trials included for comparison were correct whereas all selections in the *Nonmatching* trials were incorrect.

for the incorrectly selected nonmatching objects in the *Nonmatching* trials, $F(1, 65)=0.724$, $p=0.398$, partial $\eta^2=0.011$. The main effect of time bin was significant in both types of trials, $F(5.619, 365.259)=8.784$, $p=0.000$, partial $\eta^2=0.119$; $F(6.075, 394.861)=17.282$, $p=0.000$, partial $\eta^2=0.210$, respectively. And the interaction of LOP and time bin was not significant in either type of trials, $F(5.619, 365.259)=1.076$, $p=0.375$, partial $\eta^2=0.016$; $F(6.075, 394.861)=0.866$, $p=0.521$, partial $\eta^2=0.013$, respectively.

Then the proportion of viewing time towards the correctly selected matching objects in the *Matching* trials was compared between the deep and shallow groups over the entire 10 seconds (see Figure 8 and Table 7). A 2 (LOP: deep/shallow) × 10 (time bin: 0-1000ms, 1000-2000ms, ...9000-10000ms) repeated-measures ANOVA was conducted, with LOP as a between-subject variable and time bin as a within-subject variable. The sphericity assumption for time bin was violated, Mauchly's W=0.080, $p=0.000$. Therefore, Greenhouse-Geisser Correction was adopted for all repeated-measures analysis. The analysis revealed a significant main effect of LOP, $F(1, 65)=6.229$, $p=0.015$, partial $\eta^2=0.087$, which was consistent with the effect reported above. There was also a significant main effect of time bin, $F(5.619, 365.259)=8.784$, $p=0.000$, partial $\eta^2=0.119$, but no interaction between LOP and time bin, $F(5.619, 365.259)=1.076$, $p=0.375$, partial η^2. Next, a series of planned paired sample t-tests between the proportion of viewing time towards the correctly selected objects and the 33% chance level across all 10 time bins were conducted for deep and shallow groups separately. The results showed that greater than chance level viewing time towards the correctly selected matching objects started from the first time bin of 0-1000ms and lasted

till the last time bin of 9000-10000ms for both the deep and the shallow groups, all *p*s<0.006 except for the eighth time bin in the shallow condition with *p*=0.005 (Bonferroni correction of α=0.005).

In order to see whether there was a difference in how early the disproportional viewing time started between deep and shallow groups, the comparison was further confined into the first 2 seconds only following Hannula et al. (2007) (see Figure 9 and Table 8). The first 2 seconds were segmented into 10 time bins, with each time bin taking 200ms. A 2 (LOP: deep/shallow) × 2 (trial type: Matching/Nonmatching) × 10 (time bin: 0-200ms, 400-600ms, ...1800-2000ms) repeated-measures ANOVA was conducted, with LOP as a between-subject variable, and trial type and time bin as within-subject variables. The sphericity assumption for time bin was violated, Mauchly's W=0.041, *p*=0.000. The sphericity assumption for the interaction of time bin and trial type was also violated, Mauchly's W=0.050, *p*=0.000. Therefore, Greenhouse-Geisser correction was adopted for all the repeated-measures analysis. The analysis revealed no main effect of LOP, $F(1, 65)=3.292$, $p=0.074$, partial $\eta^2=0.048$. There was a significant main effect of trial type, $F(1, 65)=34.717$, $p=0.000$, partial $\eta^2=0.348$, and a significant main effect of time bin, $F(5.188, 337.252)=18.408$, $p=0.000$, partial $\eta^2=0.221$. The interaction of trial type and LOP was not significant, $F(1, 65)=2.844$, $p=0.096$, partial $\eta^2=0.042$. The interaction of time bin and LOP was not significant, $F(5.188, 337.252)=0.575$, $p=0.726$, partial $\eta^2=0.009$. The interaction of trial type and time bin was not significant, $F(5.709, 371.116)=1.965$, $p=0.073$, partial $\eta^2=0.029$. The interaction of trial type, time bin, and LOP was not significant, $F(5.709, 371.116)=0.458$, $p=0.831$, partial $\eta^2=0.007$.

For the *Matching* trials only (see Figure 10 and Table 8), a 2 (LOP: deep/shallow) × 10 (time bin: 0-200ms, 200-400ms, ...1800-2000ms) repeated-measures ANOVA was conducted, with LOP as a between-subject variable and time bin as a within-subject variable. The sphericity assumption for time bin was violated, Mauchly's W=0.054, p=0.000. Therefore, Greenhouse-Geisser correction was adopted for all the repeated-measures analysis. The analysis revealed a significant main effect of LOP, F(1, 65)=4.765, p=0.033, partial η^2=0.068. Participants in the deep condition spent a higher proportion of viewing time towards the correctly selected objects over the entire first 2 seconds than those in the shallow condition. There was a also significant main effect of time bin, F(5.581, 362.733)=12.734, p=0.000, partial η^2=0.164, but no interaction between LOP and time bin, F(5.581, 362.733)=0.527, p=0.775, partial η^2=0.008. For the deep group, planned paired sample t-tests between the proportion of viewing time and the 33% chance level across all 10 time bins revealed that greater than chance level viewing started from the second time bin of 200-400ms and lasted till the last time bin of 1800-2000ms, all ps<0.005 (Bonferroni correction of α=0.005). For the shallow group, however, greater than chance level viewing time did not start until the fourth time bin of 600-800ms and lasted till the last time bin of 1800-2000ms, all ps<0.005 (Bonferroni correction of α=0.005). Thus, the disproportional viewing time towards the correctly selected objects started approximately 200ms earlier in the deep condition than in the shallow condition.

Overall, the time course analysis revealed the LOP effect for the correctly selected matching objects in the *Matching* trials but not the incorrectly selected nonmatching objects in the *Nonmatching* trials over the entire 10 seconds and the

relatively earlier onset of the disproportional viewing in the deep condition during the first 2 seconds of recording.

Discussion

In Experiment 1, the effect of levels of processing manipulation on memory dependent eye movements was investigated. The behavioral data revealed a significant LOP effect in terms of memory performance. For the *Matching* trials, participants in the deep condition exhibited greater sensitivity (*d'*) than participants in the shallow condition, which is consistent with the previous studies on levels of processing.

For the eye tracking data, three different types of analysis were conducted. The between-display comparison revealed no LOP effect on either the total number of fixations or the total number of entries into the total display. However, participants across both deep and shallow groups in general made both fewer fixations and fewer entries into the *Matching* displays than the *Novel* displays, suggesting their memories for the objects and possibly for the relationship as well[18]. In addition, the fewer fixations participants made into the *Matching* displays than the *Nonmatching* displays indicated their relational memories for the object-scene pairs. Overall, the between-display comparison provided evidence for relational memory in general but no evidence for the LOP effect.

The within-display comparison was for the *Matching* trials only. Participants' correct and incorrect selections were compared, which reflects participants' relational memories of the object-scene pairs. Overall, participants exhibited disproportional (greater than the 33% chance level) viewing for both correct and incorrect selections. It

[18]Because the comparison between the *Matching* and *Nonmatching* displays would reveal relational memories for the pairing and the comparison between the *Nonmatching* and *Novel* displays would reveal item memories for the old objects, it was possible that the comparison between the *Matching* and *Novel* displays would reveal both the relational memories for the pairing and item memories for the old objects.

makes sense for people to spend more time viewing the object they select compared to the other two unselected objects, regardless of whether the selection is correct. More interestingly, participants from the deep encoding group spent more time viewing the correctly selected matching objects than participants from the shallow encoding group, suggesting a LOP effect on their relational memories of the picture pairs. The LOP effect, however, was absent for the incorrectly selected nonmatching objects.

The time course analysis further confirmed the LOP effect for the correctly selected objects over the entire 10 seconds time window and also indicated that disproportional viewing started about 200ms earlier in the deep condition than in the shallow condition.

Overall, the effect of LOP on relational memory was observed at both the behavioral and the eye movement levels in Experiment 1. Intuitively, these different eye movements recorded at retrieval may simply reflect the different levels of memory performance between deep and shallow conditions at retrieval. However, the results from Experiment 1 alone could not rule out the possibility that these eye movements might be specific to different levels of processing at encoding. In order to determine whether "levels of performance" or "levels of processing" was reflected in these eye movements, the effect of another manipulation that would also influence the levels of performance at retrieval but did not affect the levels of processing at encoding needed to be examined. Therefore, a divided attention manipulation at encoding was used in Experiment 2 to examine its effect on memory dependent eye movements while the depth of processing was held constant across the full and divided attention conditions. If both the behavioral responses and the eye movements are affected by the divided attention manipulation in a

similar way as the levels of processing manipulation in Experiment 1, then these memory dependent eye movements should just reflect different levels of performance in both Experiments. However, if the eye movements are the same between divided attention condition and full attention condition but there is a difference in terms of memory performance at the behavioral level, then the different eye movements observed in Experiment 1 may reflect different levels of processing rather than just different levels of performance.

CHAPTER 4

EXPERIMENT 2

Previous studies (e.g., Jacoby et al., 1989; Jennings & Jacoby, 1993; Jacoby, 1996; Wolters & Prinsen, 1997) have shown that, compared to a full attention condition, participants' memory performance is impaired under divided attention conditions. In Experiment 2, the effect of divided attention on participants' direct relational memory performance was tested at both the behavioral and the eye tracking levels. The overall procedure of Experiment 2 was similar to that of Experiment 1, except that the levels of processing manipulation was replaced by a divided attention manipulation. Better memory performance in the full attention encoding condition than in the divided attention encoding condition was expected and whether participants' eye movements would also show such difference was of interest. If there was difference in the eye movements between full and divided attention conditions as was observed between deep and shallow conditions in Experiment 1, then these different eye movements should simply be associated with different levels of performance in both experiments. Otherwise, the different eye movements in Experiment 1 should be specific to the levels of processing manipulation.

Methods

Participants

Seventy-six healthy college students from UNLV were recruited to participate in Experiment 2. None of these individuals had participated in Experiment 1. All participants had normal or corrected to normal vision and none of them had been diagnosed with any mental disorders. Participants were compensated with course credits

for their participation. Ten participants were excluded from the analysis due to one or several of the following reasons: calibration failure, bad memory performance (negative or chance level *d'*s)[19], or missing too many behavioral responses (e.g., no response in an entire block).

Stimuli and design

The same set of landscape pictures and object pictures in Experiment 1 were used as stimuli in Experiment 2.

Procedure

The general procedure of Experiment 2 was similar to that of Experiment 1 except that the deep/shallow encoding manipulation in the study phase was replaced by full/divided attention encoding manipulation. In the full attention condition participants focused their attention on judging whether the object-background picture pairs were pleasant or not (same as the deep encoding condition in Experiment 1). In the divided attention condition, however, besides judging the pleasantness of the picture pairs, participants were asked to complete a secondary task, the three odd digit task used by McDowd and Craik (1988). In this three odd digit task, participants heard a series of prerecorded digits (from 1 to 9) spoken by a male voice through two loud speakers. These digits were played one at a time with Eprime 1.2 software on a laptop placed behind the participants. Participants were instructed to detect whether they heard any set of three consecutive odd digits (e.g., 3, 5, 1). When they detected a set of three consecutive odd digits, they were instructed to say "Hit" aloud immediately. The experimenter pressed the spacebar on the laptop to keep a record of participants' responses. Oral feedback was given only when participants made mistakes. For example, the experimenter would say

[19]Nine participants with 0 *d'*s were kept for analysis with the same reasons mentioned earlier.

"Miss" aloud to participants if they missed saying "Hit" when there were three consecutive odd digits and would say "No" if they mistakenly said "Hit" when there were no three consecutive odd digits.

Data analysis

The data analysis approach of Experiment 2 was the same as that of Experiment 1. The effects of divided attention were investigated at both the behavioral and the eye tracking level including the between-display, within-display, and time course analysis. Behavioral responses were made on 98.7% of all the trials across all subjects, and trials without responses were not included for analysis reported below.

Results

Behavioral data

For the *Matching* trials, there was a divided attention (DA) effect, where participants exhibited significantly greater *d'* in the full attention (FA) condition than in the divided attention (DA) condition, $t(64)=3.215$, $p=0.002$ (see Figure 11 and Table 9). And the overall accuracy of the DA task (three odd digit task) was 90% for the participants in the DA condition.

Between-display data

For the number of entries into the entire display (see Figure 12 and Table 10), a 2 (attention: DA/FA) × 3 (trial type: Matching/Nonmatching/Novel) repeated-measures ANOVA was conducted, with attention as a between-subject variable and trial type as a within-subject variable. The sphericity assumption for trial type was not violated, Mauchly's $W=0.915$, $p=0.061$. The analysis revealed that there was no main effect of attention, $F(1, 64)=0.018$, $p=0.893$, partial $\eta^2=0.000$. There was a significant main effect

of trial type, $F(2, 128)=4.342$, $p=0.015$, partial $\eta^2=0.064$. Planned paired sample t-tests between each two of the three displays revealed that participants made fewer entries into the *Matching* displays than the *Nonmatching* displays regardless of the attention status, $t(65)=3.167$, $p=0.002$. There was also an interaction between attention and trial type, $F(2, 128)=3.278$, $p=0.041$, partial $\eta^2=0.049$, but planned independent t-tests between FA and DA conditions on each level of trial type revealed no DA effect for any of the three types of trials, $t(64)=0.445$, $p=0.658$; $t(64)=0.473$, $p=0.638$; $t(64)=0.446$, $p=0.657$, respectively. For the number of entries, there was no DA effect in general, but there was a relational memory effect indicated by the main effect of trial type.

