

Allocation of Attention and the Encoding of Emotional Memories

A DISSERTATION  
SUBMITTED TO THE FACULTY OF THE GRADUATE SCHOOL  
OF THE UNIVERSITY OF MINNESOTA  
BY

Michael Patrick Blank

IN PARTIAL FULFILLMENT OF THE REQUIREMENTS  
FOR THE DEGREE OF  
DOCTOR OF PHILOSOPHY

Chad J. Marsolek, Advisor

July, 2011

© Michael Patrick Blank 2011

## Acknowledgements

This was a long time coming.

My thanks especially to my advisor, Chad Marsolek, for being patient, and for teaching me to counterbalance for *everything*. In addition to teaching me how to be a better researcher, he taught me how to write effectively, how to give a good presentation, and has unfailingly good taste in both beer and music – I’m now able to discuss trappist ales in detail, and argue that Guided by Voices were better than The Beatles. Chad is an A+ guy, and he is most responsible for the researcher I am today – which I only hope is a compliment to him.

My thanks to my committee members. To Dan Kersten, for being one of the nicest, and smartest, people I know, for always listening to my ramblings about emotion, and for teaching me to sometimes step back and think about questions intuitively, rather than theoretically. Thanks also to Wilma Koutstaal, for always challenging me on the details, for helping to sort out my dissertation data, and for always making me feel better about my research. Thanks also to Katie Thomas for her help, and for being very patient during a period of tumult. I also remain indebted to the Center for Cognitive Sciences for supporting this research, and supporting me, throughout my graduate school career.

My thanks also to friends, family, and colleagues. Thanks to my family for teaching me empathy, humility, and curiosity, and for the support – emotional, fiscal, on an emergency basis, and otherwise. Thanks for all of it. To Liz, for rainbow cake, “tranquilizer jarts,” being awesome, and everything else. To Chris, for teaching me that the hardest part about fixing a car – or anything else that’s broken – is getting over the

fear that you'll break it worse, and for being one of the only people in the world to share my appreciation for the pathos of the late 1980's John Candy oeuvre. To Vaughn Steele, for being an invaluable friend and all-around good guy, which may be the highest compliment I can pay. Always willing to play catch in the lab (we never broke anything, though we did come incredibly close), explain ERP data analysis, play wiffle ball, and make tongue-in-cheek wagers about inserting the phrase "gravy boat" into papers – a wager I will now be able to collect on. Thanks to Brenton McMenamin, for being a good friend, sounding board about emotion research and Matlab code, a fellow Packers fan, and for almost winning that spaghetti eating contest. To Becky Deason, for being an invaluable source of support and voice of reason, even after moving away. Thanks to my fellow grad students (Susan Park Anderson, Alvina Kittur, Tyler Yost, Katrina Schleisman, Ben Denkinger), and other lab members or research assistants I've worked with, but especially Ricky Biga, Sara Fechtelkotter, and Paige Frey, who helped collect portions of the data reported here. Thanks to G.I. Joe, for teaching me that knowing is half the battle; I still hope to one day unlock the secret of the other half.

"Just remember what ol' Jack Burton does when the earth quakes, and the poison arrows fall from the sky, and the pillars of heaven shake. Yeah, Jack Burton just looks that big ol' storm right square in the eye and he says, 'Give me your best shot, pal. I can take it.'" – Jack Burton

“A lot of people go through life doing things badly. Racing's important to men who do it well. When you're racing, it's life. Anything that happens before or after is just waiting.” – Steve McQueen

“Back off, man...I'm a scientist.” – Peter Venkman

MPB

## Abstract

Emotional reactivity to visual scenes affects both how we attend to them and how they are remembered, but it is not clear how these attention and memory effects are related. Weapon-focus theories (e.g., Loftus, 1979) suggest that attention is restricted to emotion-provoking parts of scenes, and that such restriction of attention affects the specificity of the memory that is stored. I directly tested whether “weapon-focus-like” restriction of attention predicts subsequent visually-specific memory for emotional scenes by recording eye movements while participants viewed relatively emotional and relatively non-emotional slides during initial encoding. Even though visually-specific memory was equivalent for all types of scenes, *different* patterns of eye movements predicted subsequent memory for emotional and non-emotional scenes. For emotional scenes only, visually-specific memory was predicted when eye movements were restricted to emotional parts of the scenes during encoding. For non-emotional scenes, visually-specific memory was predicted when more fixations of shorter duration were made, and attention was relatively broadened across the scene during encoding. Experiments 2 and 3 tested whether these patterns of eye movements reflect local or global processing of scenes, but across both experiments, there was no evidence that local and global processing influenced subsequent memory effects. The subsequent memory effects from Experiment 1 were replicated in Experiment 2, but in Experiment 3, a relative broadening of attention – more fixations of shorter duration – predicted subsequent memory for *all* scenes, a pattern that had only been observed for non-emotional scenes previously. Experiment 4 was conducted to test whether this occurred because emotional reactions to emotional scenes were reduced by having participants

simply view each scene, which reduces emotional responses when compared to cases where valence and arousal judgments are made as they were in previous experiments. Experiment 4 replicated the subsequent memory effects from Experiment 3, demonstrating important boundary conditions on the subsequent memory effects established in the first two experiments. These results suggest that qualitatively distinct memory representations may be stored for emotional and non-emotional scenes, but both representations are capable of supporting visually-specific memory.

## Table of Contents

List of Figures.....	viii
Introduction .....	1
<i>Emotional Effects on Memory</i> .....	2
<i>Scene Perception: Attention and Memory for Non-Emotional Scenes</i> .....	13
Experiment 1 .....	18
<i>Method</i> .....	20
<i>Results</i> .....	30
<i>Discussion</i> .....	40
Experiment 2: Using Size Judgments to Induce Local/Global Processing .....	43
<i>Method</i> .....	48
<i>Results</i> .....	51
<i>Discussion</i> .....	60
Experiment 3: Inducing Global/Local Processing in a Blocked Design .....	62
<i>Method</i> .....	62
<i>Results</i> .....	65
<i>Discussion</i> .....	72
Experiment 4: Free Viewing of IAPS Slides.....	75
<i>Method</i> .....	76
<i>Results</i> .....	76
<i>Discussion</i> .....	83
General Discussion.....	86
<i>Eye Movements and Visually-Specific Memory</i> .....	86



	vii
<i>Disentangling Valence and Arousal Effects in Emotional Memory and Attention</i> ....	89
<i>Varied Influences of Emotional Arousal on Cognitive Processing</i> .....	91
<i>A Scene-Representation Based Conception of Emotional Memory</i> .....	94
<i>Limitations</i> .....	96
<i>Future Directions</i> .....	97
<i>Conclusion</i> .....	99
References .....	100
Appendix .....	117

**List of Figures**

Figure 1.....	28
Figure 2.....	33
Figure 3.....	35
Figure 4.....	39
Figure 5.....	44
Figure 6.....	48
Figure 7.....	54
Figure 8.....	55
Figure 9.....	59
Figure 10.....	67
Figure 11.....	69
Figure 12.....	71
Figure 13.....	78
Figure 14.....	79
Figure 15.....	82

## Introduction

Emotionally arousing events, from mildly pleasant to profoundly traumatic, are common. Anecdotally, emotional reactions seem to influence memory: most people have vivid memories of some particularly emotional or shocking event, from fond recollections of years past to what William James (1890) described as the “scars” left on the brain from traumatic events. But even though the relationship between emotion and memory is frequently studied, no doubt in part owing to its relevance in both the clinical fields (e.g., post-traumatic stress disorder; LaBar & Cabeza, 2006) and legal domains (e.g., eyewitness testimony; Loftus, 1979), the effects of emotion on the accuracy and specificity of memory remain somewhat unclear. Perhaps even more importantly, despite agreement that emotional stimuli also influence attention (e.g., Loftus, Loftus, & Messo, 1987), there is no clear understanding of how the details, contents, or specificity of emotional memory may be influenced by how those emotional events are initially encoded. Generally, research on emotion addresses either the effects of emotion on visual attention *or* episodic memory, but not how the two are related. Such a deficit is particularly notable given the extensive work on attention and memory for non-emotional scenes in the field of scene perception (see Henderson & Hollingworth, 2003, for a review). To address this shortcoming, in the following experiments, I use eye movement recordings in conjunction with memory tests to examine how visually-specific memories for emotional and non-emotional scenes differ in terms of how attention is allocated at encoding, and the details and visual specificity of the stored memory.

## *Emotional Effects on Memory*

### *Naturalistic Studies*

Though studies of emotional memory go back at least a century (e.g., Colgrove, 1899), Brown and Kulik's (1977) description of "flashbulb memories" sparked a renewed interest in the study of emotion and memory. Flashbulb memories are vivid, highly detailed, essentially veridical long-lasting memories of the circumstances in which one hears about traumatic events (typically, events of national importance, such as the assassination of John F. Kennedy). Such vivid, detailed flashbulb memories for national events have been demonstrated dozens of times, in many different cultures, and for many different types of events (e.g., Pillemer, 1984; Christianson, 1989; Cohen, Conway, & Maylor, 1994; Talarico & Rubin, 2003; Hirst et al., 2004; Berntsen & Thomsen, 2005; Luminet & Curci, 2009; Conway, Skitka, Hemmerich, & Kershaw, 2009). Emotion plays a critical role in flashbulb memories: self-reported detail and clarity of flashbulb memories positively correlate with the emotionality of the event (Pillemer, 1984; Talarico, Labar, & Rubin, 2004). In fact, the same event will induce flashbulb memories *only* in individuals for whom the event had emotional relevance (Berntsen & Thomsen, 2005). Though naturalistic studies of flashbulb memories seem to demonstrate that emotional memories are distinct from emotionally neutral autobiographical memories in both detail and clarity, they have several limitations.

Naturalistic studies of flashbulb memories are limited in several ways. Most importantly, despite their vividness, flashbulb memories are not necessarily accurate (see Neisser & Harsch, 1992, for a discussion). In fact, memory for details is often inconsistent when tested across time, even when the confidence in such detail memory

is high (McCloskey, Wible, & Cohen, 1988). Such inconsistency has led some researchers to argue that flashbulb memories are unique only in the vividness and confidence with which the memories are imbued, and not their veracity (Talarico & Rubin, 2003). Other limitations of naturalistic studies include the inability to control for rehearsal (which is likely to be increased for important national events; Weaver, 1993), and that the majority of such events are negative. Only a few studies have examined memories for positive events (Scott & Ponsoda, 1996; Bohn & Berntsen, 2007; Rasmussen & Berntsen, 2009). Controlled laboratory studies have addressed these limitations.

#### *Laboratory Studies*

The International Affective Picture System (IAPS; Lang, Bradley, & Cuthbert, 1999) is an extensively normed set of pictures varying in emotional content. Based on the “bidimensional” theory of emotion (see Lang, Greenwald, Bradley, & Hamm, 1993), the pictures elicit emotional responses across two orthogonal categories of emotion: valence and arousal. IAPS pictures engage positive (appetitive) or negative (aversive) emotional systems, and vary in terms of how strong an emotional reaction they elicit. Importantly, because these pictures reliably elicit specific patterns of physiological arousal (e.g., skin conductance, heart rate changes) and electrophysiological changes (ERP waveforms) across the dimensions of emotion (Lang et al., 1993), they allow for controlled testing of large, diverse, and balanced sets of emotional stimuli.

Emotional arousal reliably enhances memory in studies using IAPS stimuli. In an initial study, highly arousing pictures were recalled more accurately than less arousing pictures in both immediate recall tasks and a year after encoding (Bradley et al., 1992). The enhancing effect of arousal on memory is robust to many encoding tasks (Ochsner, 2000), and has been replicated many times (e.g., Bradley, Cuthbert, & Lang, 1996; Hamann, Cahill, & Squire, 1997; Adolphs, Denburg, & Tranel, 2001; Cahill & Gorski, 2003; Adolphs, Tranel, & Buchanan, 2005; Shafter, Fletcher, Pottage, Alexander, & Brown, 2009; Brohawn, Offringa, Pfaff, Hughes, & Shin, 2010; Shafer, Jordan, Cabeza, & Dolcos, 2011; Kaestner & Polich, 2011). Valence effects on memory are sometimes noted (e.g., Bradley et al., 1992; Ochsner, 2000), but not in other cases (e.g., Bradley et al., 1996; Palomba, Angrilli, & Mini, 1997); there remains some disagreement about whether and how valence affects memory (see Kensinger, 2009 and Mather & Sutherland, 2009 for opposing views on this issue). Importantly, in part because most studies using IAPS stimuli employ straightforward free recall and/or standard recognition memory tests, most discussions of emotional enhancements of memory center on enhancements in *gist* memory (see Adolphs et al., 2001; Cahill & McGaugh 1998 for discussions), because gist memory may contain enough information to differentiate target and distracter pictures in standard recognition tests, or accurately describe previously seen pictures in a free recall task. However, given the emphasis on vividness and detail in flashbulb memories, other researchers have examined how emotional memories may differ from non-emotional memories in the specific details that can be recalled.