Similarly, for the number of fixations into the entire display (see Figure 12 and Table 10), a 2 (attention: DA/FA) × 3 (trial type: Matching/Nonmatching/Novel) repeated-measures ANOVA was conducted, with attention as a between-subject variable and trial type as a within-subject variable. The sphericity assumption for trial type was violated, Mauchly's $W=0.844$, $p=0.005$. Therefore, Greenhouse-Geisser correction was adopted for all repeated-measures analysis. The analysis revealed that there was no main effect of attention, $F(1, 64)=0.971$, $p=0.328$, partial $\eta^2=0.015$. There was a significant main effect of trial type, $F(1.731, 110.764)=7.318$, $p=0.002$, partial $\eta^2=0.103$. Planned paired sample t-tests between each two of the three displays revealed that participants made fewer fixations into the *Matching* displays than the *Nonmatching* and *Novel* displays regardless of the attention status, $t(65)=3.187$, $p=0.002$, and $t(65)=2.934$, $p=0.005$, respectively. There was no interaction between attention and trial type, $F(1.731, 110.764)=0.054$, $p=0.927$, partial $\eta^2=0.001$. Again, there was no DA effect for the

number of fixations. But there was a relational memory effect indicated by the main effect of trial type.

Overall, the between-display comparison revealed no DA effect on either the number of entries or the number of fixations, although there was robust relational memory effect on these two dependent measurements.

Within-display data

Within-display comparison was conducted only for the *Matching* trials (see Figure 13 and Table 11). Participants' proportion of fixations towards both the correctly selected matching objects and the incorrectly selected nonmatching objects was greater than the 33% chance level in the DA condition, $t(32)=8.840$, $p=0.000$ and $t(32)=5.347$, $p=0.000$, respectively. And it was the same in the FA condition, $t(32)=11.656$, $p=0.000$, and $t(32)=2.668$, $p=0.012$, respectively. A 2 (attention: DA/FA) × 2 (accuracy: correct/incorrect) repeated-measures ANOVA was conducted, with attention as a between-subject variable and accuracy as a within-subject variable. The analysis revealed no main effect of attention, $F(1, 64)=0.023$, $p=0.881$, partial $\eta^2=0.000$. There was a significant main effect of accuracy, $F(1, 64)=18.862$, $p=0.000$, partial $\eta^2=0.228$. Participants directed a higher proportion of fixations to correctly selected objects than to incorrectly selected objects in the *Matching* trials, regardless of the attention status. There was no interaction between attention and accuracy, $F(1, 64)=0.538$, $p=0.466$, partial $\eta^2=0.008$. Overall, there was no DA effect on the proportion of fixations, but there was relational memory effect indicated by the main effect of accuracy.

Similar analyses were conducted for the proportion of viewing time (see Figure 13 and Table 11). Participants' proportion of viewing time towards both the correctly

selected matching objects and the incorrectly selected nonmatching objects was greater than the 33% chance level in the DA condition, $t(32)=8.639$, $p=0.000$, and $t(32)=5.569$, $p=0.000$, respectively. And it was the same in the FA condition, $t(32)=10.918$, $p=0.000$, and $t(32)=2.270$, $p=0.030$, respectively. A 2 (attention: DA/FA) × 2 (accuracy: correct/incorrect) repeated-measures ANOVA was conducted, with attention as a between-subject variable and accuracy as a within-subject variable. The analysis revealed no main effect of attention, $F(1, 64)=0.458$, $p=0.501$, partial $\eta^2=0.007$. There was a significant main effect of accuracy, $F(1, 64)=22.032$, $p=0.000$, partial $\eta^2=0.256$. Participants directed higher proportion of viewing time to the correctly selected objects than to the incorrectly selected objects, regardless of the attention status. There was no interaction between attention and accuracy, $F(1, 64)=1.074$, $p=0.304$. Again, there was no DA effect on the proportion of viewing time, but there was relational memory effect indicated by the main effect of accuracy.

The within-display comparison showed no DA effect on either the proportion of fixations or the proportion of viewing time, although there were relational memory effects based on the comparison between correct and incorrect selections on these two measurements.

Time course analysis data

Participants' proportion of viewing time towards the correctly selected matching objects as well as the incorrectly selected nonmatching was examined across the entire 10 seconds of the picture combination duration (see Figure 14 and Table 12). Again, the 10 seconds were segmented into 10 time bins with each time bin taking 1000ms. A 2

(attention: DA/FA) × 2 (trial type: Matching/Nonmatching)[20] × 10 (time bin: 0-1000ms, 1000-2000ms, ...9000-10000ms) repeated-measures ANOVA was conducted, with attention as a between-subject variable, trial type and time bin as within-subject variables. The sphericity assumption for time bin was violated, Mauchly's W=0.117, p=0.000. And the sphericity assumption for the interaction of trial type and time bin was also violated, Mauchly's W=0.151, p=0.000. Therefore, Greenhouse-Geisser correction was adopted for all the repeated-measures analysis. The analysis revealed no main effect of attention, F(1, 64)=0.137, p=0.712, partial η^2=0.002. There was a significant main effect of trial type, F(1, 64)=29.389, p=0.000, partial η^2=0.315, and a significant main effect of time bin, F=(5.913, 378.424)=15.768, p=0.000, partial η^2=0.198. The interaction of trial type and attention was not significant, F(1, 64)=1.469, p=0.230, partial η^2=0.022. The interaction of time bin and attention was not significant, F(5.913, 378.424)=1.360, p=0.230, partial η^2=0.021. The interaction of trial type and time bin was not significant, F(6.530, 417.907)=0.741, p=0.628, partial η^2=0.011. And the interaction of trial type, time bin, and attention was not significant, F(6.530, 417.907)=1.120, p=0.350, partial η^2=0.017.

For the *Matching* trials (see Figure 15 and Table 12), a 2 (attention: DA/FA) × 10 (time bin: 0-1000ms, 1000-2000ms, ...9000-10000ms) repeated-measures ANOVA conducted, with attention as a between-subject variable, and time bin as a within-subject variable. The sphericity assumption for time bin was violated, Mauchly's W=0.160, p=0.000. Therefore, Greenhouse-Geisser correction was adopted for all the repeated-measures analysis. The analysis revealed no main effect of attention, F(1, 64)=0.135, p=0.715, partial η^2=0.002. There was a significant main effect of time bin, F(6.531,

[20]Again, only correct selections in the *Matching* trials were included for comparison and all selections in the *Nonmatching* trials were incorrect.

418.002)=8.283, p=0.000, partial η^2=0.115, but no interaction between attention and time bin, F(6.531, 418.002)=0.984, p=0.439, partial η^2=0.015. A series of planned paired sample t-tests between the proportion of viewing time towards the correctly selected objects and the 33% chance level across all 10 time bins were conducted separately for DA and FA groups. The results showed that greater than chance level viewing time towards the correctly selected matching objects started from the second time bin of 1000-2000ms and lasted till the last time bin of 9000-10000ms for the DA group, all ps<0.005 (Bonferroni correction of α=0.005). Such disproportional viewing time, however, started from the first time bin of 0-1000ms and lasted till the last time bin of 9000-10000ms for the FA group, suggesting an earlier onset in the FA condition, all ps<0.005 (Bonferroni correction of α=0.005).

A similar set of analysis was conducted for the first 2 seconds which were also segmented into 10 time bins, with each time bin taking 200ms (see Figure 16 and Table 13). A 2 (attention: DA/FA) × 2 (trial type: Matching/Nonmatching) × 10 (time bin: 0-200ms, 200-400ms, ...1800-2000ms) repeated-measures ANOVA was conducted, with attention as a between-subject variable, trial type and time bin as within-subject variables. The sphericity assumption for time bin was violated, Mauchly's W=0.020, p=0.000. And the sphericity assumption for the interaction of trial type and time bin was also violated, Mauchly's W=0.038, p=0.000. Therefore, Greenhouse-Geisser correction was adopted for the repeated-measures analysis. The analysis revealed no main effect of attention, F(1, 64)=0.000, p=0.996, partial η^2=0.000. There was a significant main effect of trial type, F(1, 64)=20.177, p=0.000, partial η^2=0.240, and a significant main effect of time bin, F(4.645, 297.288)=26.385, p=0.000, partial η^2=0.292. The interaction of trial type and

attention was not significant, $F(1, 64)=2.340$, $p=0.131$, partial $\eta^2=0.035$. The interaction of time bin and attention was not significant, $F(4.645, 297.288)=1.599$, $p=0.165$, partial $\eta^2=0.024$. The interaction between trial type and time bin was significant, $F(5.120, 327.698)=2.439$, $p=0.033$, partial $\eta^2=0.037$. The interaction of trial type, time bin, and attention was not significant, $F(5.120, 327.698)=1.164$, $p=0.327$, partial $\eta^2=0.018$.

For the *Matching* trials only (see Figure 17 and Table 13), a 2 (attention: DA/FA) × 10 (time bin: 0-200ms, 200-400ms, ...1800-2000ms) repeated-measures ANOVA was conducted, with attention as a between-subject variable and time bin as a within-subject variable. The sphericity assumption for time bin was violated, Mauchly's W=0.021, $p=0.000$. Therefore, Greenhouse-Geisser correction was adopted for all the repeated-measures analysis. The analysis revealed no main effect for attention, $F(1, 64)=0.844$, $p=0.362$, partial $\eta^2=0.013$. There was a significant main effect of time bin, $F(4.683, 299.732)=17.943$, $p=0.000$, partial $\eta^2=0.219$, but no interaction between attention and time bin, $F(4.683, 299.732)=1.138$, $p=0.340$, partial $\eta^2=0.017$. For the DA group, planned paired sample t-tests between the proportion of viewing time and the 33% chance level across all 10 time bins revealed that greater than chance level viewing started from the fifth time bin of 800-1000ms and lasted till the last time bin of 1800-2000ms, all ps<0.005 (Bonferroni correction of $\alpha=0.005$). For the FA group, however, greater-than-chance viewing time started from the fourth time bin of 600-800ms and lasted till the last time bin of 1800-2000ms, all ps< 0.005 (Bonferroni correction of $\alpha=0.005$). Thus, the disproportional viewing time towards the correctly selected matching objects started approximately 200ms earlier in the FA condition than the DA condition.

Overall, the time course analysis revealed no DA effect over either the entire 10 seconds or the first 2 seconds, although participants' showed relational memory effects over both time intervals.

Discussion

In Experiment 2, how memory dependent eye movements at retrieval would be changed under full versus divided attention at encoding was investigated. As expected, participants in the FA condition exhibited greater sensitivity to the object-scene pairings than participants in the DA condition at the behavioral level.

The between-display comparison revealed that participants made fewer fixations in the *Matching* displays than the *Novel* displays, suggesting their memories for the studied objects and possibly relational memories for the object-scene pairings as well.

As the within-display comparison suggested, more fixations and viewing time were spent on the correctly selected objects than the incorrectly selected objects in the *Matching* trials regardless of the attention status, indicating their relational memory for the picture pairs in general. However, there was no main effect of the divided attention manipulation on any of the eye tracking measurements across all three types of eye tracking data analysis, although the time course analysis for both the entire 10 seconds and the first 2 seconds showed a relatively earlier onset of the disproportional viewing in the FA condition than in the DA condition.

CHAPTER 5

GENERAL DISCUSSION

Original research question and hypothesis

Ever since the 1960s, dissociations between explicit and implicit memories have been observed under a variety of manipulations including levels of processing and divided attention. These dissociations, however, were only observed in explicit and implicit item memories. In order to determine whether explicit and implicit relational memories would dissociate in a similar way, investigation on the effects of levels of processing and divided attention manipulations on participants' relational memories of object-scene pairs both directly and indirectly was proposed. The original hypothesis of the present study was that if implicit relational memory behaved in the same way as implicit item memory, it should not be affected by these encoding manipulations and similar dissociations between explicit and implicit relational memories would be observed, as predicted by the declarative memory theory. In contrast, if implicit relational memory behaved differently than implicit item memory, it should be affected by these encoding manipulations and different dissociations would be observed, as predicted by the relational memory theory. The goal was to test these hypotheses at both the behavioral and the eye movement levels. And as noted below, the original goal was modified after piloting these direct and indirect tests.

Behavioral pilots and current experiments

Four pilots (two are reported in full detail here) were conducted with the levels of processing manipulation before the formal eye tracking experiments were started. As a result, the pilot studies failed to show a levels of processing (LOP) effect on participants'

overall sensitivity (*d'*) in the indirect tests and *d'* was negative or around 0 in both the deep and shallow conditions. These negative or chance level *d'*s might suggest that there was no implicit relational memory or that the relatedness judgment task was not a very effective indirect task in terms of measuring implicit relational memory. However, there is no existing indirect memory test in the literature for picture pairs. The relatedness judgment task was developed with the expectation that it would be the most sensitive indirect judgment to the influence of relational memory for the object-scene pairs, and thus, although possible, it is still not clear what other conceptual or perceptual judgment might reflect indirect relational memory. Although one way to elicit an influence of memory in indirect tasks is to speed up participants' responses and look at the reaction time, it was not feasible for this study because of the constraints of the fixed time window (10 seconds) to record eye movements.

Without information on the type of judgment that might indirectly reflect memory of the picture pairs, as well as the constraints of the time window for recording eye movements, the proposed eye tracking experiments were modified by shifting the research question from the dissociations between explicit and implicit relational memories under levels of processing and divided attention to the effects of these encoding manipulations on memory dependent human eye movements at retrieval. It seems that this is the first study directly looking at the effects of levels of processing and divided attention on memory dependent eye movements.

In Experiment 1, participants were asked to encode the object-scene picture pairs at either the deep or the shallow level and later to select which one of a set of three objects was paired with a studied background. In Experiment 2, participants were

instructed to encode the object-scene pairs under either full attention (FA) condition or divided attention (DA) condition. The relational memory effect was found at both the behavioral and the eye movement levels in both experiments. In Experiment 1, the LOP effect was found in both the behavioral and the eye movement data. In Experiment 2, however, the DA effect was only observed at the behavioral level.

Relational memory effects

The relational memory effect on the object-scene picture pairs was observed at both the behavioral and the eye movement levels. In both Experiment 1 and 2, participants showed sensitivity to the pairings across the different levels of our manipulations.

At the eye movement level, the relational memory effect was revealed by both the comparison between *Matching* and *Nonmatching* displays (between-display comparison) and the comparison between correct and incorrect selections in the *Matching* displays (within-display comparison). Participants generally made fewer fixations (and also fewer entries in Experiment 2) into the *Matching* displays than into the *Nonmatching* displays, which was consistent with the results from Hannula et al. (2007). Similar to infants in habituation studies, participants spent less time viewing the displays with original object-scene pairs which suggested that they had relational memories of the picture pairings. For the *Matching* displays only, participants generally directed a greater proportion of fixations and a greater proportion of viewing time to the correctly selected objects than to the incorrectly selected objects, which suggests that they had memories of the picture pairings. Moreover, as revealed by the time course analysis in both Experiments, the greater viewing of the correctly selected matching objects in the *Matching* trials than of

the incorrectly selected nonmatching objects in the *Nonmatching* trials over both the entire 10 seconds and the first 2 seconds also index participant's relational memories of the pairings.

These robust relational memory effects on eye movements are consistent with previous studies (e.g., Ryan et al., 2000; Hannula et al., 2007; Hannula & Ranganath, 2009) and further support the idea that human eye movements can be used as a veridical index of memory effect (Hannula et al., 2012).

Levels of performance or levels of processing?

In Experiment 1, there was a LOP effect at the behavioral level. Deep encoding led to better performance than shallow encoding. At the eye tracking level, although there was no LOP effect based on the between-display comparisons, the within-display comparison did show a LOP effect for trials with relational memory (the correct *Matching* trials) but not for trials without relational memory (the incorrect *Matching* trials). According to the time course analysis, there was a LOP effect for the correctly selected matching objects in the *Matching* trials but not for the incorrectly selected nonmatching objects in the *Nonmatching* trials over the entire 10 seconds of recording and the disproportional viewing emerged approximately 200ms earlier in the deep group than in the shallow group.

It seems that this is the first study that directly addresses the effect of levels of processing on human memory dependent eye movements. The LOP effect indexed by different eye movements was observed in several different comparisons. Intuitively, these different eye movements could simply be associated with different levels of performance at retrieval. However, the results from Experiment 1 alone could not confirm whether

levels of performance or levels of processing were reflected by these eye movements. Therefore, Experiment 2 was conducted with the divided attention manipulation which could also influence memory performance but would keep the depth of processing constant. Because participants in both the FA and DA conditions encoded the picture parings in the same way (they were both instructed to fulfill the pleasantness judgment task), eye movements under the divided attention manipulation should only be associated with memory performance but should not be associated with the depth of encoding. If participants' eye movements were affected under both the levels of processing manipulation and the divided attention manipulation in a similar way, then these eye movements could be said to reflect different levels of performance. Otherwise, if there was a dissociation in the eye movements between these two encoding manipulations, then it might be expected that eye movements reflected something specific about the encoding conditions, which could be indirectly related to the depth of processing during encoding.

The results showed that, although participants' memory performance was affected by the divided attention manipulation in Experiment 2 in a fashion similar to how it was affected by the levels of processing manipulation in Experiment 1, the eye movements at retrieval were generally unaffected by divided attention. Such a dissociation between memory performance and eye movements under the divided attention manipulation suggests that the eye movements observed in Experiment 1 were not necessarily associated with different levels of memory performance in general. Instead, the eye movements recorded at retrieval may be uniquely associated with different levels of processing at encoding.

LOP vs DA: why different effects on eye movements?

Although participants' memory performance was affected by both the levels of processing manipulation and the divided attention manipulation in these two experiments, their eye movements were affected by levels of processing but not by divided attention. Such a dissociation seems to be counterintuitive because it makes the most sense to expect that eye movements recorded at retrieval would simply reflect levels of memory performance at retrieval. Why do these two manipulations have the same effect on behavioral performance but different effects on eye movements?

Despite the exploratory nature of the current study, the null effect of divided attention on eye tracking may still be explainable. The LOP and DA manipulations might be associated with two different types of encodings. Imagine these two encoding manipulations are used in a recognition memory task with words. For the LOP manipulation, participants have to adopt different encoding strategies (e.g., relying on meaning vs relying on spelling of words) in order to follow the deep or shallow encoding instructions. For the DA manipulation, however, participants just need to allocate some attentional resources to the secondary task but can still adopt the same type of encoding strategy (e.g., always relying on meanings of words) across both FA and DA encoding conditions. If so, encoding in the deep and shallow conditions is qualitatively different, whereas encoding in the FA and DA conditions may just be quantitatively different. Therefore, the different eye tracking results between Experiment 1 and 2 might reflect different cognitive mechanisms despite the similar patterns observed in the behavioral performance. The significant effect of LOP on eye movements might reflect two different encoding mechanisms underlying recognition memory between deep and shallow

conditions, whereas the null effect of DA on eye movements might just reflect one common encoding mechanism between FA and DA conditions.

Levels of processing theory and circularity

The levels of processing theory has been criticized on the absence of an objective index of depth of processing and thus the potential for circularity (Baddley, 1978). That is, deeper level processing is thought to cause better memory performance and better memory performance is thought to reflect deeper processing. A good way to defend the levels of processing theory against such circularity is to provide a more objective index for depth of processing besides memory performance itself (Craik, 2002). For example, Vincent et al. (1996) measured participants' cardiovascular responses as objective indexes of processing depth in two recognition memory tasks to break this circularity. Three levels of processing were manipulated from judging whether the words were in upper case to judging whether the words were pleasant. Their results indicated that deeper processing at encoding was associated with increased heart rate at encoding as well as increased suppression of heart rate variability at retrieval.

Even though physiological measurements like cardiovascular responses have been used as an objective index for different levels of processing in memory, there have been no studies using human eye movements at retrieval. The modified experiments provided a good opportunity to see how human eye movements are affected by different levels of encoding when memory is retrieved. Results from the two experiments in this study suggested that memory dependent eye movements at retrieval are specifically associated with different levels of processing at encoding rather than different levels of memory performance in general. Given that the levels of processing theory has been criticized on

the potential circular explanations of memory performance and processing depth, these different eye movements at retrieval between deep and shallow encoding conditions might be used as additional measurements (other than performance) to indirectly index the depth of processing during encoding, which might provide promising evidence to help the levels of processing theory against the circularity criticism.

Limitations of the current study

There were several limitations of the current study. First, although the LOP effect was found at both the behavioral and the eye movement levels in Experiment 1, the LOP effect was observed in the within-display comparison but not in the between-display comparison. One possible explanation is based on the nature of the two types of comparisons. Specifically, the within-display comparison is based on the comparison of the matching and nonmatching objects within the *Matching* display and thus demands direct memory use. The between-display comparison, however, is based on the comparison of the entire screen between the *Matching*, *Nonmatching*, and *Novel* displays and is akin to free viewing after the effect of behavioral selection has been controlled. Additional studies are needed in order to determine whether this explanation is true. Second, a between-subjects design was adopted for both the levels of processing and divided attention manipulations. It might be better to use within-subjects comparisons for these effects so that individual differences might be better controlled. Third, there were only 20 *Matching* trials in total. As a result, a very small variation in the number of correct trials could cause a dramatic change in participants' behavioral measurements (e.g., those 0 *d'* participants). Fourth, object-scene picture pairs were used as stimuli in the present study. Given that the LOP effects are more robust with verbal materials (e.g.,

words) than nonverbal materials (e.g., pictures), the LOP effect on picture pairs found in the present study might be specific for our materials and the generalizability of the conclusions might be compromised.

Conclusions

In the present study, the influence of levels of processing and divided attention on human eye movements was investigated in recognition memory tasks where relational memory for object-scene picture pairs was tested. This is the first study directly looking at the effects of these popular encoding manipulations on human memory dependent eye movements. Behaviorally, there were both LOP and DA effects on performance. Despite the null effect of DA in the eye tracking measurements and the exploratory nature of the current study, the LOP effect on the eye movements at retrieval might be used as indirect indexes of depth of processing and thus help bolster the levels of processing theory against the circularity criticism.

APPENDIX 1

IRB APPROVAL FORM

UNLV
UNIVERSITY OF NEVADA LAS VEGAS

INFORMED CONSENT

Department of Psychology

TITLE OF STUDY: Relational Memory

INVESTIGATOR(S): Colleen Parks

CONTACT PHONE NUMBER: 702-895-0139

Purpose of the Study
You are invited to participate in a research study. The purpose of this research is to examine relationships between memory, awareness, and eye movements.

Participants
You are being asked to participate in the study because you are fluent in English and are 18 years or older and have normal or corrected-to-normal vision.

Procedures
If you volunteer to participate in this study, you will be asked to do a variety of tasks that will vary depending on the condition to which you are assigned. The tasks you may be asked to do include: providing basic demographic information, providing potentially sensitive medical information, rating pictures or words on various scales; generating words in response to verbal prompts; having your eye movements recorded. Participants are randomly assigned to experimental conditions.

Benefits of Participation
Although there are no direct benefits of this testing to you, many people find that participating in research is a good learning experience. A full explanation of the study will be provided to you at the end of the session and you may ask the experimenter any questions you have about the study. You may also contact Colleen Parks with any questions you may have (colleen.parks@unlv.edu).

Risks of Participation
The risks of participating in this research are minimal (that is, no more than that involved in daily life).

If you are assigned to the condition in which eye movements are recorded you will be asked to keep your head still, which could result in some discomfort. This discomfort is temporary; it will begin to feel better once you move your head. The risk of physical harm to you is minimal.

Cost /Compensation
There *will not* be financial cost to you to participate in this study. The study will take approximately one hour. UNLV students taking psychology courses will receive course credit as compensation for

Participant Initials _____

Approved by the UNLV IRB. Protocol #1304-4433
Received: 05-28-13Approved: 05-31-13 Expiration:05-30-14

APPENDIX 2

POST-TEST AWARENESS QUESTIONNAIRE

DIRM Exprt 1 Subject # _____

CB_____

Instructions

The following is a questionnaire about the landscape-object relatedness selection task you just finished. It is very important that you answer the questions *in order* and that you do not change your response to a question after moving on to other questions. If you feel that you need to qualify a "yes or no" question with an explanation, please do so. Please use the back of the sheet if necessary.

1. What did you think was the purpose of the task you just finished?

2. What was your general strategy in completing the landscape-object relatedness selection task?

3. Did you notice any relations between the landscapes and objects while you were doing this task?

☐ Yes ☐ No

3.a If yes, can you describe the relations you noticed?

4. Did you intentionally use your memory of the landscape-object pairs to complete this task or not?

☐ Yes ☐ No

4.a If yes, approximately how many selections were made based on your memory instead of your hunch? (The total # of selections you were supposed to make was 60.)

APPENDIX 3

TABLES AND FIGURES

Table 1.
Predictions on the effects of LOP and DA in direct and indirect tests

	Memory performance will be affected or not			
	Relational memory theory		Declarative memory theory	
Encoding manipulations	Direct condition	Indirect condition	Direct condition	Indirect condition
Levels of processing	**Yes**	**Yes**	**Yes**	**No**
Full/divided attention	**Yes**	**Yes**	**Yes**	**No**

Note. Predictions are based on both Relational memory theory and Declarative memory theory respectively. LOP indicates levels of processing and DA indicates divided attention. A "Yes" in the cell means our measurements will be affected by these manipulations whereas a "No" in the cell means our measurements will not be affected by these manipulations.

Table 2.