### *Visual Specificity of Emotional Memory*

A more recent approach to emotional memory effects has been to examine the visual specificity of memory for individual objects. In an initial study (Kensinger, Garoff-Eaton, & Schacter, 2006), participants viewed a series of negatively arousing objects (e.g., a grenade) and emotionally neutral objects (e.g., a shovel). In a memory test that followed, some test items were different exemplars of the same type of object (e.g., a different picture of a grenade), whereas other test items were exactly the same as seen previously. Participants were better able to discriminate the exact object that was seen previously when it was negative than when it was emotionally neutral, demonstrating enhanced item-specific memory for negatively arousing objects. Similar item-specific memory effects have subsequently been replicated, though only for negatively arousing, and not positively arousing, objects (Kensinger, Garoff-Eaton, & Schacter, 2007b; Kensinger & Choi, 2009).

Visual specificity of memory has also been tested for whole scenes rather than individual objects. A common technique for measuring visually-specific memory is mirror-reflection, whereby some test items are presented in a mirror-reflected orientation compared with encoding. Reflection-specific memory is exhibited when recognition of test items in the “same” reflection as encoding exceeds recognition performance for mirror-reflected test items, presumably because a gist-based memory typically would not allow for differentiation of left-right orientation of the scene (or objects within the scene). Reflection-specific memory has been demonstrated many times for non-emotional objects and scenes (Cooper, Schacter, Ballesteros, & Moore,

1992; Lawson, 2004; Standing, Conezio, & Haber, 1970), and memory for such non-emotional stimuli is also robust for many other picture manipulations (see e.g., Reingold, 2002). In an initial study comparing memory for highly arousing IAPS slides to low-arousal (essentially non-emotional) IAPS slides (Blank & Marsolek, 2006), equivalent reflection-specific memory was demonstrated for both types of scenes at short delays. Thus, even though *gist* memory is enhanced for emotionally arousing IAPS slides, and visually-specific memory for arousing individual objects is enhanced, some initial evidence indicates that visually-specific memory for highly arousing and low-arousal IAPS slides is *equivalent*. One goal of the present study is to further explore this effect.

### *Tradeoffs in Emotional Memory*

Though memory for emotional pictures may tend to be more accurate than for neutral pictures, memory tradeoffs may underlie this effect. Early naturalistic studies of flashbulb memories indicated that memory for central thematic details of emotional events (e.g., “I was eating lunch when I heard what happened”) is more consistent than memory for peripheral details (e.g., “I was talking to John when I heard what happened;” McCloskey et al., 1988). Subsequently, researchers have hypothesized that a unique aspect of memory for emotional stimuli is an enhancement of memory for central, thematic details that occurs with a concomitant decrement in memory for peripheral, non-arousing details (Reisberg, Heuer, McLean, & O’Shaughnessy, 1988).

Early studies used slide shows to demonstrate central-peripheral tradeoffs in emotional memory. In slide show studies, a story is depicted through a series of



semantically interconnected pictures. Generally, a few slides in the middle of the story are altered or replaced to create both emotionally-arousing and emotionally-neutral versions of the slide show. For example, a neutral show depicts a woman riding a bicycle to the store. In the emotional version, the woman is shown being hit by a car and lying wounded next to the bicycle (Christianson & Loftus, 1991). Central details, such as the color of the woman's coat, are remembered more accurately in arousing versions than non-arousing versions of the slide shows. Peripheral details, such as the color of a car in the background, are remembered *less* accurately in arousing than non-arousing slide shows. The central-peripheral tradeoff in memory has been demonstrated in multiple slide show studies (Burke, Heuer, & Reisberg, 1992; Loftus & Burns, 1982; Cahill & McGaugh, 1995).

More recent studies have examined broader sets of stimuli. In one study (Kensinger, Piguet, Krendl, & Corkin, 2005), forty negatively arousing images were modified so that they contained both a highly arousing central element (e.g., a man pointing a gun at the viewer), and a non-arousing peripheral element (e.g., a black diamond in the upper corner of the image). For each image, an alternate version was created in which the emotionally arousing element was replaced with a neutral object (e.g., an ice cream cone replaces the gun), while the rest of the picture was unchanged. As in slide show studies, a central-peripheral memory tradeoff was observed for arousing images: central details were remembered more accurately for arousing than neutral images, whereas for peripheral details, memory was *poorer* for arousing compared with neutral images. This pattern demonstrates a true tradeoff: as memory for central details increases (relative to neutral scenes), memory for peripheral details

falls (relative to neutral scenes). Subsequent follow-ups applied the same procedure with figure-ground images, testing memory for background (peripheral) and foreground (central) information, once again demonstrating a central-peripheral tradeoff in memory for emotional images (Kensinger, Garoff-Eaton, & Schacter, 2007a; Kensinger, Garoff-Eaton, & Schacter, 2007b). Central-peripheral tradeoffs are frequently reported across a variety of stimuli and task settings (Waring & Kensinger, 2009; Riggs, McQuiggan, Farb, Anderson, & Ryan, 2011; Waring, Payne, Schacter, & Kensinger, 2009; Buchanan & Tranel, 2008; Wessel & Merkelbach, 1998; Brown, 2003; Tooley et al., 1987).

In sum, emotional arousal strongly influences memory. Emotion enhances gist memory, as demonstrated in many studies using IAPS slides (e.g., Adolphs et al., 2001). Visual specificity of memory for emotional *objects* is enhanced, compared to non-emotional objects (Kensinger et al., 2006), but visually-specific memory may be equivalent for emotional and non-emotional *scenes* (Blank & Marsolek, 2006). Importantly, these effects may not be conflicting: emotional stimuli produce a memory tradeoff, with central thematic details being remembered more accurately for emotional than non-emotional stimuli; peripheral details are remembered *less* accurately for emotional than non-emotional stimuli. This memory tradeoff may explain emotion's varied effects on memory. If a highly detailed memory for the central, thematic objects/elements of an emotional scene is stored, then enhancements in overall gist-based memory might be expected as a consequence of the enhanced "central" memory, because such details are thematically relevant. In the same way, enhanced visually-specific memory for individual emotional objects may be the result of a highly detailed

memory for the central element. Finally, if the central elements of emotional scenes are remembered with enough detail, they could support visually-specific memory for the entire scene. In other words, whereas memory for non-emotional scenes may derive from a combination of central and peripheral information, memory for emotional scenes may derive primarily from central, thematic information. Though the central-peripheral tradeoff may help to explain many effects of emotion on memory, it is important to consider a mechanism by which the tradeoff might occur.

### *The Role of Attention in Emotional Memory*

Central-peripheral tradeoffs in emotional memory may arise from how attention is allocated during encoding. According to Easterbrook's (1959) cue utilization hypothesis, attention should be restricted to emotionally arousing aspects of the environment, because in an evolutionary sense, emotionally arousing information is highly relevant to the organism. Perhaps the most common instantiation of this hypothesis is the "weapon-focus effect" frequently studied in eyewitness memory research (Loftus, 1979). Witnesses to crimes typically focus their attention on the weapon – the threat – and often do not attend to "peripheral" details such as the clothing or face of the assailant. As a result, identifying the perpetrator often proves challenging for many eyewitnesses.

Across a variety of laboratory studies, it has been demonstrated that emotionally arousing objects draw our attention. Arousing stimuli "pop out" and are found more quickly than neutral stimuli in visual search tasks (Soares, Esteves, Lundqvist, & Öhman, 2009; Öhman, Juth, & Lundqvist, 2010; Lundqvist & Öhman, 2005; Öhman,

Flykt, & Esteves, 2001). In the attentional blink paradigm, emotional targets are more likely to be detected than neutral targets (Anderson & Phelps, 2001). Emotional stimuli (even those that have been classically conditioned to be arousing) are more effective cues than neutral stimuli in attentional cuing studies (Koster, Crombez, Van Damme, Verschuere, & De Houwer, 2004). Emotional items also draw attention and prevent it from being directed elsewhere. In the Stroop task, it takes longer to name the ink color of emotional than neutral words (Pratto & John, 1991), presumably because processing resources are engaged by the emotional content of the word. Math tasks are completed slower when task-irrelevant emotional pictures remain in view (Schimmack, 2005), and invalid emotional cues slow performance even more than non-emotional invalid cues in cuing experiments (Koster et al., 2004).

Electrophysiological markers also provide evidence that emotion draws attention. One such component, the early posterior negativity, occurs within about 250 ms of stimulus onset, and is thought to reflect enhanced sensory processing of a stimulus, or “selection” of a stimulus for future elaborative processing (Schupp, Junghöfer, Weike, & Hamm, 2004; Versace, Bradley, & Lang, 2010). A second component, the late positive potential, begins about 400 ms post-stimulus onset (Lang, Bradley, & Cuthbert, 1997; Dolcos & Cabeza, 2002), and is thought to reflect enhanced elaborative or semantic processing of the stimulus. Both components show greater amplitudes when viewing emotional (compared with neutral) stimuli.

There is also evidence that emotional elements in the context of a scene draw attention. In a weapon-focus study, Loftus et al. (1987) examined differences in eye movements when participants viewed a scene showing a person pointing a gun at a

cashier and the same scene but depicting the person handing a check to the cashier. Overall, fewer fixations are made when viewing the gun scene than the check scene, more fixations land on the gun than the check, and the fixations are of longer duration when they land on the gun than the check. Though this is strong evidence for “weapon focus” effects in eye movements, in many similar weapon-focus studies eye movements were not recorded (e.g., Tooley et al., 1987; Christianson, 1987); researchers simply assumed that such patterns of eye movements were occurring. “Weapon focus” or attention-restricting effects of emotional elements within scenes have yet to be replicated across a wide range of scenes, though they are predicted by Easterbrook’s (1959) cue utilization hypothesis.

An important element of attention-restricting explanations for the central-peripheral tradeoff must be taken into account. Central-peripheral tradeoffs do *not* occur simply because visual attention is spatially oriented to emotion-provoking parts of scenes. If this were the case, any object that draws eye movements the way that weapons or other emotional stimuli do would cause a central-peripheral memory tradeoff. In fact, one early explanation of weapon-focus effects in eye movements was that eye movements are directed towards emotion-provoking parts because they are surprising, distinctive, and/or unexpected. In fact, distinctive or semantically incongruent objects (e.g., an octopus in a farm field) do quickly draw eye movements (Loftus & Mackworth, 1978; Underwood & Foulsham, 2006), and hold attention for longer periods of time than unsurprising objects (Friedman, 1979; Antes & Penland, 1981). Critically, though, central-peripheral tradeoffs do not occur for unexpected, but not emotionally arousing, objects (Christianson, Loftus, Hoffman, & Loftus, 1991). In

that study, when the number of fixations and the duration of fixations on central details were equated, memory was still more accurate for central details when the slide was emotional than when it featured unusual or non-emotional objects. Thus, a *critical* component of attention-restriction theories of central-peripheral memory tradeoffs is that the central-peripheral tradeoff requires the confluence of two conditions: visual attention that is spatially oriented/focused to a particular location, *and* engagement of emotional reactions. Absent either one of these factors, a central-peripheral memory tradeoff does not occur. Importantly, this implies that emotion does not simply guide visual attention to a particular location, it also serves to, in some fashion, enhance encoding of objects at that location.

#### *Summary of Attention-Restriction Theories of Emotional Memory*

Attention-restriction theories of emotional memory suggest a mechanism by which emotional memories are stored, and describe the details that are stored in memory. By this view, when a scene is emotionally arousing, attention is spatially restricted to emotion-provoking elements of the scene (for example, a weapon). Presumably, this effect can be indexed by fewer fixations of longer duration that are oriented towards emotion-provoking parts (e.g., Loftus et al., 1987). When this pattern of eye movements occurs *and* emotional reactions are engaged, the stored memory will be highly detailed for central, thematic elements or parts (i.e., the weapon), but less detailed for peripheral, non-arousing elements (in comparison to an emotionally neutral memory). Patterns of eye movements, then, should predict when emotional memories of this type are stored. However, given that such attention-restricting theories imply a

relationship between attentional allocation at encoding and the details stored in memory, as well as an assumption that eye movements reflect the allocation of visual attention, it is critical to consider the wealth of research on relationship between attention and memory for *non-emotional* scenes.