Descriptive statistics for Pilot 1

LOP	Task	*Mean*	*SD*	*N*
Deep	Direct	0.2567	0.56686	12
	Indirect	-0.1482	0.44043	11
Shallow	Direct	-0.2231	0.64363	13
	Indirect	-0.4478	0.54645	18

Note. The dependent measurement was participants' *d'* in the *Matching* trials.

Table 3.
Descriptive statistics for Pilot 2

Task type	*Mean*	*SD*	*N*
Deep Indirect	-0.2395	0.48193	12
Shallow Indirect	-0.0927	0.63572	13

Note. The dependent measurement was participants' *d'* in the *Matching* trials.

Table 4.

Descriptive statistics for behavioral data in Experiment 1

Task type	*Mean*	*SD*	*N*
Deep direct	1.6258	0.93844	32
Shallow direct	1.0147	0.76841	34

Note. The dependent measurement was participants' *d'* in the *Matching* trials.

Table 5.

Descriptive statistics for between-display comparison in Experiment 1

LOP	Trial type	Dependent measurement	*Mean*	*SD*	*N*
Deep	Matching	Total number of entries	1.8985	0.80909	33
		Total number of fixations	25.0964	4.88811	
	Nonmatching	Total number of entries	1.9606	0.85080	
		Total number of fixations	26.4882	4.66206	
	Novel	Total number of entries	1.9824	0.86315	
		Total number of fixations	25.7885	4.56848	
Shallow	Matching	Total number of entries	1.8482	0.82426	34
		Total number of fixations	24.8988	4.18995	
	Nonmatching	Total number of entries	1.8971	0.73609	
		Total number of fixations	26.0762	4.67209	
	Novel	Total number of entries	2.0188	0.85313	
		Total number of fixations	25.5388	4.53899	

Note. The dependent measurements were total number entries and total number of fixations into the total AOIs in the three types of trials.

Table 6.

Descriptive statistics for within-display comparison in Experiment 1

LOP	Accuracy	Dependent measurement	*Mean*	*SD*	*N*
Deep	Correct	Proportion of fixations	0.4948	0.08625	33
		Proportion of viewing time	0.5315	0.10663	
	Incorrect	Proportion of fixations	0.4042	0.13435	
		Proportion of viewing time	0.4170	0.16455	
Shallow	Correct	Proportion of fixations	0.4365	0.07152	34
		Proportion of viewing time	0.4624	0.09645	
	Incorrect	Proportion of fixations	0.4100	0.09270	
		Proportion of viewing time	0.4226	0.11247	

Note. The dependent measurements were proportion of fixations and proportion of viewing time towards the selected object AOIs in the *Matching* trials.

Table 7.

Descriptive statistics for time course analysis (10s) in Experiment 1

LOP	Trial type	Time bin (ms)	*Mean*	*SD*	*N*
Deep	Matching	0-1000	0.4091	0.08865	33
		1000-2000	0.5061	0.13995	
		2000-3000	0.5667	0.16448	
		3000-4000	0.5791	0.15952	
		4000-5000	0.5518	0.14819	
		5000-6000	0.5248	0.15094	
		6000-7000	0.5121	0.16338	
		7000-8000	0.5297	0.15995	
		8000-9000	0.5403	0.16544	
		9000-10000	0.5385	0.18976	
	Nonmatching	0-1000	0.3403	0.07148	
		1000-2000	0.4173	0.08228	
		2000-3000	0.4533	0.09502	
		3000-4000	0.4948	0.10462	
		4000-5000	0.5048	0.10097	
		5000-6000	0.4739	0.12674	
		6000-7000	0.4633	0.11332	
		7000-8000	0.4300	0.15015	
		8000-9000	0.4358	0.13358	
		9000-10000	0.4179	0.14781	
Shallow	Matching	0-1000	0.3800	0.07847	34
		1000-2000	0.4597	0.09530	
		2000-3000	0.4771	0.13761	
		3000-4000	0.5044	0.13656	
		4000-5000	0.5326	0.14802	
		5000-6000	0.4703	0.18343	
		6000-7000	0.4726	0.17379	
		7000-8000	0.4191	0.17240	
		8000-9000	0.4506	0.16106	
		9000-10000	0.4718	0.12359	
	Nonmatching	0-1000	0.3409	0.06626	
		1000-2000	0.4015	0.09126	
		2000-3000	0.4594	0.08742	
		3000-4000	0.5209	0.12561	
		4000-5000	0.4968	0.10923	
		5000-6000	0.4609	0.13813	
		6000-7000	0.4135	0.12316	
		7000-8000	0.4000	0.12613	
		8000-9000	0.3974	0.09768	
		9000-10000	0.4074	0.10587	

Note. The dependent measurement was proportion of viewing time towards the correctly selected matching AOIs in *Matching* trials and the incorrectly selected nonmatching AOIs in *Nonmatching* trials respectively.

Table 8.

Descriptive statistics for time course analysis (2s) in Experiment 1

LOP	Trial type	Time bin (ms)	*Mean*	*SD*	*N*
Deep	Matching	0-200	0.3509	0.16077	33
		200-400	0.3894	0.10971	
		400-600	0.4058	0.12947	
		600-800	0.4318	0.13443	
		800-1000	0.4548	0.15472	
		1000-1200	0.4791	0.13178	
		1200-1400	0.5124	0.17293	
		1400-1600	0.5155	0.16612	
		1600-1800	0.5142	0.15752	
		1800-2000	0.4985	0.18202	
	Nonmatching	0-200	0.3448	0.12039	
		200-400	0.3167	0.08298	
		400-600	0.3230	0.09518	
		600-800	0.3570	0.10999	
		800-1000	0.3818	0.10190	
		1000-1200	0.3697	0.11315	
		1200-1400	0.3891	0.11687	
		1400-1600	0.4245	0.12959	
		1600-1800	0.4258	0.13120	
		1800-2000	0.4133	0.13100	
Shallow	Matching	0-200	0.3285	0.12427	34
		200-400	0.3150	0.11657	
		400-600	0.3718	0.13969	
		600-800	0.4100	0.13106	
		800-1000	0.4329	0.12457	
		1000-1200	0.4453	0.13319	
		1200-1400	0.4803	0.17469	
		1400-1600	0.5009	0.14708	
		1600-1800	0.4359	0.14376	
		1800-2000	0.4324	0.18616	
	Nonmatching	0-200	0.3385	0.10425	
		200-400	0.3297	0.09935	
		400-600	0.3238	0.11830	
		600-800	0.3432	0.12067	
		800-1000	0.3718	0.12549	
		1000-1200	0.3903	0.10573	
		1200-1400	0.4115	0.14845	
		1400-1600	0.4041	0.15605	
		1600-1800	0.3847	0.12783	
		1800-2000	0.4076	0.13641	

Note. The dependent measurement was proportion of viewing time towards the correctly selected matching AOIs in *Matching* trials and the incorrectly selected nonmatching AOIs in *Nonmatching* trials respectively.

Table 9.

Descriptive statistics for behavioral data in Experiment 2

Task type	*Mean*	*SD*	*N*
FA direct	1.5836	1.01389	33
DA direct	0.8411	0.85556	33

Note. The dependent measurement was participants' *d'* in the *Matching* trials.

Table 10.

Descriptive statistics for between-display comparison in Experiment 2

Attention	Trial type	Dependent measurement	*Mean*	*SD*	*N*
FA	Matching	Total number of entries	1.8006	0.76173	33
		Total number of fixations	22.4267	5.88682	
	Nonmatching	Total number of entries	1.8318	0.82697	
		Total number of fixations	23.3439	5.87321	
	Novel	Total number of entries	1.8848	0.92959	
		Total number of fixations	23.2742	5.92923	
DA	Matching	Total number of entries	1.7203	0.70319	33
		Total number of fixations	23.7624	5.17695	
	Nonmatching	Total number of entries	1.9273	0.81270	
		Total number of fixations	24.5167	4.48849	
	Novel	Total number of entries	1.7924	0.74153	
		Total number of fixations	24.5470	4.35680	

Note. The dependent measurements were total number entries and total number of fixations into the total AOIs in the three types of trials.

Table 11.

Descriptive statistics for within-display comparison in Experiment 2

Attention	Accuracy	Dependent measurement	*Mean*	*SD*	*N*
FA	Correct	Proportion of fixations	0.4679	0.06795	33
		Proportion of viewing time	0.4848	0.08148	
	Incorrect	Proportion of fixations	0.3882	0.12526	
		Proportion of viewing time	0.3852	0.13956	
DA	Correct	Proportion of fixations	0.4588	0.08369	33
		Proportion of viewing time	0.4797	0.09955	
	Incorrect	Proportion of fixations	0.4021	0.07749	
		Proportion of viewing time	0.4161	0.08877	

Note. The dependent measurements were proportion of fixations and proportion of viewing time towards the selected object AOIs in the *Matching* trials.

Table 12.

Descriptive statistics for time course analysis (10s) in Experiment 2

Attention	Trial type	Time bin (ms)	*Mean*	*SD*	*N*
FA	Matching	0-1000	0.3986	0.08568	33
		1000-2000	0.4763	0.11156	
		2000-3000	0.4947	0.13332	
		3000-4000	0.5424	0.10582	
		4000-5000	0.5417	0.15930	
		5000-6000	0.5091	0.15081	
		6000-7000	0.4681	0.15751	
		7000-8000	0.4790	0.12610	
		8000-9000	0.4745	0.15298	
		9000-10000	0.5204	0.14422	
	Nonmatching	0-1000	0.3320	0.05951	
		1000-2000	0.3876	0.10257	
		2000-3000	0.4500	0.10018	
		3000-4000	0.4650	0.12322	
		4000-5000	0.4658	0.12062	
		5000-6000	0.4344	0.09665	
		6000-7000	0.3880	0.12059	
		7000-8000	0.4044	0.12020	
		8000-9000	0.3827	0.11806	
		9000-10000	0.4325	0.09558	
DA	Matching	0-1000	0.3554	0.09130	33
		1000-2000	0.4772	0.13987	
		2000-3000	0.5164	0.15514	
		3000-4000	0.4862	0.15263	
		4000-5000	0.5406	0.16945	
		5000-6000	0.5145	0.16989	
		6000-7000	0.4845	0.17883	
		7000-8000	0.5061	0.18320	
		8000-9000	0.4711	0.17858	
		9000-10000	0.4722	0.14919	
	Nonmatching	0-1000	0.3347	0.06529	
		1000-2000	0.4292	0.09163	
		2000-3000	0.4265	0.09246	
		3000-4000	0.5004	0.10807	
		4000-5000	0.4585	0.12041	
		5000-6000	0.4767	0.13137	
		6000-7000	0.4445	0.14735	
		7000-8000	0.4378	0.14379	
		8000-9000	0.4285	0.14169	
		9000-10000	0.4036	0.13706	

Note. The dependent measurement was proportion of viewing time towards the correctly selected matching AOIs in *Matching* trials and the incorrectly selected nonmatching AOIs in *Nonmatching* trials respectively.

Table 13.

Descriptive statistics for time course analysis (2s) in Experiment 2

Attention	Trial type	Time bin (ms)	*Mean*	*SD*	*N*
FA	Matching	0-200	0.3342	0.11749	33
		200-400	0.3150	0.11806	
		400-600	0.3844	0.12862	
		600-800	0.4346	0.11343	
		800-1000	0.4727	0.14516	
		1000-1200	0.4326	0.15498	
		1200-1400	0.5192	0.17593	
		1400-1600	0.5004	0.19106	
		1600-1800	0.4725	0.13469	
		1800-2000	0.4713	0.12813	
	Nonmatching	0-200	0.2948	0.12625	
		200-400	0.3132	0.09790	
		400-600	0.3584	0.07360	
		600-800	0.3707	0.10553	
		800-1000	0.3506	0.10329	
		1000-1200	0.3714	0.15270	
		1200-1400	0.3859	0.14486	
		1400-1600	0.3942	0.11076	
		1600-1800	0.3836	0.10826	
		1800-2000	0.3852	0.10406	
DA	Matching	0-200	0.2833	0.17647	33
		200-400	0.3076	0.15494	
		400-600	0.3413	0.12955	
		600-800	0.3865	0.14498	
		800-1000	0.4196	0.14472	
		1000-1200	0.4406	0.19945	
		1200-1400	0.4752	0.19231	
		1400-1600	0.4722	0.22618	
		1600-1800	0.5082	0.16236	
		1800-2000	0.5179	0.14979	
	Nonmatching	0-200	0.3211	0.12281	
		200-400	0.2945	0.11063	
		400-600	0.3134	0.10179	
		600-800	0.3466	0.10575	
		800-1000	0.3761	0.11751	
		1000-1200	0.3957	0.12112	
		1200-1400	0.4433	0.12966	
		1400-1600	0.4621	0.12640	
		1600-1800	0.4234	0.12643	
		1800-2000	0.4175	0.11863	

Note. The dependent measurement was proportion of viewing time towards the correctly selected matching AOIs in *Matching* trials and the incorrectly selected nonmatching AOIs in *Nonmatching* trials respectively.

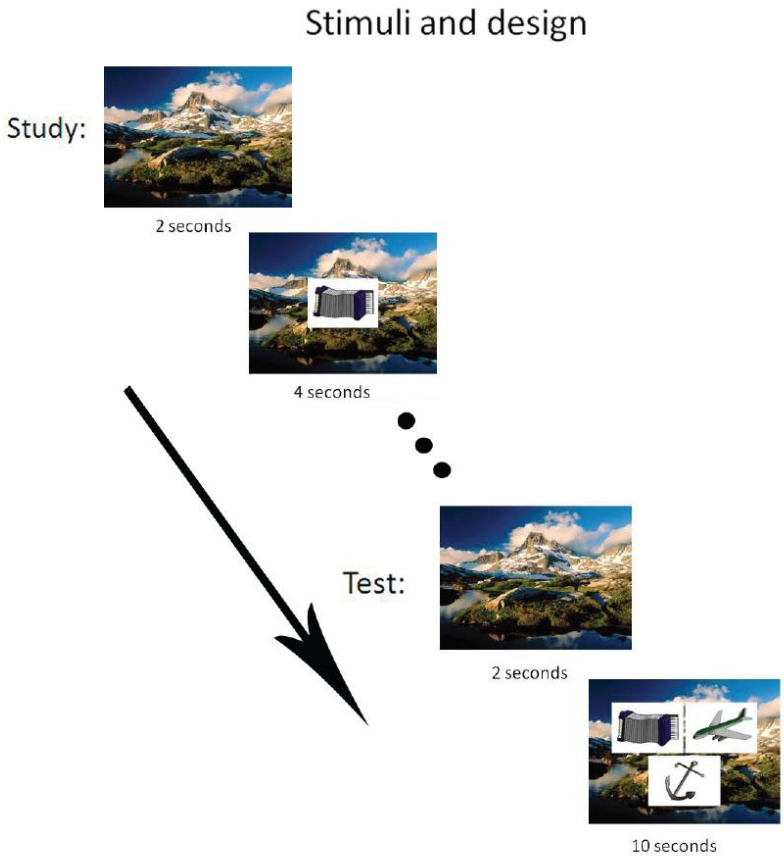

Figure 1. Sample stimuli and procedure of the present study.

Note. In the study phase, each trial starts with a scene picture shown for 2s followed by a scene-object pair shown for another 4s[21]. In the test phase, each trial starts with a scene picture shown for 2s followed by three-object-scene combination for another 10s. The intervals between two successive trails in both study and test phase are both 1.5s.

[21]The duration of the object-scene pairs was 2s for two earlier behavioral pilots that are not reported in this paper. Moreover, the sizes of the landscapes and objects were 500 × 400 pixels and 200 × 140 pixels respectively in the behavioral pilots and 800 × 600 and 300 × 300 respectively in the eye tracking experiments.

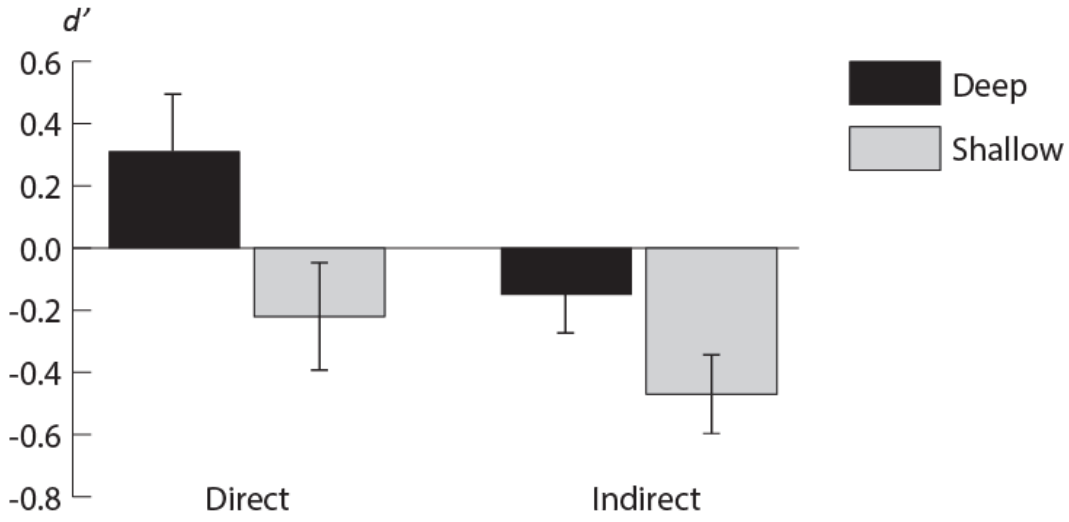

Figure 2. *d'* for *Matching* trials in deep and shallow encoding conditions of both direct and indirect tests in Pilot 1.

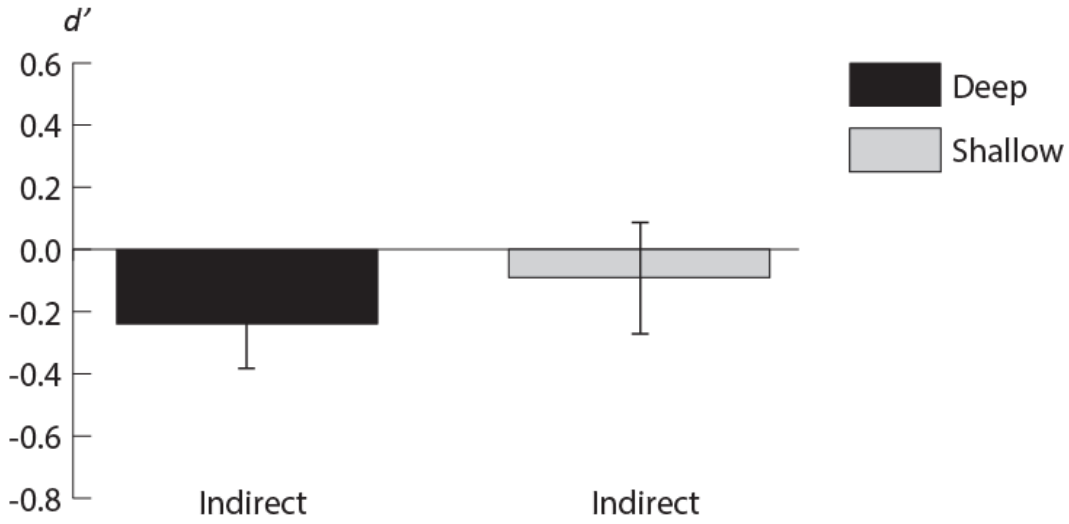

Figure 3. *d'* for *Matching* trials in deep and shallow encoding conditions of indirect test in Pilot 2.

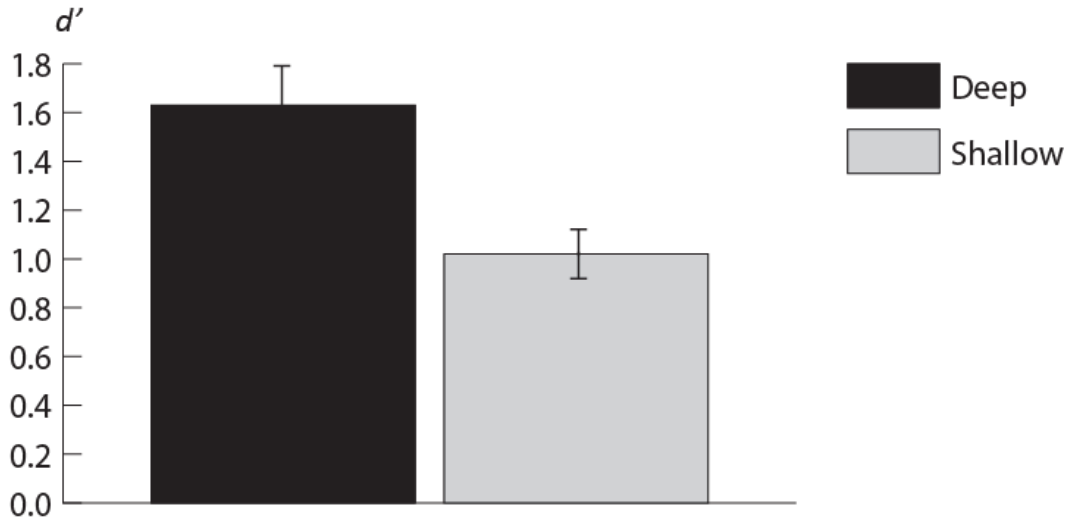

Figure 4. *d'* for *Matching* trials in deep and shallow encoding conditions in Experiment 1.

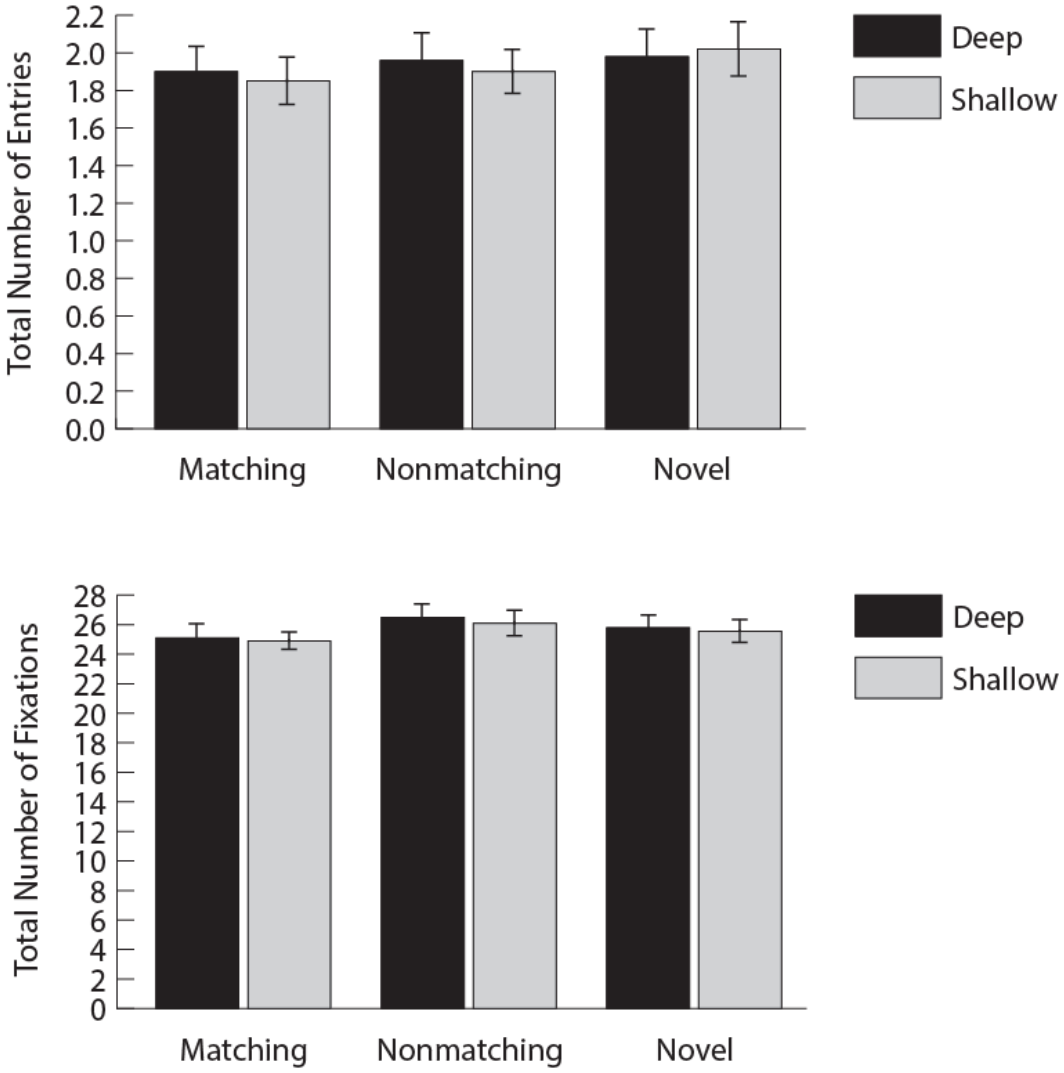

Figure 5. Between-display comparison in Experiment 1.