### *Scene Perception: Attention and Memory for Non-Emotional Scenes*

The field of scene perception has examined how memories for emotionally neutral scenes are encoded and the details that are stored and remembered. One of the key elements to scene perception research is the use of eye movement recordings. Typically, fixations – periods of relative (spatial) stability of the eye, lasting 300-400 ms on average – are punctuated by saccades: rapid, high velocity reorienting of the location of gaze lasting less than 100 ms (Yarbus, 1967). Location of gaze shifts frequently in part because high-resolution visual information is only obtained close to the center of gaze, but processing of visual input is suppressed during saccades (see Matin, 1974). Thus, when viewing a static scene, the visual input can be thought of as a series of “snapshots” of visual information, with highest resolution at the location of gaze. One of the primary goals of scene perception research is to investigate how such visual information is integrated into short- and long-term representations and memories for scenes.

Henderson and colleagues (Henderson & Hollingworth, 2003) offer several reasons why eye movement recordings are useful investigative tools. First, vision is active and continuous, reflecting the selection of information in real time: eye movements are *temporally* sensitive indices of visual processing. Second, eye

movements reflect visual and cognitive processing of the stimulus at the point of fixation. In other words, eye movements are *spatially* sensitive, and index the locus of visual selective attention.<sup>1</sup> For these reasons, eye movement recordings have proven especially useful in studying scene perception and scene memory.

### *Gist-Based Theories of Scene Perception and Memory*

Some early theories of scene memory argued that scene representations are primarily gist-based. According to these theories (O'Regan, 1992; Rensink, 2000), information about fixated-upon objects is stored *only* during a single fixation. When attention is directed to a new location, little (if any) information about the previously-attended object is stored in memory. By this view, scene memories consist of information only about the gist/general category of the scene and the spatial layouts of elements within the scene. No specific details about objects within the scene are stored in the long-term; such object-specific information is only available when that object is being fixated on. Most evidence for gist-based theories of scene representations derives from studies of change blindness.

Change blindness happens when changes to scenes are difficult to notice if they occur during an eye movement or a brief “flicker” of the scene (see Simons & Levin, 1997, for a review). For example, a video might depict two people in a scene switching heads. When this change occurs while the participant is fixating at the changed location, it is easily detected. When this change occurs while the participant is making

---

<sup>1</sup> Although covert attention (visual attention directed away from fixation) can be dissociated from location of gaze (Posner & Peterson, 1990), overt and covert attention are tied under normal viewing conditions (see e.g., Findlay, 2005).



a saccade, it is rarely detected. Changes in spatial location (Bridgeman, Hendry, & Stark, 1975; Henderson, 1997), object size (McConkie & Currie, 1996), spatial orientation (Henderson & Hollingworth, 1999a), and color changes (Grimes, 1996) can all induce change blindness when they occur during a saccade. “Flickering” a scene by briefly interspersing a blank gray screen between the two versions of the picture can also induce change blindness (Rensink, O’Regan, & Clark, 1997), as can changes made during a blink (O’Regan, Deubel, Clark, & Rensink, 2000). Proponents of gist-based theories argue that because changes are only noticed when the participant fixates on the area that changes, scene memories do not contain detailed object information in the long-term; that information is only available when the object is being fixated upon and attended to. However, several lines of evidence argue against such an explanation.

#### *Evidence Against Gist-Based Theories*

Two major lines of evidence have been used to argue against gist-based theories of scene memory. First, memory for scenes is more accurate and robust than gist-based memories can account for. Recognition accuracy can exceed 90% even with multiple day delays and a large set of more than 2,500 photographs (Standing, Conezio, & Huber, 1970). Participants are even able to discriminate left-right orientation of previously seen pictures more than 75% of the time, and demonstrate similarly robust memory even for a larger set of 10,000 pictures (Standing, 1973). It is unlikely that such highly accurate and detailed memory could be demonstrated if only the gist of these scenes was remembered in the long-term. Perhaps more importantly, however, more recent studies have demonstrated that even when participants demonstrate

“change blindness” by not consciously detecting changes to scenes, their eye movements tend to linger in the area where the change occurred (Hollingworth, Williams, & Henderson, 2001; Ryan & Cohen, 2004). Hollingworth and colleagues argue that these eye movements amount to *implicit* detection of the changes, and suggest that change blindness studies which rely solely on conscious, explicitly reported detection of changes substantially underestimate participants’ actual change detection abilities.

### *Visual Memory Theory of Scene Representation*

The visual memory theory of scene representation (Henderson & Hollingworth, 1999; Henderson & Hollingworth, 2003a) suggests that individuals possess a much more robust scene memory than is proposed by gist-based theories. According to visual memory theory, multiple detailed object representations are built up as we fixated across a scene. These object representations contain detailed information about object type, color, orientation, size, and category, in both the short-term (during a fixation) and the long-term (across multiple fixations or several day delays). Thus, when attention is oriented to an object within a scene, visual and semantic information about the object is stored; this information remains in the short term store when attention is redirected, and further processing may consolidate the object representation into a long-term “object file.” Object files are linked to a representation of the spatial layout of the scene and the scene gist. Therefore, scene representations in visual memory theory are made up of three components: a spatial layout of the scene and the objects within the scene, a

coarse description of the scene gist, and a set of detailed object files that are built up as different objects are fixated upon.

### *Evidence for Visual Memory Theory*

Initial evidence for visual memory theory comes from a series of change detection studies. In this group of studies, participants attempted to detect changes made to objects a short time after they had been fixated upon, a task that should be difficult or impossible by gist-based theories of scene memory. An initial study rotated objects 90° in depth; participants were able to recognize that such rotations had occurred 25% of the time (Henderson & Hollingworth, 1999). Subsequent experiments have demonstrated that object deletions are recognized up to 75% of the time (Henderson & Hollingworth, 1999; 2003b). Token changes (replacing an object with another object from the same basic-level category) and type changes (replacing an object with another object from a *different* basic-level category) are recognized about 30% of the time (Hollingworth & Henderson, 2002; Henderson & Hollingworth, 2003b), indicating that some information about object orientation and category must be stored beyond the current fixation.

Other evidence for visual memory theory comes from a series of short- and long-term memory tests for objects within scenes. In a short-term test, a memory test would be initiated at some point after the participant had viewed the target object in the scene (but not when it was currently being fixated upon). Distracters included token changes and orientation changes. Both are recognized accurately about 80% of the time (Hollingworth & Henderson, 2002). Importantly, however, if the memory test is

initiated *before* the target object has been fixated upon, recognition is at chance levels, implying that fixations are required to encode and store an object representation.

Long-term memory for such changes is similar with delays as short as several fixations between encoding and test up to 24 hours between encoding and test (Hollingworth & Henderson, 2002; Hollingworth, 2005).

Visual memory theory highlights the importance of fixations in building scene representations. One early study directly supports this implication. Loftus (1972) recorded eye movements while participants viewed photographs of landscapes; participants then completed a recognition test for all pictures. Trials in which more fixations were made were more likely to be correctly remembered, an effect demonstrated across multiple viewing times and various task demands during encoding. From the perspective of visual memory theory, this effect occurs because as more fixations are made, object representations are built up and encoded in memory. Though similar patterns can be seen in data from more recent experiments (e.g., Hollingworth, 2005), this effect is yet to be replicated using a broader set of complex scenes. However, one of the principal underpinnings of visual memory theory – critical to the current experiment – is that fixations allow us to build up and store the object representations that make up scene memory.

### **Experiment 1**

The primary goal of Experiment 1 was to investigate the relationship between eye movements made at encoding and the visual specificity of subsequent memory for emotional and non-emotional scenes. Eye movements were recorded while participants

viewed a set of highly arousing and relatively non-arousing IAPS slides (both positive and negative valence), to verify that “weapon focus-like” restriction of attention occurs across a wide variety of emotion-provoking scenes. Then, a reflection-specific memory test was administered, to replicate an initial finding that memory for emotional and non-emotional scenes is similarly visually-specific (Blank & Marsolek, 2006). Most importantly, a subsequent memory analysis will be used to selectively examine whether different patterns of eye movements are made to subsequently remembered slides than subsequently forgotten slides, depending on whether those slides are emotionally arousing or emotionally neutral.

The subsequent memory paradigm is a powerful way to investigate the behavioral or neurobiological correlates of successful memory encoding (e.g., Paller, Kutas, & Mayes, 1987; Dolcos & Cabeza, 2002). In subsequent memory analyses, encoding trials are retroactively grouped according to whether they are subsequently remembered in a memory test (“hits”) or subsequently forgotten (“misses”). Both ERP waveforms (e.g., Fabiani, Karis, & Donchin, 1986; Rugg, 1995) and fMRI activations (e.g., Brewer, Zhao, Desmond, Glover, & Gabrieli, 1998) have been shown to differ for subsequent “hits” than for subsequent “misses,” reflecting a so-called “subsequent memory” or “hit-miss” effect for those measures. In each of the experiments described below, eye movements made at encoding were used as dependent measures in a subsequent memory analysis, because while both attention-restricting theories of emotional memory and visual memory theory of scene representation emphasize the importance of eye movements made during encoding, the two theories make competing claims about how those eye movements influence the memories that are stored.

By attention-restricting theories of emotional memory, subsequent memory effects in eye movements should *differ* for emotional and non-emotional scenes. Visually-specific memories of emotional scenes should be encoded when attention is restricted to emotion-provoking parts of scenes. In other words, for emotional slides, fewer fixations, of longer duration, in emotionally salient areas (reflecting a weapon focus-like restriction of attention) should be made to subsequent “hits” than subsequent “misses.” This should *only* be true for emotional scenes. For less emotional scenes, the opposite should be true. Because small numbers of fixations demonstrably impair memory for details of non-emotional scenes (Christianson et al., 1991; Loftus, 1972), more fixations of shorter duration (reflecting a relative broadening of attention) should be made to subsequent “hits” than subsequent “misses.” In contrast, if subsequent memory effects in eye movements are the *same* for emotional and non-emotional scenes, with more fixations (of shorter duration) predicting subsequent visually-specific memory for all scenes (as in Loftus, 1972), such results would align with visual memory theory of scene representation, which emphasizes the importance of fixations as the “currency” by which scene representations are built up, regardless of whether the scene is emotional or emotionally neutral.

### *Method*

#### *Participants*

Forty-eight undergraduate students (half female) at the University of Minnesota volunteered. All received course credit or cash compensation for participating and all participants had normal or corrected-to-normal vision. One participant was replaced in

the final data analysis due to computer errors during data collection; two participants were replaced in the final data analysis due to excessive head movement or blinking that affected eye tracking calibration.

### *Materials*

Stimuli were 128 slides from the IAPS (Center for Study of Emotion and Attention, 1999). Based on the primary dimensions of affective ratings, valence (negative and positive) and arousal (low to high), slides were grouped into four sets of 32, representing four possible categories: negative valence high-arousal, positive valence high-arousal, negative valence low-arousal, and positive valence low-arousal (Lang, Bradley, & Cuthbert, 1999). Normative ratings for all high-arousal slides were greater than 5.10 (mean = 5.76); norms for all low-arousal slides were less than 4.91 (mean = 4.33). Valence norms were greater than 5.97 (mean = 7.01) for all positive slides, and less than 4.71 (mean = 3.52) for all negative slides. All slides were chosen such that normative valence and arousal ratings did not differ between gender of rater, and no slides contained any text. In addition, positively and negatively valenced slides were equated on rated levels of arousal, and high- and low-arousal slides were balanced on rated levels of emotional valence (see Appendix A for a complete list of slides used).

Four lists of 32 slides were created for counterbalancing purposes, containing eight slides from each of the four valence-arousal categories. The lists were balanced on average valence, arousal, and dominance scores (Center for Study of Emotion and Attention, 1999), and rated degrees of left-right symmetry (similarity between the original and mirror-reversed versions of the slide). An enantiomorph (mirror-

reflection) of each slide was created, yielding a total of 8 lists: four containing only original orientation IAPS slides, and four containing only mirror-reflected IAPS slides. All slides were sized to fit in a maximum 20 x 20 cm space, subtending a maximum visual angle of 30.1°. An 16 mm cross was used as a central fixation point, and a highly scrambled neutral photographic slide, sized to fit in a 20 x 20 cm space, was used as a backward pattern mask during the recognition test.