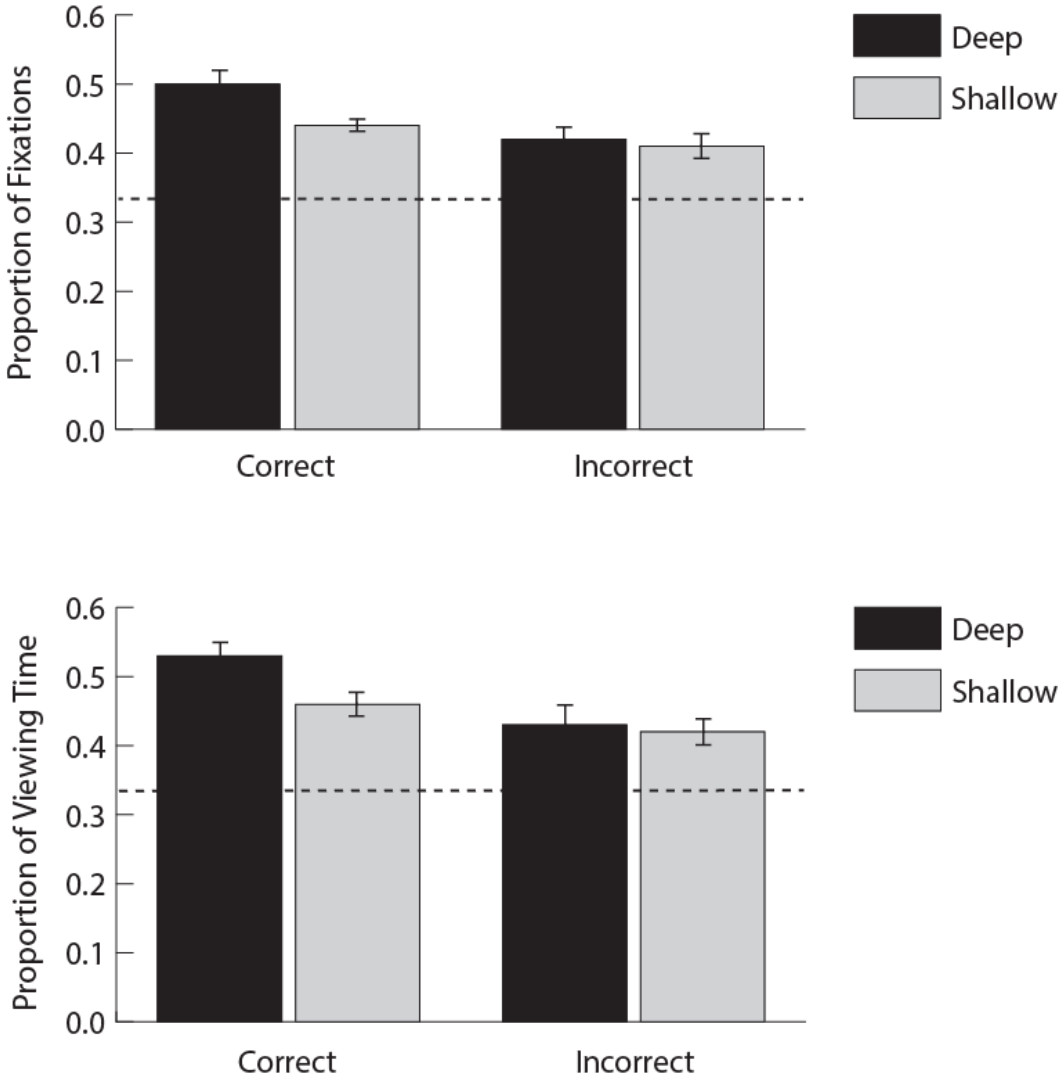

Figure 6. Within-display comparison in Experiment 1. Dash line represents the 33% chance level.

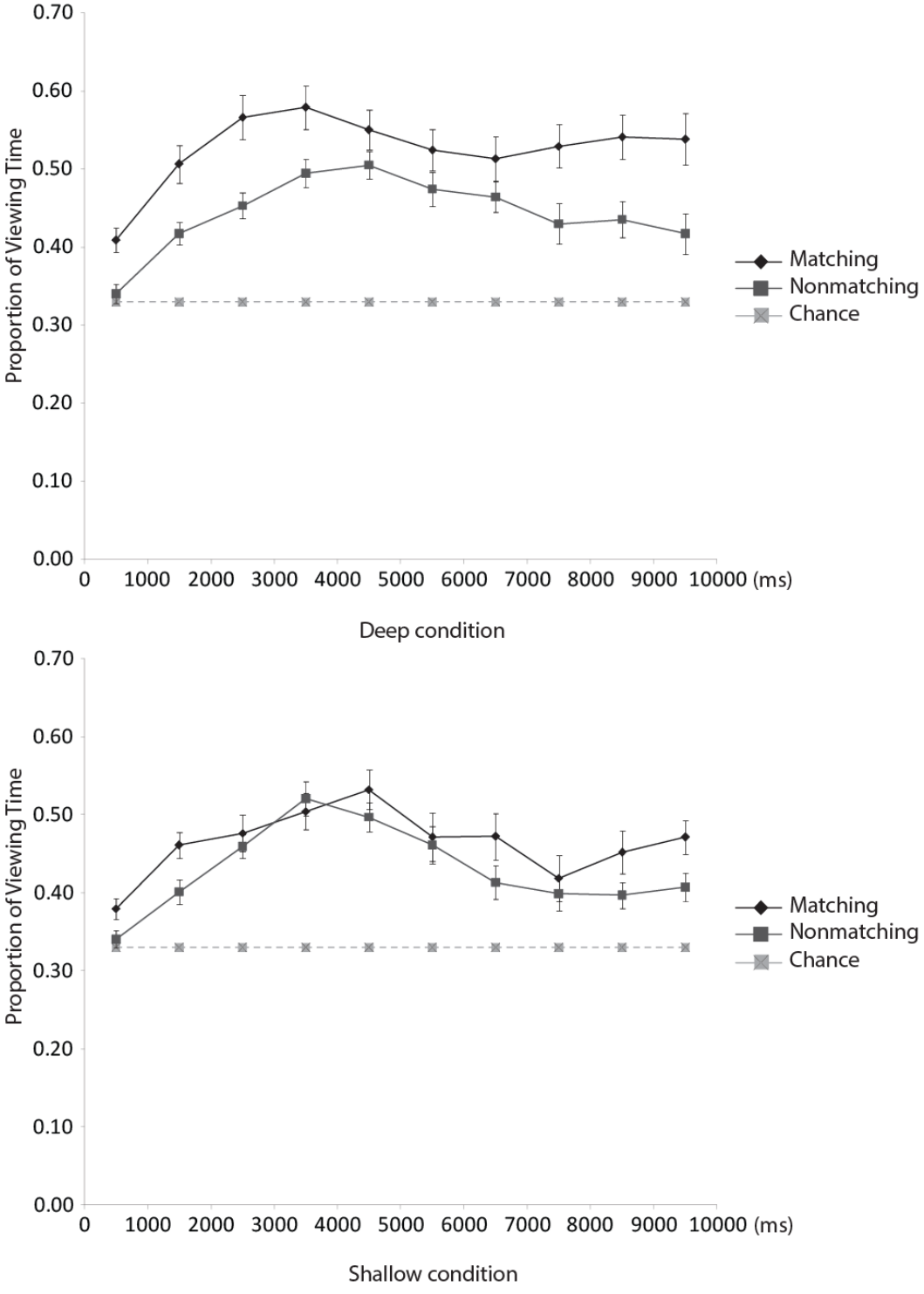

Figure 7. Time course analysis of the entire 10s for *Matching* and *Nonmatching* trials in deep and shallow encoding conditions in Experiment 1.

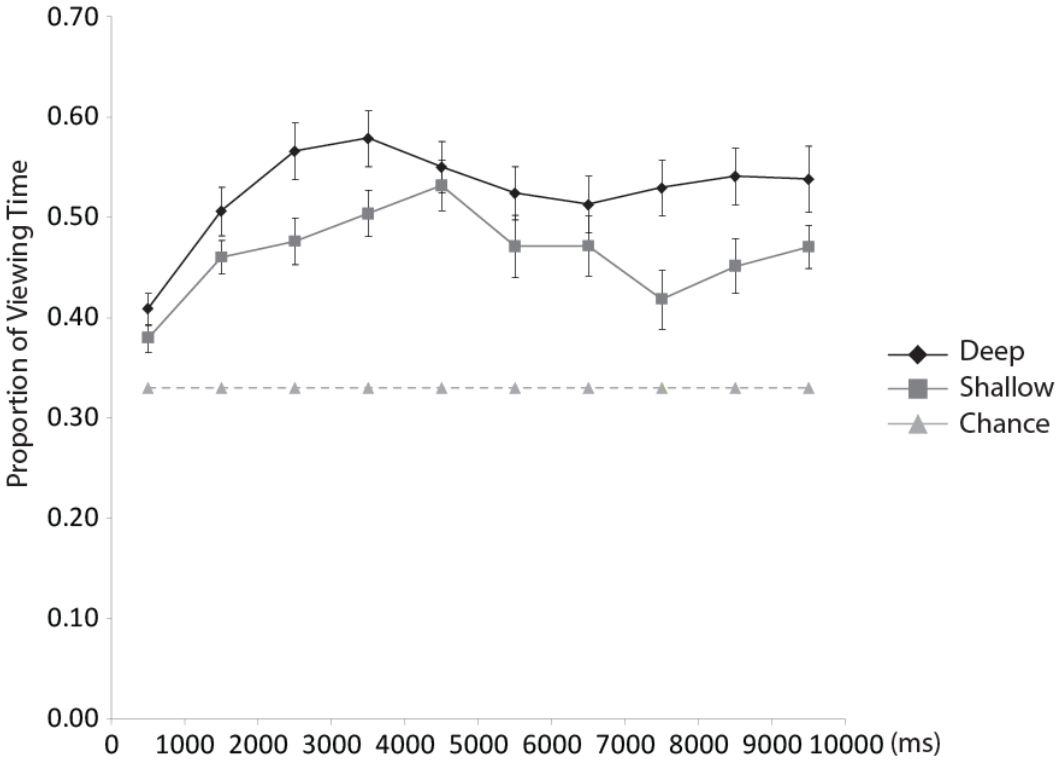

Figure 8. Time course analysis of the entire 10s for the correct *Matching* trials only between deep and shallow encoding conditions in Experiment 1.

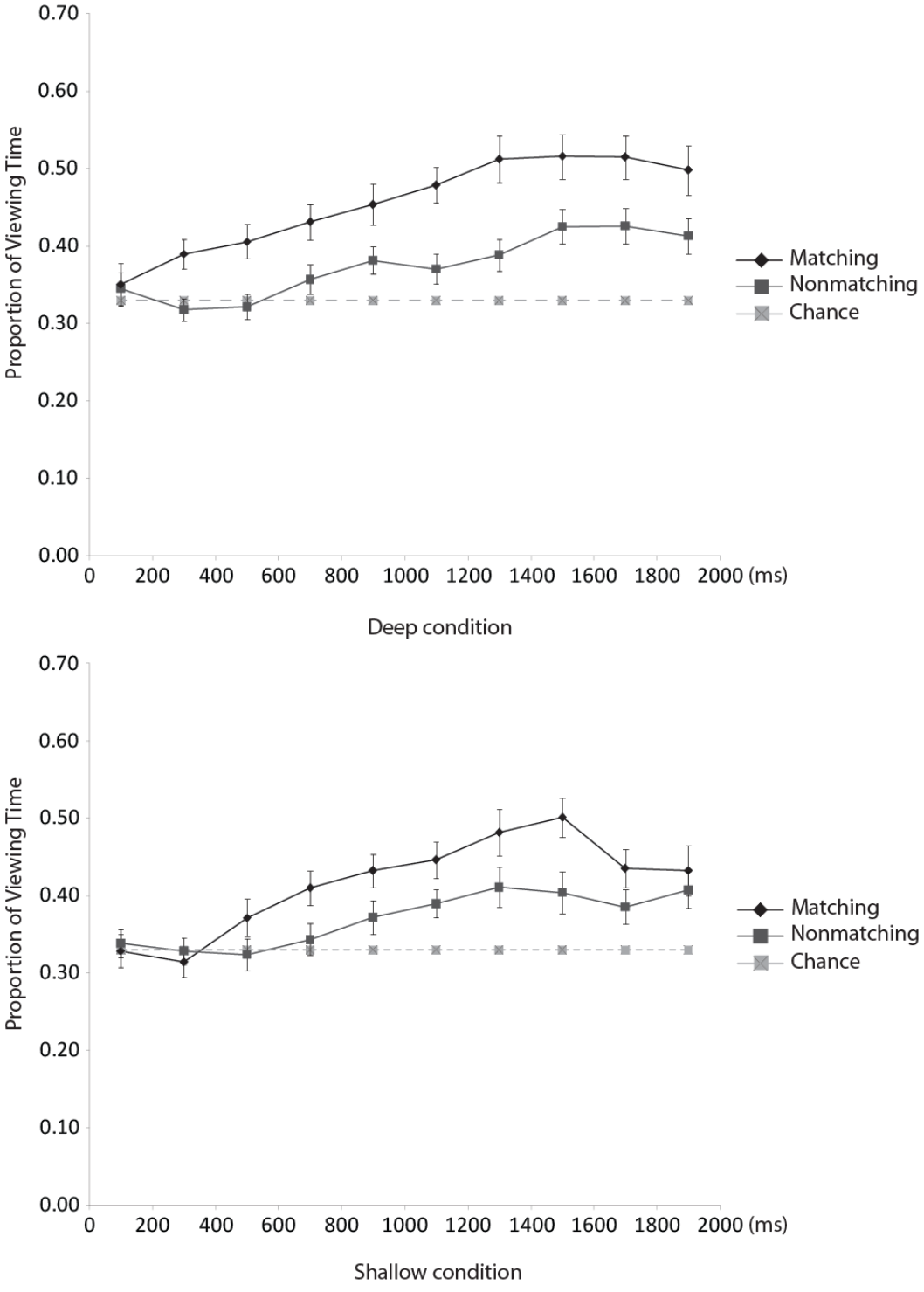

Figure 9. Time course analysis of the first 2s for *Matching* and *Nonmatching* trials in deep and shallow encoding conditions in Experiment 1.