Stimuli were presented at a resolution of 800 x 600 on a 17" monitor running at 60 Hz, controlled by a Pentium-based computer. E-Prime experimental software (Schneider, Eschman, & Zuccolotto, 2002) controlled stimulus presentation. Eye movements were recorded at 30 Hz, using the ViewPoint EyeTracker PC-60 infrared camera and software from Arrington Research, Inc., accurate to within a degree of visual angle.

### *Procedure*

*Encoding Phase.* The encoding phase consisted of 128 trials (plus two filler trials each at the beginning and end to attenuate primacy and recency effects). Participants were seated 55 cm from the computer screen (maintained by forehead rest) and told that the purpose of the experiment was to investigate processing of emotional stimuli; the eye tracking equipment was then calibrated before the encoding phase began. Calibration was maintained and corrected during the encoding phase by using the central fixation cross for slip correction. For each trial, a central fixation cross was presented for 500 ms. Then, an IAPS slide appeared in the center of the display for 2 s. Participants were told to look at the slide during the entire time it was presented and



prepare to rate the slide on two dimensions of emotional response; encoding was incidental. Immediately after the offset of the slide, the emotional valence Self-Assessment Manikin (SAM; Lang, Bradley, & Cuthbert, 1997) appeared centrally on the screen. Participants then rated the feeling they experienced while viewing the slide, from 1 (very sad) to 9 (very happy), and spoke this number aloud. Immediately following, the emotional arousal SAM appeared centrally on the screen, and participants rated the feeling of arousal experienced while viewing the slide, from 1 (calm) to 9 (excited), and spoke aloud this number. Participants were asked to make the arousal rating independently of the valence rating, so that positive or negative slides could be low, moderate, or highly arousing. The next trial began 2 s after the previous trial, during which time the display was blank.

For each participant, thirty-two slides were presented from each of the four valence by arousal categories; of these thirty-two, sixteen were presented in a mirror-reflection compared with the slides' original orientation in IAPS, and the remaining sixteen were presented in their original orientation. Trial orders were pseudo-randomized such that no more than three consecutive trials represented the same arousal category (high or low), valence category (positive or negative), or target/distracter status at test (i.e., same reflection or different reflection compared with encoding). Counterbalancing lists were rotated through the old/new conditions and original/enantiomorph conditions so that each slide represented each of those conditions an equal number of times across participants.

*Test Phase.* A 128 trial recognition memory test immediately followed the encoding phase. Each trial began with a central fixation cross for 1500 ms, then a

nonsense pattern mask for 33 ms, immediately followed by an IAPS slide presented for 33 ms. The mask and brief presentation were used solely to make the task more difficult, not to make presentations subliminal. A blank screen followed the IAPS slide, during which time the participants judged whether the slide was the same or different reflection as had been presented previously, and indicated their response by pressing one of two marked keys on the keyboard. Participants were informed that half the slides would appear mirror-reflectd (compared with the reflection seen at encoding), and that slides should be considered “Old” *only* if they were seen in the same reflection as at encoding. Otherwise, they were to respond “New.” Thus, the memory test required participants to discriminate the left-right reflection of each previously-seen slide. Immediately following this old/new judgment, a confidence scale appeared centrally on the screen and participants rated their confidence in the preceding judgment by pressing one of six marked keys on the keyboard (1 = slide was definitely old, 6 = slide was definitely new). The next trial began 1 s after the confidence judgment, during which time the screen was blank.

Each participant viewed 128 IAPS slides during the recognition memory test. For each participant, 64 of the slides were “new” (mirror-reversed compared with encoding) while the remaining 64 were old (same reflection as encoding), yielding 16 “old” same-reflection IAPS slides in each of the four valence by arousal conditions. Trial orders were pseudo-randomized such that no more than three consecutive trials represented the same normatively measured arousal level (high or low), normatively measured valence level (positive or negative), or target/distracter status.

*Recording and Processing of Eye Movements*

For all experiments, eye movements during encoding were recorded at 30 Hz, yielding 60 data points per trial. To differentiate fixations and saccades, samples were excluded from analysis any time the sample-to-sample velocity exceeded a threshold (set to the default setting of the eye tracker software), or when a blink occurred (as measured by pupil aspect ratio and reflecting fewer than 5% of all samples). Fixations were calculated by taking the mean of location of gaze coordinates for any grouping of samples between two high-velocity saccades (as suggested by Salvucci & Goldberg, 2000). To account for eye movements made during a blink, when x,y coordinates did not change from pre-blink to post-blink, the blink samples were removed and the grouping was counted as a single fixation. Otherwise, the blink was treated as a saccade, with the first fixation ending when the blink begins, and second fixation beginning when the blink ends. As an additional constraint, fixations were required to be at least 100 ms in length, for accurate handling of cases where velocity dipped briefly during a longer saccade. Trials were excluded from analysis when they contained fewer than 30 samples of usable fixation data (2% of all trials). In keeping with past studies of weapon focus effects (e.g., Loftus et al., 1987), both the number of fixations and the length of the longest fixation during each 2-second encoding trial served as measures of restriction of attention.<sup>2</sup>

---

<sup>2</sup> Practically, number of fixations and longest looks must be negatively correlated, because as the number of fixations increases, the maximum possible longest fixation decreases. However, longest fixations may help to more accurately account for “restriction of attention” when few fixations are made: in the case where only two fixations are made, the two fixations could be 1000 ms each, reflecting little restriction of attention compared to the case where the two fixations are 300 ms and 1700 ms.

Though fixations provide a gross measure of restriction of attention, they do not account for the locus of visual attention. Because weapon focus effects should orient and restrict attention to emotionally salient regions in each slide, I also used a third dependent measure of eye movements to reflect the *location* of fixations.

To quantify the location of emotionally salient regions, an additional group of 24 participants viewed the complete set of IAPS slides while their eye movements were recorded. The presentation of slides was balanced so that the original orientation and mirror-reversed versions of slides were each seen by half of the participants. Rather than providing valence and arousal judgments, we asked each participant to fixate on the most “emotionally salient” region in each slide and fixate there until the slide disappeared (each slide was presented for 2 seconds). Because our low-arousal slides contain emotional content and are not completely neutral, participants were able to perform this task for all slides. The 24 “emotionally salient” locations derived for each slide were then submitted to a hierarchical cluster analysis. Hierarchical cluster analysis does not automatically determine a specific number of clusters for each slide, but rather how the clusters should be grouped. Therefore, I set a distance threshold that yielded a minimum of two and a maximum of five clusters when it was applied across all slides. Clusters containing only one data point were ignored. Cluster fit (cophenetic correlation, reflecting interrater agreement and ranging from 0 to 1) was high, though there was a slight tendency for more agreement on emotionally salient locations for high-arousal slides (.855) than low-arousal slides (.830),  $t(126) = 1.97, p < .06$ . I then classified each slide based on whether the mean x,y location of points making up the largest cluster was found to the left or right of center (see Figure 1). As a final

dependent measure of weapon-focus like restriction of attention, for each trial I summed the total time (in ms) fixating on the side of the IAPS containing the most emotionally salient region (values ranged from 0 – 2000 ms; the mean was 1125 ms). Though coarse, this measure best accounts for noise in eye tracking calibration (in particular, degradation of calibration during the encoding phase), differences in physical size of emotionally salient aspects within scenes, and interrater agreement on the location of such emotionally salient objects.

**A** Emotionally Salient Locations



**B** Grouped into Clusters



**C** Defining the Emotional "Side"



*Figure 1-* The emotionally salient side of each IAPS. A) Each point represents one participant's choice of the most emotionally salient location on the slide. B) Cluster analysis was used to group these locations together. C) The left/right half of the slide that contained the mean x,y location of the largest cluster (i.e., the cluster with the greatest number of points) was marked the "emotionally salient" side of the slide – for this slide, the right side. Total time fixating on that side during encoding was used to measure restriction of attention to emotional parts of scenes.

### *Visual Features of Slides*

High- and low-arousal slides might have systematic differences in low-level visual features (e.g., prevalence of flesh tones, the glint of gun metal) in ways that influence how visual attention is directed to those slides, but that may not reflect emotional processing. To confirm that weapon-focus like patterns of eye movements derive from emotional and/or semantic information, and not low-level visual features, I computed saliency maps for each IAPS slide.

Saliency maps derive from biologically plausible computational models of the visual system, and highlight local variations or discontinuities in color, contrast, orientation, and spatial frequency. For an image, a saliency map can be computed specifying a saliency value for each pixel of the image; fixations are expected to be oriented to high-saliency locations in an image. Visual saliency is an above chance predictor of fixation location across a variety of objects and scenes (see e.g., Walther & Koch, 2006), though it typically works best when images have little semantic content (Parkhurst, Law, & Niebur, 2002) or when visual saliency is combined with semantic information (Torralba, Oliva, Castelhana, & Henderson, 2006). I tested for systematic differences between low-level visual features of the IAPS slides in this experiment using saliency maps calculated as described by Walther and Koch (2006). There were no differences of mean saliency level, standard deviation of saliency values, or number of distinct visually salient regions between positive high-arousal, positive low-arousal, negative high-arousal, and negative low-arousal slides ( $p > .2$  for all comparisons). I also found no visual saliency differences when comparing emotionally salient regions

of slides with all others parts of the slides. Thus, high- and low-arousal slides do not seem vary in the distinctive bottom-up visual features indexed by saliency maps, nor do emotional locations within slides differ from non-emotional locations in terms of distinctive, bottom-up visual features. Therefore, any restriction of attention to emotional parts of scenes observed in eye movements would be due to emotional/semantic, and not purely visual, information.

## *Results*

### *Eye Movements during Encoding*

Preliminary analyses showed no effects of participant gender, so all analyses reported here are collapsed across gender. Normatively rated valence (positive vs. negative) and normatively rated arousal (low vs. high) of the IAPS slides were the within-subjects independent variables in three separate repeated-measures ANOVAs, with participants as the random variable. The three dependent variables were: fixations, duration of longest fixation, and time fixating on the emotional side of the slide, each used to examine restriction of attention. Fewer fixations, longer duration fixations, and more time fixating on the emotional side would reflect a restriction of attention.

As predicted, significantly fewer fixations were made to high-arousal (3.95) than to low-arousal (4.17) slides, in a significant main effect of arousal  $F(1,47) = 58.4$ ,  $MS_e = .041$ ,  $p < .001$ ,  $d = 2.23$ , demonstrating a weapon-focus like restriction of attention. The main effect of valence  $F(1,47) = 4.75$ ,  $MS_e = .042$ ,  $p < .05$ ,  $d = .64$ , was significant, as was the valence by arousal interaction,  $F(1,47) = 25.3$ ,  $MS_e = .038$ ,  $p < .001$ ,  $d = 1.47$ . Examining the interaction further, the arousal effect was largely driven by

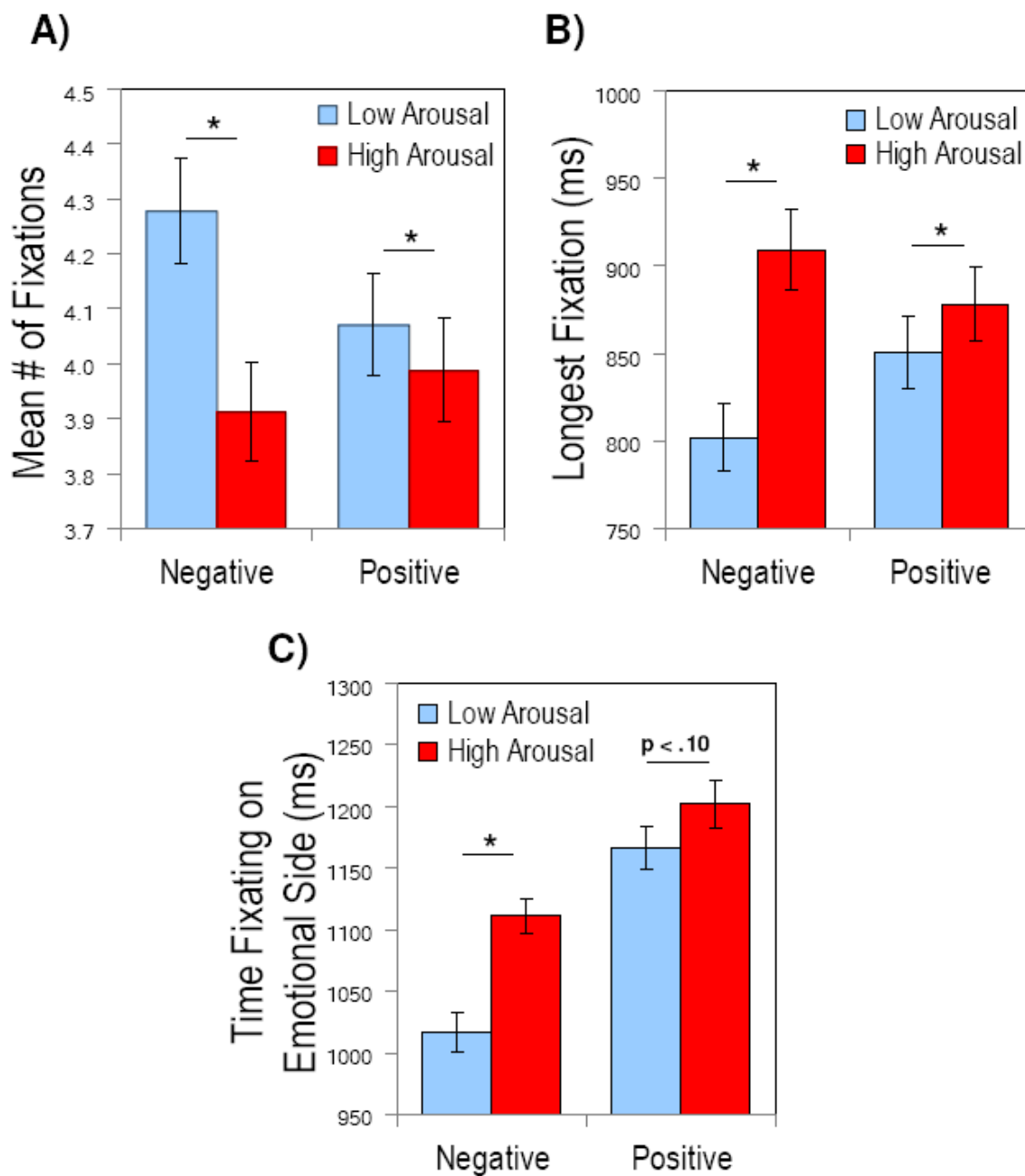


negative slides: fewer fixations were made to high-arousal negative slides (3.91) than low-arousal negative slides (4.28),  $F(1,47) = 82.8$ ,  $p < .001$ ,  $d = 2.65$ , for the test of simple effects. However, attention was similarly restricted for high-arousal positive slides (3.99) compared to low-arousal positive slides (4.07),  $F(1,47) = 4.1$ ,  $p < .05$ ,  $d = .59$ ; see Figure 2a.

For longest looks, the pattern of effects was similar. Lengthier longest fixations were made to high-arousal (894 ms) than low-arousal slides (826 ms), in a significant main effect of arousal,  $F(1,47) = 63.3$ ,  $MS_e = 3432.2$ ,  $p < .001$ ,  $d = 2.32$ , reflecting a weapon-focus like restriction of attention to high-arousal slides. The valence by arousal interaction,  $F(1,47) = 25.9$ ,  $MS_e = 2941.2$ ,  $p < .001$ ,  $d = 1.48$ , was also significant. As with fixations, attention-restricting effects were larger for negative slides than positive, with longer longest-look fixations made to high-arousal negative slides (909 ms) than low-arousal negative slides (802 ms);  $F(1,47) = 108.9$ ,  $p < .001$ ,  $d = 3.04$ . The same was true for positive high-arousal slides (878 ms) compared to positive low-arousal slides (850 ms),  $F(1,47) = 4.7$ ,  $p < .05$ ,  $d = .63$ ; see Figure 2b.

More time was spent looking to the emotional side for high-arousal slides (1157 ms) than low-arousal slides (1092 ms), reflecting a restriction of attention to emotion-provoking aspects of scenes, in a significant main effect of arousal,  $F(1,47) = 27.9$ ,  $MS_e = 7216.7$ ,  $p < .001$ ,  $d = 1.54$ . Not surprisingly, given reported positivity biases in attention (see e.g., Bradley et al., 1997) there was also a main effect of valence, with more time looking to positive sides (1184 ms) than negative sides (1064 ms),  $F(1,47) = 116.7$ ,  $MS_e = 5936.5$ ,  $p < .001$ ,  $d = 3.15$ . The valence by arousal interaction was also significant,  $F(1,47) = 5.9$ ,  $MS_e = 7011.2$ ,  $p < .05$ ,  $d = .71$ . As before, attention

narrowing effects were more prominent for negative pictures (1111 ms for negative high-arousal versus 1017 ms for negative low-arousal)  $F(1,47) = 47.9, p < .001, d = 2.02$ , than positive slides (1202 ms for positive high-arousal versus 1166 ms for positive low-arousal slides)  $F(1,47) = 3.10, p = .08, d = .51$ , see Figure 2c.

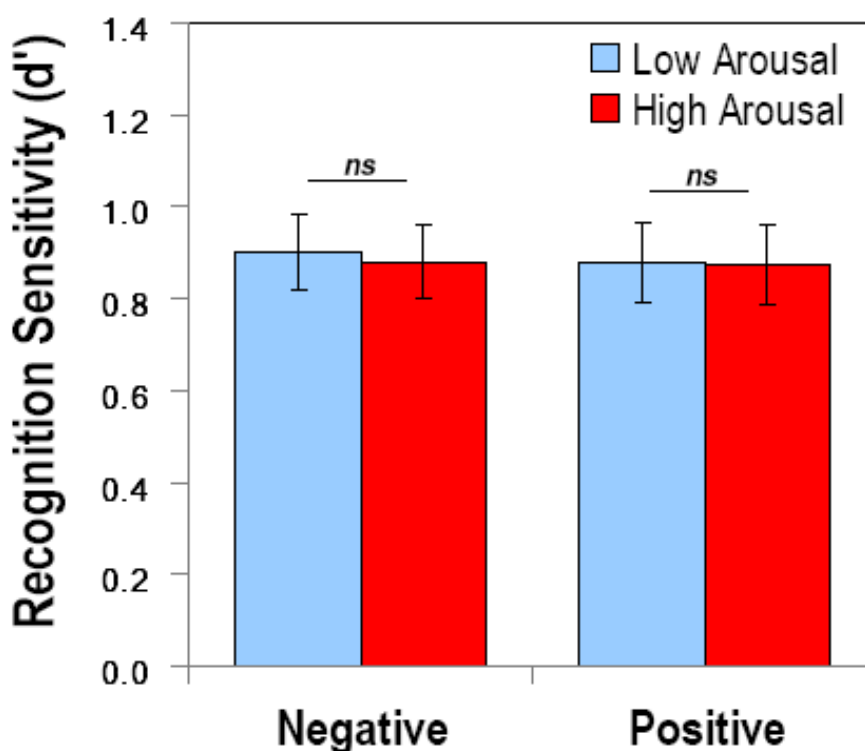


*Figure 2 - Eye movements during encoding. A) Fewer fixations were made overall to high-arousal than low-arousal slides, though this effect was driven by negative slides. B) Longest looks were lengthier when viewing high-arousal compared with low-arousal slides, though this effect was also more prominent for negatively valenced slides. C) More time is spent fixating on the emotionally salient side of the IAPS slide for high-arousal slides compared with low-arousal slides. All three measures reflect a relative restriction of attention to emotionally salient parts of high-arousal slides. Error bars represent standard error of the mean.*

### *Memory Performance*

For each participant, hit and false-alarm rates were used to calculate estimates of recognition sensitivity ( $d'$ ) for previously seen slides. Because 0 and 1 are undefined in  $z$ -space, proportions of 0 were converted to  $1/2N$ , and proportions of 1 were converted to  $1-(1/2N)$ , as suggested by Snodgrass and Corwin (1988). Note that because the task required discriminating same-reflection from different-reflection slides,  $d'$  does not index “recognition” performance in the sense of the participant demonstrating a memory for the slide having been presented (as would be typical). Instead,  $d'$  indexes the extent of visually-specific memory, with values above zero indicating visually-specific memory.

Recognition sensitivity was the dependent measure in a repeated-measures ANOVA, using participants as the random variable. Valence (positive vs. negative) and arousal (low vs. high) were within-subjects independent variables. Though memory performance overall was well above chance, (overall  $d' = .88$ ;  $t(47) = 13.0$ ,  $p < .001$ ,  $d = 1.89$  for the test against chance performance), indicating significant visually-specific memory, valence and arousal did not affect memory performance, all  $F$ s  $< 1$ ; see Figure 3.



*Figure 3* – Visually-specific memory performance. Reflection-specific memory performance was well above chance, but did not differ between valence and arousal conditions. Error bars represent standard error of the mean.

### *Subsequent Memory*

For an analysis of subsequent memory, same-reflection encoding trials (i.e., subsequent targets) were coded according to whether the slide was subsequently correctly recognized (hit) or incorrectly rejected (miss) during the test phase, yielding a new independent variable (see e.g., Paller et al., 1987). Only same-reflection targets were analyzed for two reasons. First, from principles of signal detection theory (e.g., Green & Swets, 1966), different-reflection distracters should be considered noise with respect to reflection-specific memory. Second, correct rejection of different-reflection distracters was the product of some trials in which participants recognized that the slide is mirror-reflected compared to encoding (thus demonstrating reflection-specific

memory), as well as some other trials in which the participant either did not remember having seen the slide at all, or did not remember the orientation of the slide (thus demonstrating no visually-specific memory). Because of this, performance on different-reflection distracters is not necessarily a good indicator of visually-specific memory.

In addition, I also used confidence judgments to further clarify hits and misses. After each old/new judgment, participants judged whether they had low, medium, or high confidence in their choice. On low confidence trials, participants performed essentially at chance levels in discriminating old from new slides (mean accuracy on low confidence trials = 51.9%). To counteract this, I used a method common in subsequent memory research (see e.g., Otten, Henson, & Rugg, 2001; Brewer et al., 1998). Rather than simply compare hits and misses, I only counted trials as “hits” when they were given medium or high confidence judgments (these medium/high confidence hits reflect 51.3% of trials); all low confidence hits were pooled with misses.

Three separate repeated-measures ANOVAs were conducted, with arousal (high vs. low) and subsequent memory (hit vs. miss) as independent variables, and participants as the random variable. The dependent variables were the number of fixations, duration of the longest fixation, and time spent fixating on the emotional side of the slide. Because visual memory theory and attention-restriction theories make competing *a priori* predictions about emotional and non-emotional scenes, the subsequent memory effect was examined separately for low- and high-arousal slides.

For fixations, the main effect of arousal was again significant,  $F(1,47) = 11.3$ ,  $MS_e = .119$ ,  $p < .01$ ,  $d = .98$ . There was a significant main effect of subsequent memory