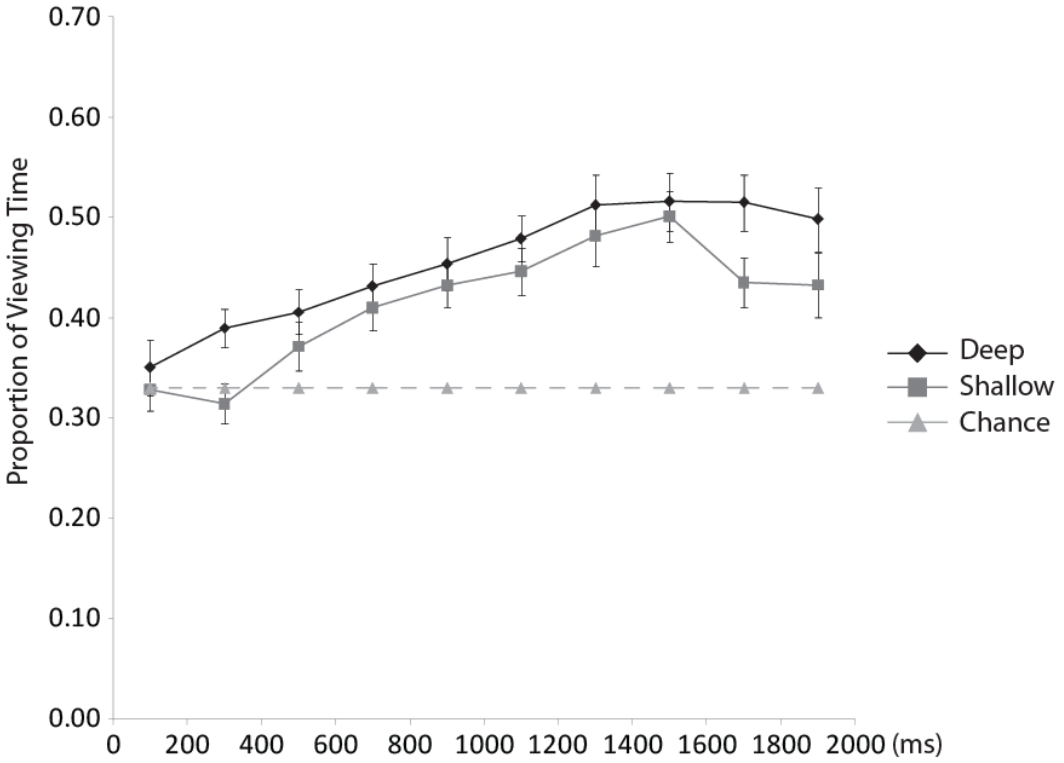

Figure 10. Time course analysis of the first 2s for the correct *Matching* trials only between deep and shallow encoding conditions in Experiment 1.

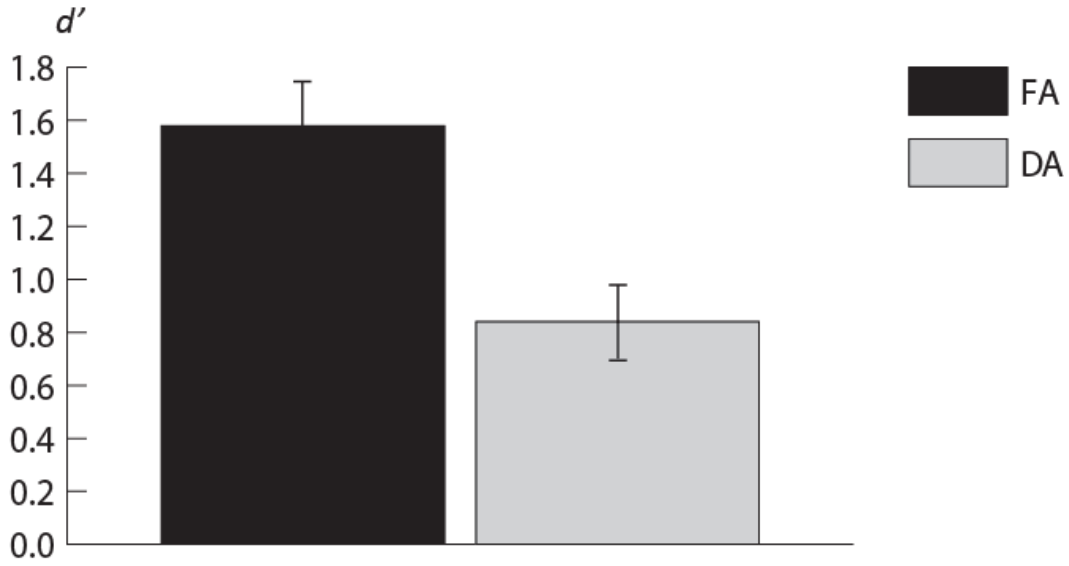

Figure 11. *d'* for *Matching* trials in FA and DA encoding conditions in Experiment 2.

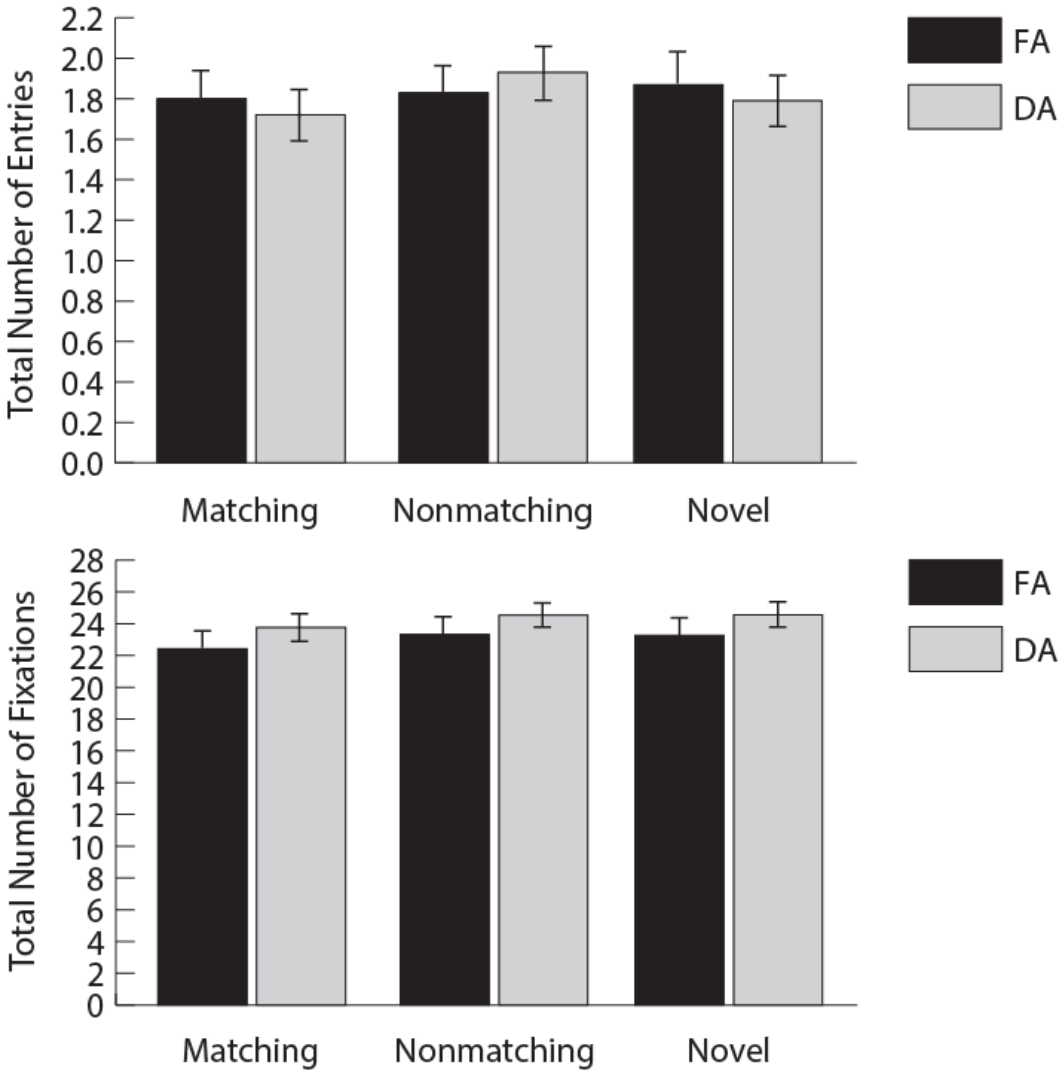

Figure 12. Between-display comparison in Experiment 2.

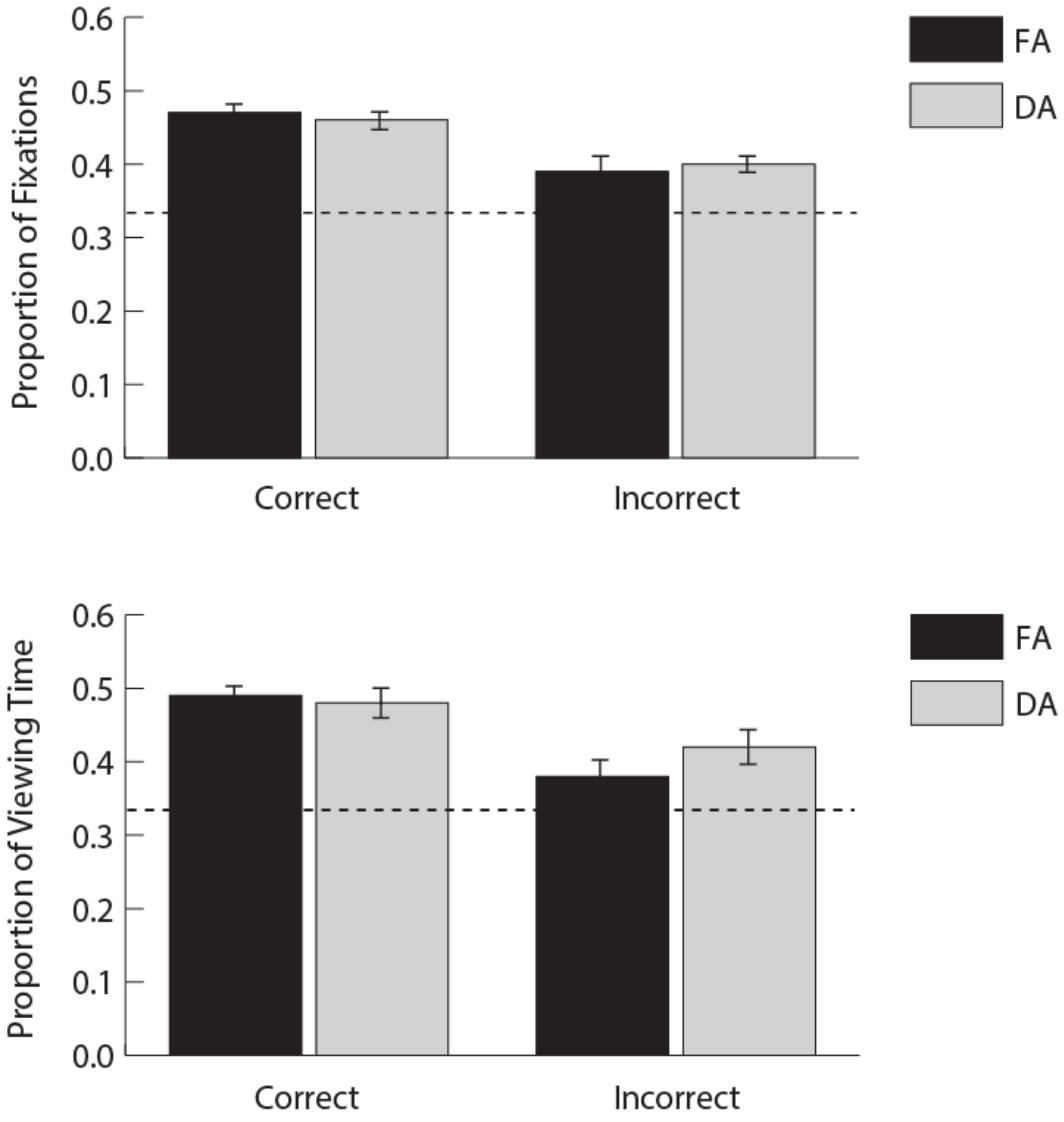

Figure 13. Within-display comparison in Experiment 2. Dash line represents the 33% chance level.