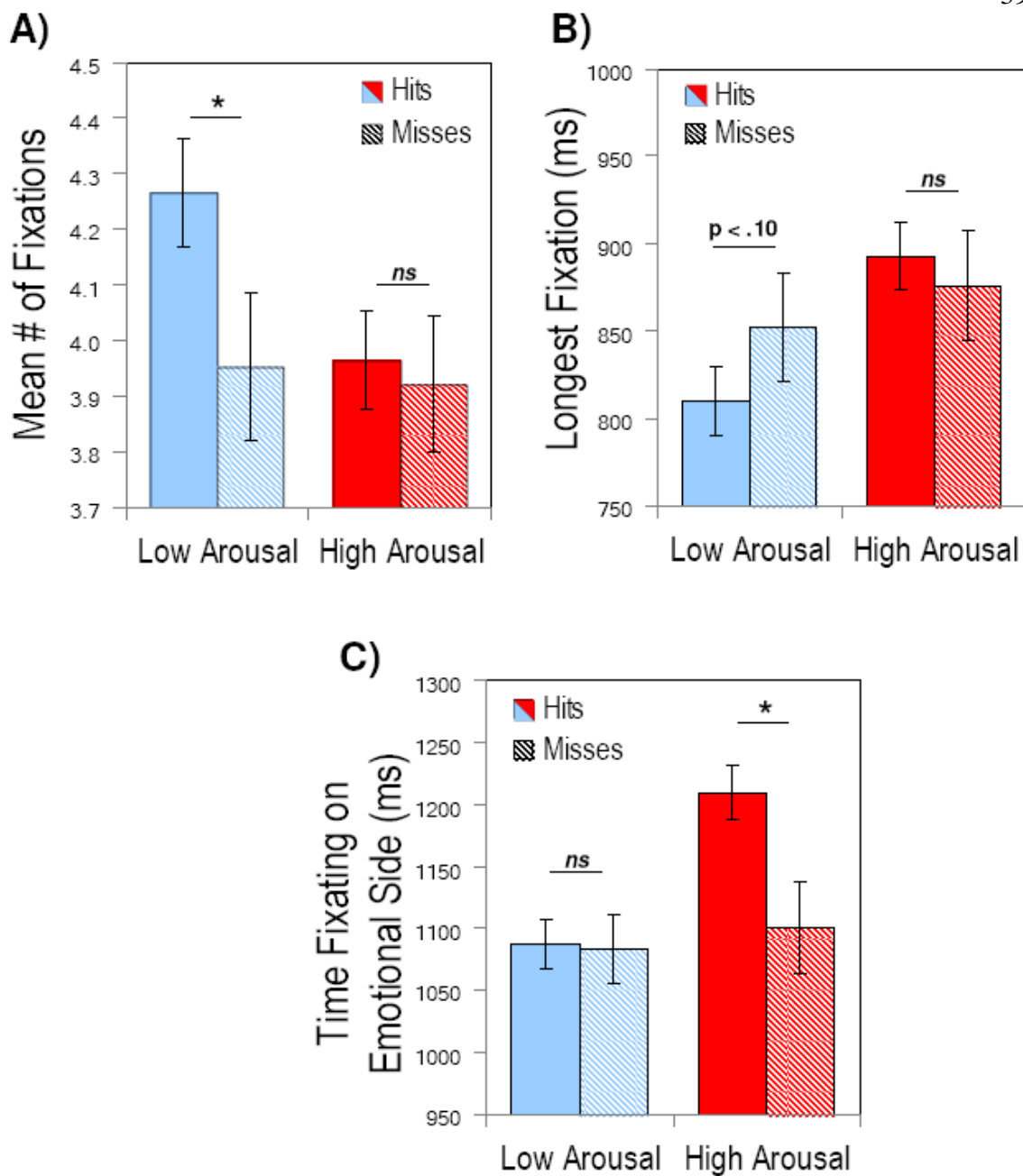
(hits vs. misses),  $F(1,47) = 5.5$ ,  $MS_e = .275$ ,  $p < .05$ ,  $d = .68$ , but, critically these effects were subsumed by a significant arousal by subsequent memory interaction,  $F(1, 47) = 6.1$ ,  $MS_e = .140$ ,  $p < .05$ ,  $d = .72$ . To clarify this interaction, the effects of subsequent memory were examined separately for low- and high-arousal slides. Fixations predicted memory for low-arousal slides: more fixations were made to low-arousal hits (4.27) than low-arousal misses (3.95),  $F(1,47) = 12.3$ ,  $p < .001$ ,  $d = 1.02$ , as would be predicted by results from Loftus (1972). This pattern did not hold for high-arousal slides, as equivalent numbers of fixations were made to high-arousal hits (3.97) and high-arousal misses (3.92),  $F(1,47) < 1$ , *ns*; subsequent memory effects in number of fixations are observed only for low-arousal slides, see Figure 4a.

Results are similar for longest fixations. The main effect of arousal  $F(1,47) = 11.4$ ,  $MS_e = 11897$ ,  $p < .001$ ,  $d = .99$ , was subsumed by a trending arousal by subsequent memory interaction,  $F(1,47) = 3.6$ ,  $MS_e = 11515$ ,  $p < .07$ ,  $d = .55$ . The interaction was similar to that for fixations; there was a trend for shorter duration longest looks to predict subsequent memory for low-arousal hits (810 ms) compared to low-arousal misses (852 ms),  $F(1,47) = 2.73$ ,  $p < .10$ ,  $d = .48$ , but no predictive effect of fixation duration given that high-arousal hits (893 ms) were as lengthy as high-arousal misses (876 ms),  $F(1,47) < 1$ , *ns*, for the test of simple effects; see Figure 4b.

Lastly, I examined subsequent memory effects for time fixating on the emotional side. Main effects of arousal,  $F(1,47) = 17.4$ ,  $MS_e = 13418.9$ ,  $p < .001$ ,  $d = 1.22$ , and subsequent memory,  $F(1,47) = 4.5$ ,  $MS_e = 33426.3$ ,  $p < .05$ ,  $d = .62$ , were subsumed by a significant arousal by subsequent memory interaction,  $F(1,47) = 4.95$ ,  $MS_e = 26701.4$ ,  $p < .05$ ,  $d = .65$ . However, unlike the number or duration of fixations,

there was no subsequent memory effect for low-arousal slides: low-arousal hits (1087 ms) were equivalent to low-arousal misses (1086 ms),  $F(1,47) < 1$ , *ns*. In contrast, more time was spent fixating on emotional regions for high-arousal hits (1209 ms) than high-arousal misses (1101 ms),  $F(1,47) = 7.1$ ,  $p < .05$ ,  $d = .78$ ; see Figure 4c.





*Figure 4* – Subsequent memory effects in eye movements. A,B) More fixations and shorter duration fixations during encoding predicts subsequent visually-specific memory for low-arousal slides only, as predicted. Number and duration of fixations do *not* predict subsequent visually-specific memory for high-arousal slides. C) Time fixating on the emotionally salient side of the IAPS slide predicts subsequent visually-specific memory *only* for high-arousal slides. Error bars represent standard error of the mean.

### *Discussion*

Results from Experiment 1 clarify several aspects of the relationship between emotion, attention, and memory. First, attention-restricting effects were demonstrated when participants viewed high-arousal IAPS slides. Participants made fewer fixations of shorter duration when viewing emotionally arousing scenes than when viewing less emotional slides. Moreover, those fixations tended to land on the emotionally salient side of the image. Thus, the weapon-focus effects demonstrated by Loftus et al. (1987) are replicated across a broad range of emotional scenes, not just those with weapons. Second, reflection-specific memory was equivalent for low- and high-arousal scenes, replicating an initial study (Blank & Marsolek, 2006). Most importantly, however, despite visually-specific memory being equal in magnitude for emotional and less emotional scenes, the link between the allocation of visual attention at encoding and the visual specificity of subsequent memory was different for emotional and less emotional scenes.

More fixations and shorter fixations were made to low-arousal slides that were subsequently remembered than those that were subsequently forgotten, expanding on past results (Loftus, 1972). These results are in line with visual memory theory, and provide further evidence that fixations are the building blocks of scene representations – when more fixations are made, more object representations can be stored, yielding a more detailed memory for the scene. Crucially, however, this effect is not universal: the number and duration of fixations *do not* predict subsequent memory for emotionally arousing scenes. Rather than the sheer number of fixations, the results indicate that the

*location* of fixations matters for emotional scenes – attention must not be just restricted, it must be oriented to emotionally salient parts of the scene.

Given this double dissociation in subsequent memory effects, it seems there are two “pathways” by which a visually-specific memory can be stored. For non-emotional scenes, when attention is relatively broadened and many fixations are made across the scene, visually-specific memory is enhanced, presumably because multiple object representations are stored. Because of this, memories for non-emotional scenes might be said to be more “whole-scene” based in that they contain information from multiple objects/areas across the scene. In contrast, for emotional scenes, focusing on the emotionally salient part of the scene may allow for a highly detailed representation of that object/element to be stored, at the expense of other objects in the scene. In sum, then, memories for non-emotional scenes might be said to be relatively more “whole-scene” based in that they contain information from multiple object representations across the scene. Memories for emotional scenes might be said to be more “parts” based in that they contain a highly detailed representation of the emotion-provoking side of the scene (or the emotion-provoking object on that side), but few, if any, other object representations. Critically, though, such qualitatively distinct memory representations are both capable of supporting visually-specific memory; in fact, in this experiment, they led to equivalent levels of visually-specific memory.

Importantly, these results suggest that a revision may be needed for visual memory theory of scene representation. According to visual memory theory, object representations are built up by fixating on different objects in a scene: when more fixations are made, the stored memory is more detailed because it contains more object

representations. However, the number of fixations did *not* predict subsequent memory for emotionally arousing scenes. Such a finding does not necessarily imply that visual memory theory is incorrect about the nature of scene representations. Emotional scenes may differ from emotionally neutral scenes only in that the representations of emotional objects are especially detailed. But even if the representations are similar in form, visual memory theory should, in the future, account for those special cases (e.g., emotionally arousing scenes) in which the relationship between eye movements and memory is altered.

To provide a stronger theoretical account of the different ways attention can be allocated across scenes, Experiments 2 and 3 were conducted to test whether distinct attentional processing biases underlie the interaction between emotion and subsequent memory observed in Experiment 1.

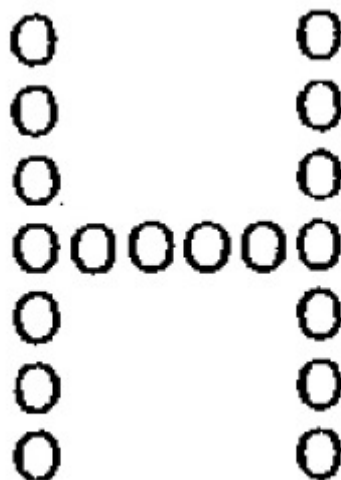
## **Experiment 2: Using Size Judgments to Induce Local/Global Processing**

In Experiment 1, visually-specific memory was equivalent for high- and low-arousal slides, but different patterns of eye movements predicted subsequent memory for high- and low-arousal slides. For low-arousal slides, a broadening of attention across the scene – more fixations of shorter durations – predicted visually-specific memory. In contrast, for emotional scenes, restricting attention to the emotion-provoking side predicted visually-specific memory. Theoretical accounts of this finding would be stronger if they clarified how the *processing* of the two types of scenes differs (rather than just the patterns of eye movements). This was the goal of Experiment 2.

### *Local and Global Processing*

High- and low-arousal scenes might differ in the extent to which they engage global or local processing (e.g., Navon, 1977; Kimchi, 1992). Local processing is featural, in that attention or processing resources are oriented to the specific details or properties of the smaller elements within larger figures. In contrast, global processing is holistic or configural, in that attention or processing resources are allocated across the entire figure, processing the spatial configuration or interrelation of multiple elements within the whole. A simple example can be seen in a hierarchical stimulus commonly used in studies of local and global processing (see Figure 5; Navon, 1977). For a large letter “H” composed of smaller letter “Os,” global processing entails attending to the global *form* – the letter H – whereas local processing would entail attending to local features – the letter O. It is important to note that global and local processing are usually considered in terms of a processing bias, meaning that one type of information

is processed first or allocated more processing resources, even though both types of information are typically processed.



*Figure 5 - A hierarchical Navon letter (Navon, 1977)*

Biases towards local and global processing have been studied for many types of stimuli. For example, faces are recognized most efficiently via global, holistic processing (e.g., Thompson, 1980; Tanaka & Farah, 1993; Tanaka & Sengco, 1997; Farah, Wilson, Drain, & Tanaka, 1998). In fact, there is a general bias towards global processing of most kinds of stimuli, known as the “global precedence effect” (see Kimchi, 1992 for a review). Despite this, local processing may be more efficient and more likely to be used for certain stimuli or tasks (e.g., Hsiao & Cottrell, 2009; Dodson, Johnson, & Schooler, 1997; Kimchi & Palmer, 1982), and even for a given participant, tendencies towards local or global processing are flexible given particular task demands (Kimchi, 1992).

The patterns of eye movements observed in Experiment 1 may reflect local or global processing.<sup>3</sup> When viewing emotional slides, eye movements were restricted to the more emotion-provoking half of the slide. Such a pattern of eye movements may reflect *local* processing of the scene, as attention and processing resources are oriented towards a small number of individual parts or elements within the scene. In contrast, for low-arousal slides, eye movements were broadened across many different parts of the scene. This broadening pattern may reflect *global* processing of the scene, as attention and processing resources are allocated to many different elements across the larger configuration of the scene.

There is evidence that emotional arousal leads to local processing of stimuli. In one study (Baumann & Kuhl, 2005), positively arousing words led to faster processing of local information in a subsequent task than did emotionally neutral words – in other words, emotionally arousing words were able to overcome the global precedence effect. More recently, highly arousing positive pictures have been shown to not only restrict the breadth of attention (as in the “weapon focus effect”), but also cause biases towards local processing in subsequent tasks (Gable & Harmon-Jones, 2008; Harmon-Jones & Gable, 2009).

To test whether the subsequent memory effects observed in Experiment 1 were caused by local or global processing biases when encoding emotional and non-emotional scenes, I experimentally induced local and global biases, on a trial-by-trial basis in Experiment 2 and with a blocked design in Experiment 3. By the local/global

---

<sup>3</sup> Because the distinction between local and global is hierarchical in nature, the terms themselves are relative: a face can be processed globally, but individual parts of the face can also be processed globally in some cases. In these experiments, I define global and local relative to the size of the *scene* as a whole (for global processing), or an individual object within the scene (for local processing).

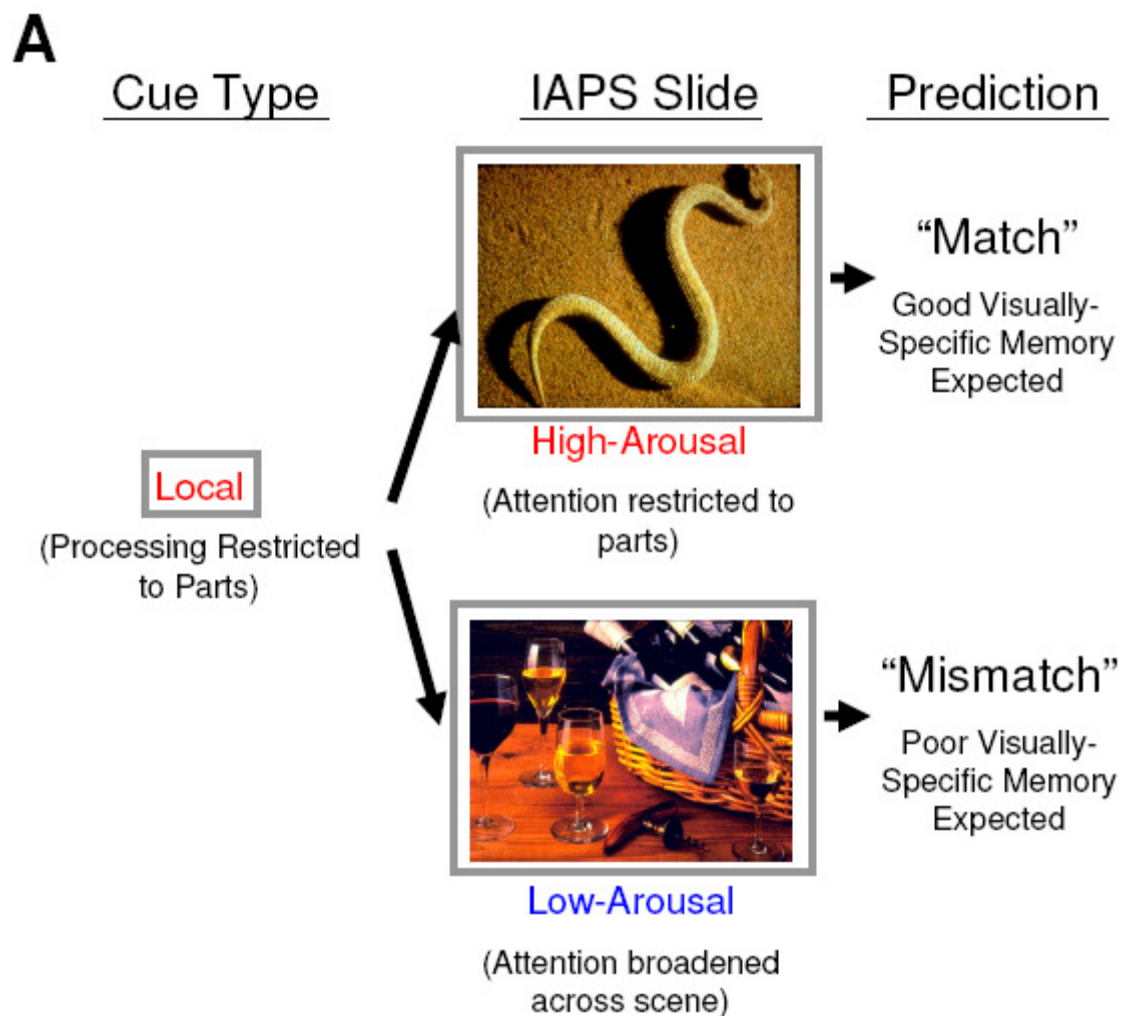
hypothesis, local processing (i.e., restriction of attention) should be associated with effective encoding of high-arousal, emotional scenes only, whereas global processing (i.e., broadening of attention) should be associated with effective encoding of relatively non-emotional low-arousal scenes.

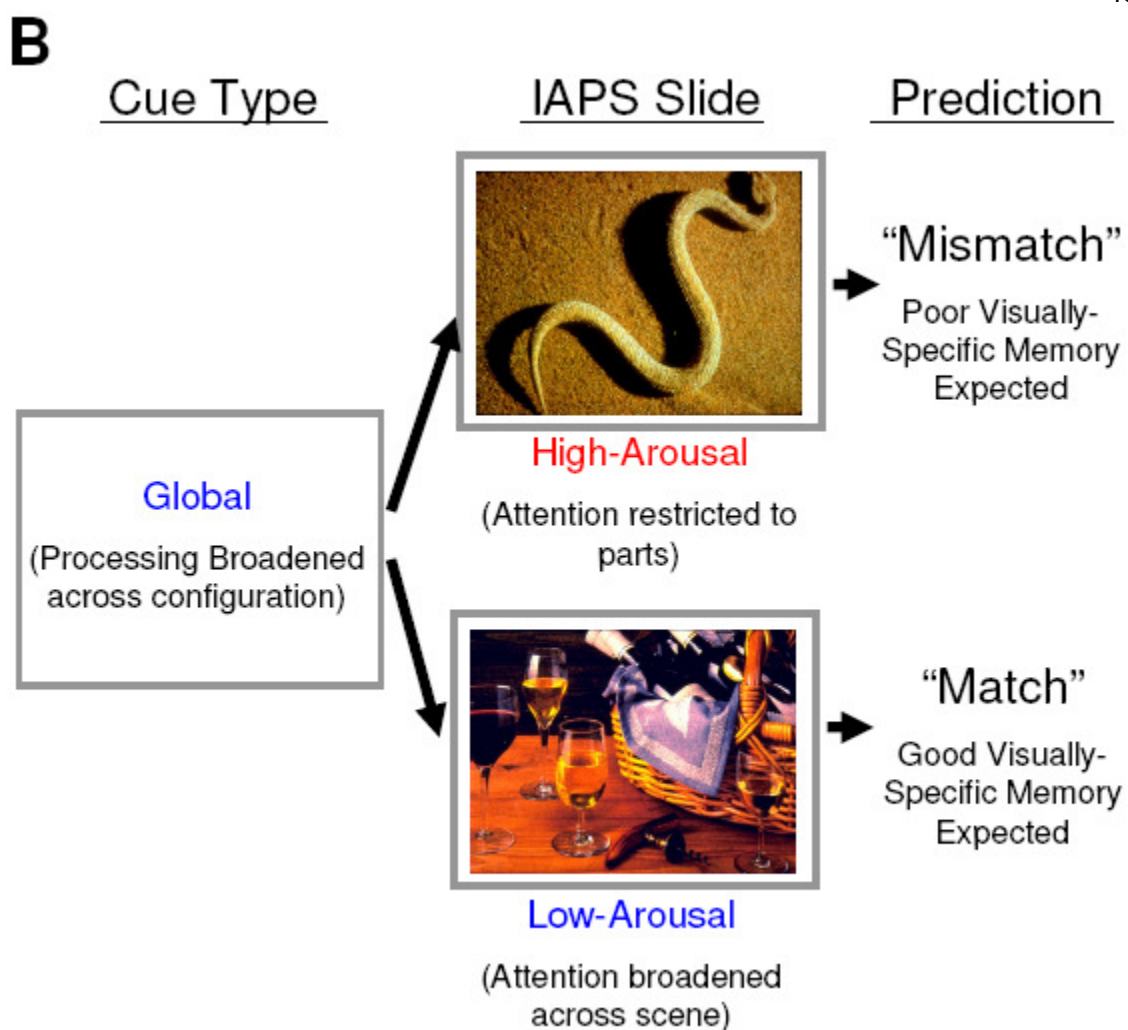
### *Predictions*

Experiment 2 was similar in design to the first experiment, except that global and local processing biases were induced on a trial-by-trial basis before participants viewed each IAPS slide during the encoding phase. To accomplish this, a large (roughly whole-slide sized) box or a small (roughly object-sized) box immediately preceded each IAPS slide; participants were asked to remember the box size, in order to make a box size comparison immediately after viewing the slide. Small boxes were always presented in a location centered on the most emotionally salient part of each IAPS, thus cuing participants to both a local (object-sized) processing bias and a particular spatial location, ensuring that local processing occurs at the point of highest emotional salience. For each trial, the box size either matched the emotional arousal of the slide (i.e., large, global boxes preceding low-arousal slides, or small, local boxes preceding high-arousal slides), or mismatched the emotional arousal of the slides (i.e., small, local boxes preceding low-arousal slides or large, global boxes preceding high-arousal slides). If global/local processing biases underlie the subsequent memory effects observed in Experiment 1, then when the induced processing bias and emotional arousal do not coincide, costs should be incurred. In particular, visually-specific memory for “mismatched” trials should be poorer than for “match” trials, and



subsequent memory effects should be diminished or abolished for “mismatch” trials. In contrast, for “matched” processing bias and emotional arousal, visually-specific memory should be enhanced, and the pattern of subsequent memory effects observed in Experiment 1 should be replicated (see Figure 6).





*Figure 6* – Induced local or global processing may match or mismatch processing of the IAPS slide. Local processing (A) matches high-arousal slides, as attention is restricted to individual parts. Global processing (B) matches low-arousal slides, as attention is broadened across the scene. “Matched” processing should enhance visually-specific memory, and subsequent memory effects in eye movements should be replicated. “Mismatched” processing should decrement visually-specific memory and subsequent memory effects in eye movements should be diminished.

### *Method*

#### *Participants*

Forty-eight undergraduate students with normal or corrected-to-normal vision (half female) participated for course credit.

### *Materials*

The same set of 128 IAPS slides and counterbalancing lists were used as in Experiment 1. All boxes used for size judgments depicted a black rectangular outline on a white background. Large box exemplars were roughly the size of each IAPS slide, created by randomly assigning a length and width within a range of 10 to 40 pixels of the actual length and width of each slide, and centering it on the screen. Test boxes were randomly shifted to a new location on the screen to prevent the use of screen boundaries in making size judgments. Test boxes were either the exact same box as seen previously (targets), or the length and width were randomly altered by between 50 and 60 pixels (distracters).

Small box exemplars were centered on the mean x,y location of the points making up the largest emotionally salient cluster for each picture (as described in Experiment 1). Each small box exemplar was created with a random length and width between 16 and 24 pixels. Test boxes were either the exact same box as seen previously (targets), or length and width were randomly altered by between 6 and 8 pixels (distracters). As for large boxes, small test boxes were shifted to a new location on the computer screen, to prevent the use of screen boundaries or other landmarks in making the size judgment. To ensure that the size rating task was relatively easy and ensure equivalent performance for small and large box judgments, pilot testing was used to determine appropriate size and shift amounts.

### *Procedure*

*Encoding Phase.* The encoding phase consisted of 128 trials (plus two filler trials each at the beginning and end to attenuate primacy and recency effects). Participants were

seated 55 cm from the computer screen (maintained by forehead rest) and told that the purpose of the experiment was to investigate processing of emotional stimuli; the eye tracking equipment was then calibrated before the encoding phase began. For each trial, a central fixation cross was presented for 500 ms. Then, a to-be-remembered box appeared on screen for 1000 ms. Half of the boxes were “large” (roughly the size of the picture), and intended to induce a global processing bias; half of the boxes were “small” (centered on an emotionally salient region) and intended to induce a local processing bias. Immediately following, an IAPS slide appeared in the center of the display for 2 s. Participants were instructed to try and remember the size of the box that preceded the slide (regardless of its location) while preparing to rate the valence and arousal of the slide, but as in Experiment 1 were not told to try and remember the IAPS slides. After the offset of the slide, the test box appeared on screen for 1000 ms against a white background, before being replaced by a blank white screen. In half of all trials, the test box was the same size as the to-be-remembered box, in the other half the test box was a different size than the to-be-remembered box. In all trials the test box was shifted to a new spatial location. The participant was to decide whether the to-be-remembered and test boxes were the same size and speak their answer aloud. Immediately after the offset of the slide, participants viewed the valence and arousal SAMs and rated the valence and arousal of the IAPS slide as described previously. The next trial began 2 s after the previous trial, during which time the display was blank.