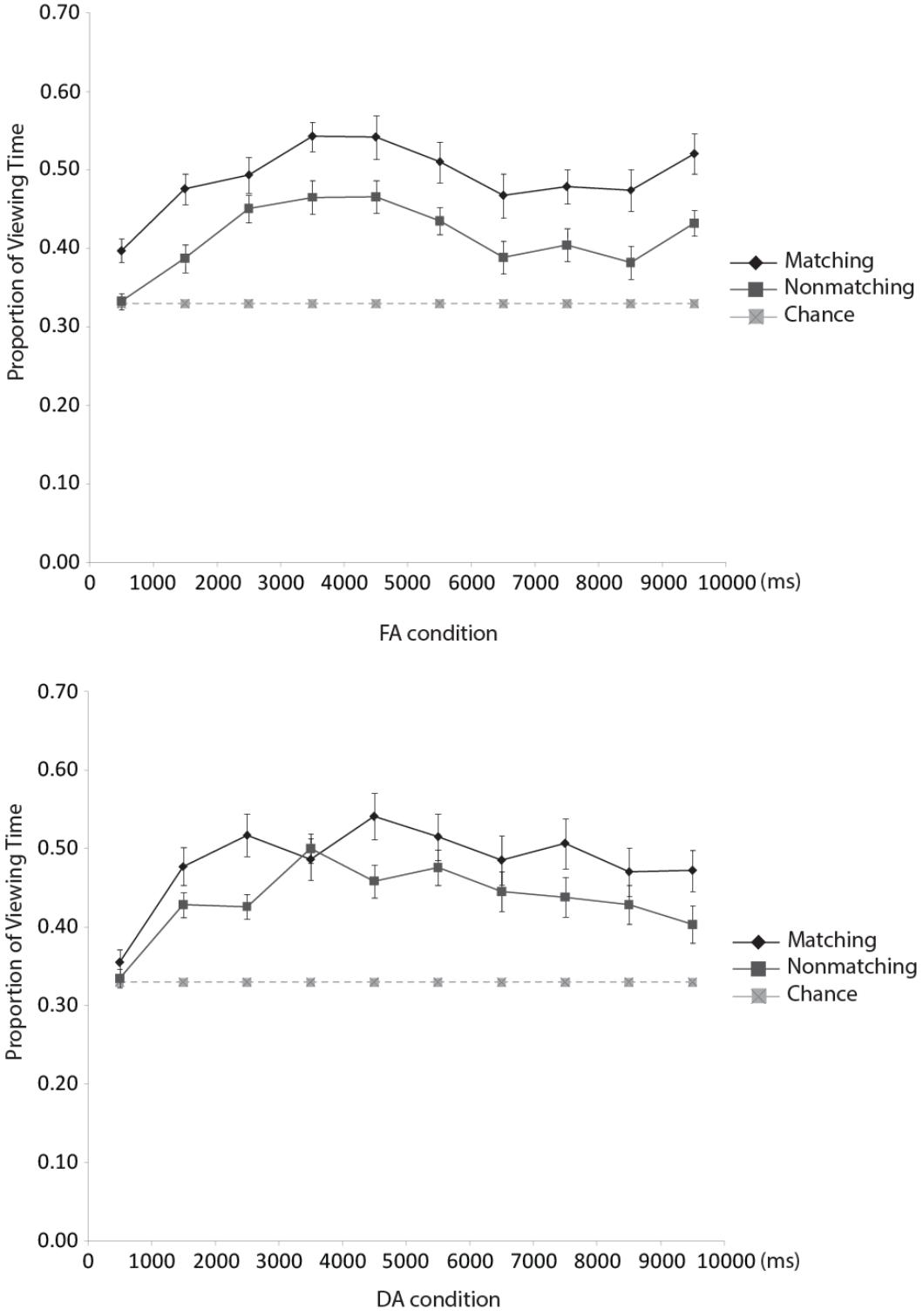

Figure 14. Time course analysis of the entire 10s for *Matching* and *Nonmatching* trials in FA and DA encoding conditions in Experiment 2.

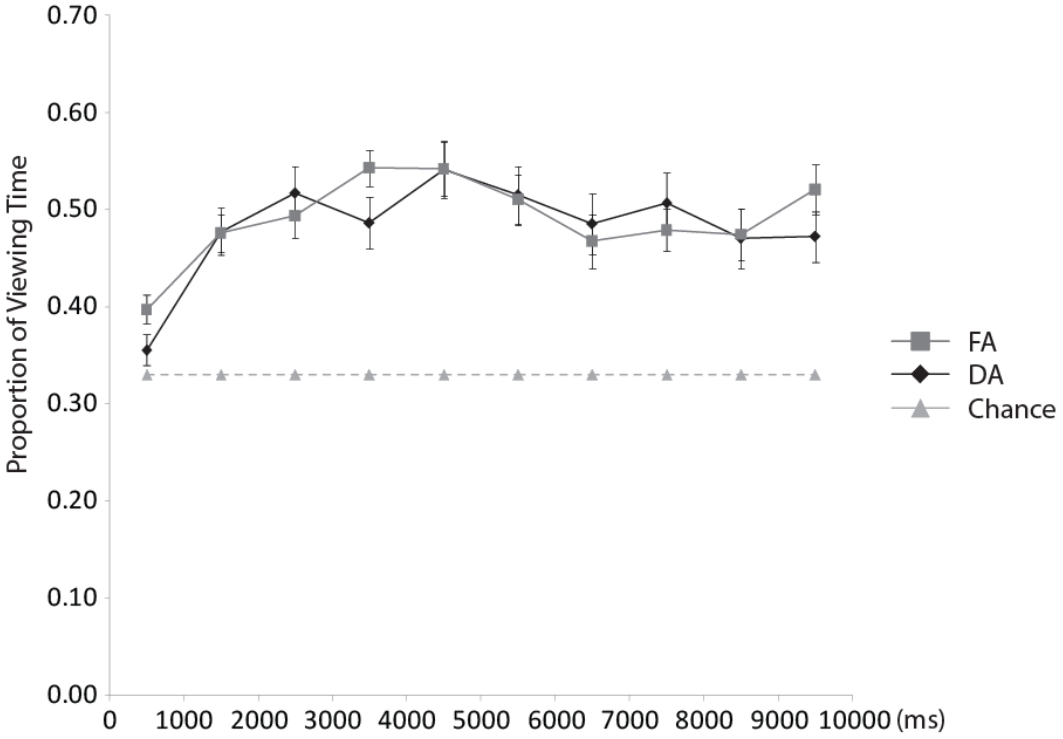

Figure 15. Time course analysis of the entire 10s for the correct *Matching* trials only between FA and DA encoding conditions in Experiment 2.

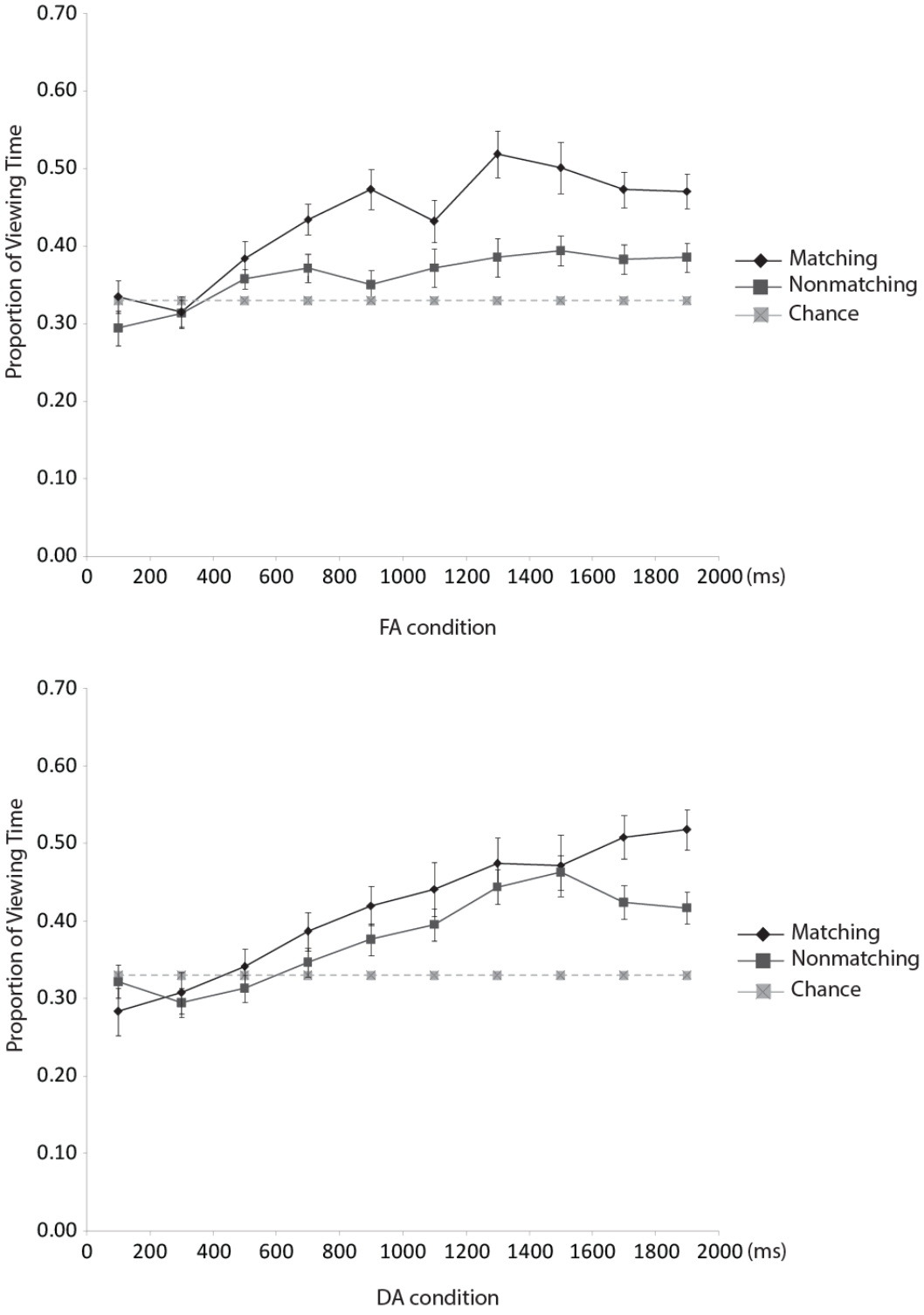

Figure 16. Time course analysis of the first 2s for *Matching* and *Nonmatching* trials in FA and DA encoding conditions in Experiment 2.

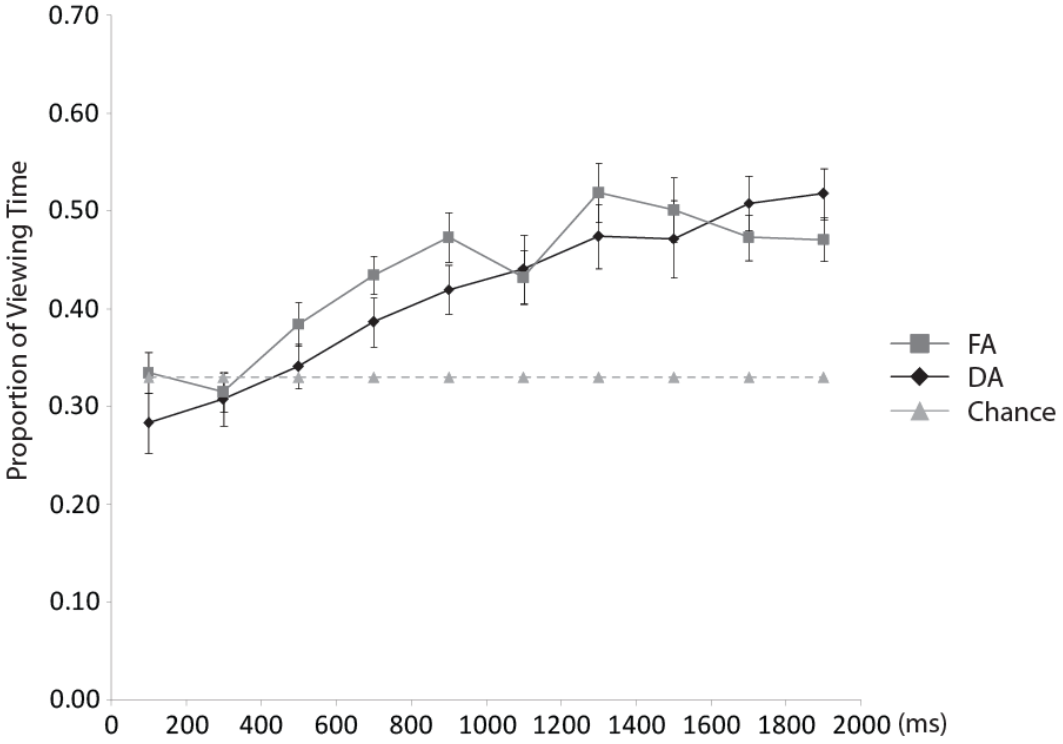

Figure 17. Time course analysis of the first 2s for the correct *Matching* trials only between FA and DA encoding conditions in Experiment 2.

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UNLV GPSA Book Scholarship, Spring 2012

Thesis Title: Performance or processing? Effects of levels of processing and divided attention on memory-related eye movements

Thesis Examination Committee:

Chairperson, Colleen Parks, Ph.D.
Committee Member, Mark Ashcraft, Ph.D.
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