For each participant, thirty-two slides were presented from each of the four valence-arousal categories; of these thirty-two, sixteen were paired with a “large” box, and the remaining sixteen were paired with a “small” box. Trial orders were pseudo-

randomized such that no more than three consecutive trials represented the same arousal category (high or low), valence category (positive or negative), target/distracter status (*same* reflection at test or *different* reflection at test), box size (large or small), or correct size judgment response (same or different). Counterbalancing lists were rotated through the old/new, original/enantiomorph, box size, and size judgment target/distracter (same or different) conditions so that each slide represented each of those conditions an equal number of times across participants.

*Test Phase.* The test phase was conducted exactly as in Experiment 1. Trial orders were pseudo-randomized such that no more than three consecutive trials represented the same normatively measured arousal level (high or low), normatively measured valence level (positive or negative), IAPS target/distracter status (same or different), box size at encoding (big or small), or size judgment target/distracter at encoding (same or different).

## *Results*

### *Size Judgments*

The accuracy of box size judgments was analyzed to ensure that large and small size judgments were not substantially different in difficulty. Box size (large vs. small), valence (positive vs. negative) and arousal (low vs. high) were the within-subjects independent variables in a repeated-measures ANOVA, with participants as the random variable. Overall size judgment accuracy was very good (74.5%), though large box size judgments (70.6%) were somewhat more difficult than small box judgments (78.5%),

$F(1,47) = 7.4$ ,  $MS_e = .082$ ,  $p < .01$ ,  $d = .79$ . No other effects were significant in this analysis.

### *Eye Movements at Encoding*

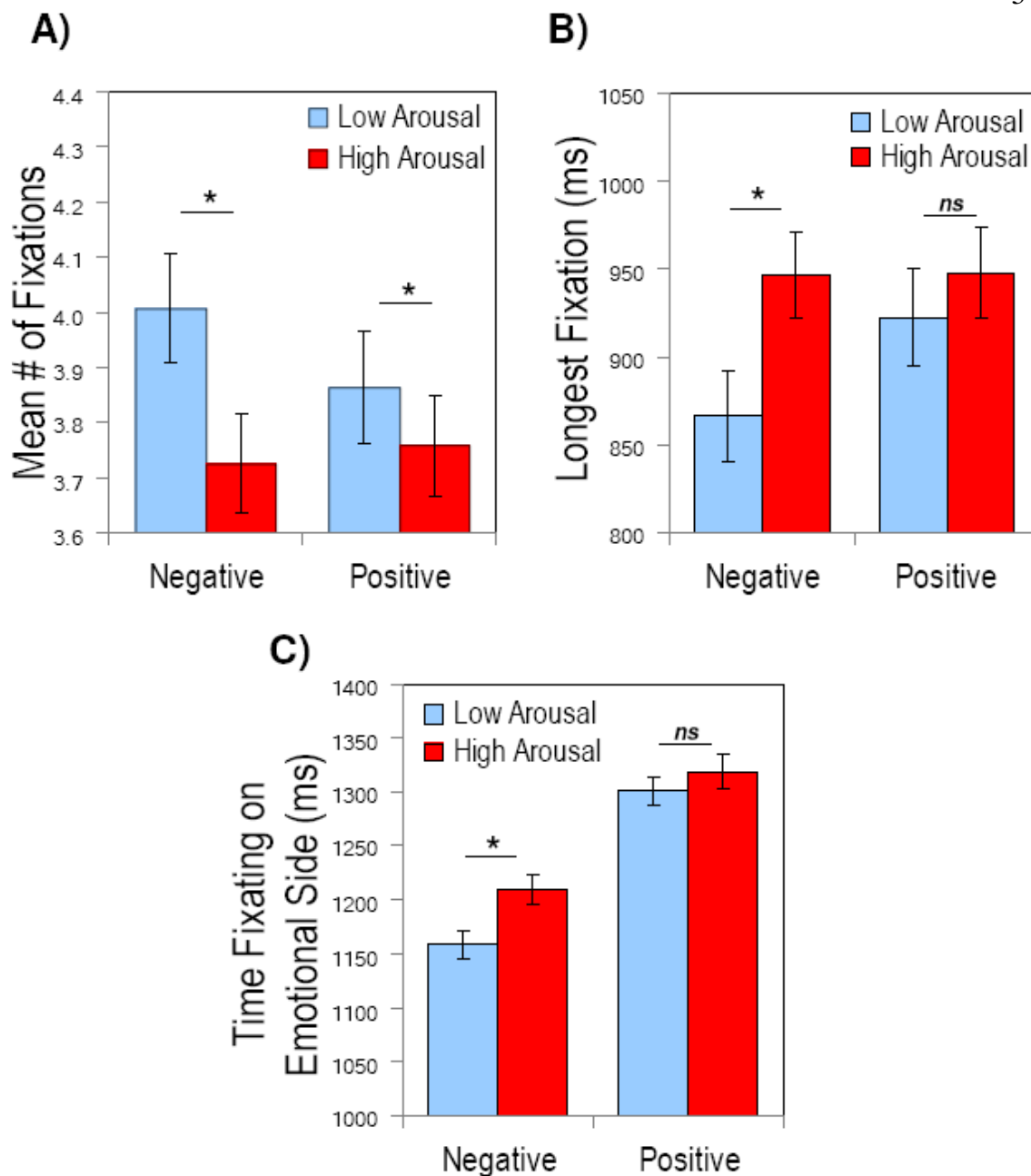
Box size (large vs. small), valence (positive vs. negative) and arousal (low vs. high) were within-subjects independent variables in three repeated-measures ANOVAs, with participants as the random variable. Fixations, longest looks, and time fixating on the emotional side while viewing the IAPS slide were dependent measures used to examine attention restriction effects in eye movements.

Attention restricting effects in fixations replicated Experiment 1. Fewer fixations were made while viewing high-arousal slides (3.74) compared with low-arousal slides (3.94),  $F(1,47) = 25.3$ ,  $MS_e = .142$ ,  $p < .001$ ,  $d = 1.47$ , for the main effect of arousal. The valence by arousal interaction was also significant  $F(1,47) = 12.3$ ,  $MS_e = .060$ ,  $p < .001$ ,  $d = 1.02$ . The attention-restricting effect of emotional arousal was significant for negative slides, with fewer fixations made to high-arousal negative slides (3.73) than low-arousal negative slides (4.01)  $F(1,47) = 40.3$ ,  $p < .001$ ,  $d = 1.85$ , as well as for positive slides, with fewer fixations made to high-arousal positive slides (3.86) than low-arousal positive slides (3.76),  $F(1,47) = 4.9$ ,  $p < .05$ ,  $d = .65$ ; see Figure 7a. As might be expected, fewer fixations were made following small boxes (3.73) than large box exemplars (3.94),  $F(1,47) = 12.6$ ,  $MS_e = .339$ ,  $p < .001$ ,  $d = 1.04$ . However, box size did not interact with valence or arousal; all box size interaction  $F$ s  $< 1$ .

Valence and arousal effects on fixation durations replicated Experiment 1 as well. Overall, lengthier longest fixations were made to high-arousal slides (947 ms) than low arousal slides (894 ms),  $F(1,47) = 17.1$ ,  $MS_e = 15648.6$ ,  $p < .001$ ,  $d = 1.21$ , for

the main effect of arousal. The main effect of valence was significant,  $F(1,47) = 10.0$ ,  $MS_e = 8019.8$ ,  $p < .01$ ,  $d = .92$ , as was the valence by arousal interaction,  $F(1,47) = 10.3$ ,  $MS_e = 6906.8$ ,  $p < .01$ ,  $d = .94$ . Longer fixations were made to high-arousal negative slides (946 ms) than low-arousal negative slides (866 ms),  $F(1,47) = 32.6$ ,  $p < .001$ ,  $d = 1.67$ . For positive slides, although numerically longer fixations are made to high-arousal positive slides (948 ms) than low-arousal positive slides (922 ms), this effect does not achieve significance,  $F(1,47) = 2.37$ ,  $p = .13$ ,  $d = .45$ ; see Figure 7b. Longer fixations were made following small boxes (944 ms) than big boxes (898 ms), in a significant effect of box size,  $F(1,47) = 7.8$ ,  $MS_e = 26344.6$ ,  $p < .01$ ,  $d = .81$ . However, as with the number of fixations, box size did not interact with either valence or arousal; all box size interaction  $F$ s  $< 2$ .

For time fixating on emotional side, results were similar to Experiment 1. The main effect of arousal was significant,  $F(1,47) = 8.3$ ,  $MS_e = 13523.0$ ,  $p < .01$ ,  $d = .84$ ; eye movements were directed more towards the emotional side of high-arousal (1264 ms) than low-arousal slides (1230 ms). A positivity bias was once again observed for positive (1309 ms) compared with negative (1184 ms) slides,  $F(1,47) = 87.9$ ,  $MS_e = 17236.4$ ,  $p < .001$ ,  $d = 2.74$ , but the valence by arousal interaction was not significant; see Figure 7c. More time was spent fixating on the emotional side following small boxes (1311 ms) compared with big boxes (1181 ms),  $F(1,47) = 65.9$ ,  $MS_e = 24684.4$ ,  $p < .001$ ,  $d = 2.37$ , an unsurprising effect given that small boxes cue attention to the emotional side of the slide. However, as with other eye movement measures, box size did not interact with valence and arousal; all box size interaction  $F$ s  $< 2$ .

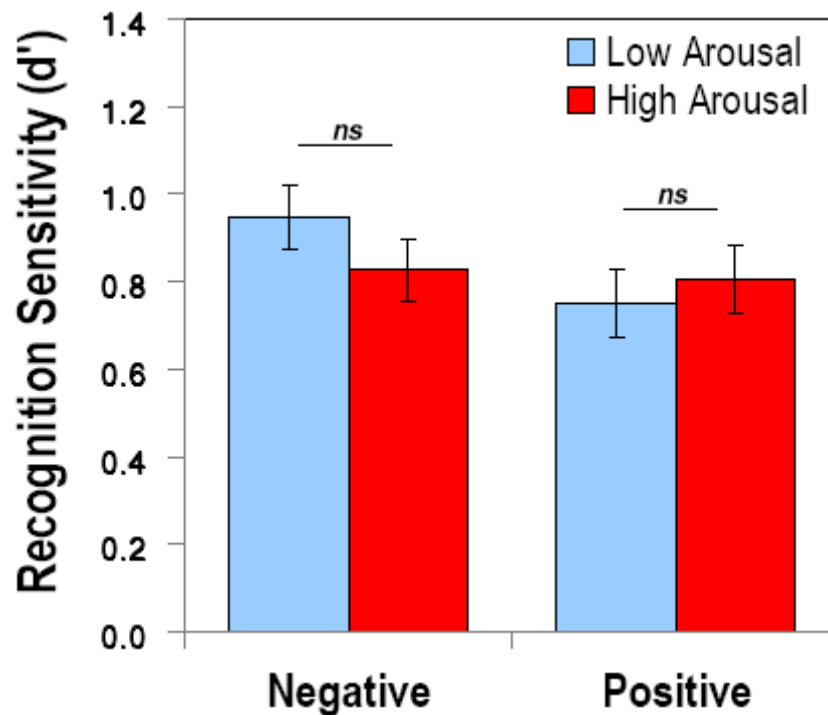


*Figure 7* – Eye movements during encoding. A) Fewer fixations were made overall to high-arousal than low-arousal slides, though this effect was driven by negative slides. B) Longest looks were lengthier when viewing high-arousal compared with low-arousal slides, though this effect was also more prominent for negatively valenced slides. C) More time is spent fixating on the emotionally salient side of the IAPS slide for high-arousal slides compared with low-arousal slides. All three measures reflect a relative restriction of attention to emotionally salient parts of high-arousal slides. Box size did not interact with these effects. Error bars represent standard error of the mean.



*Recognition Memory*

To test for visually-specific memory,  $d'$  estimates were obtained as described for Experiment 1 and submitted to a repeated-measures ANOVA, with participants as the random variable and box size (big vs. small), valence (negative vs. positive), and arousal (low vs. high) as independent variables. Visually-specific memory overall was similar to Experiment 1 and well above chance (mean overall  $d' = .84$ ;  $t(47) = 17.6$ ,  $p < .001$ ,  $d = 2.54$ ). No effects were significant in this analysis; see Figure 8.



*Figure 8* - Visually-specific memory performance. Reflection-specific memory performance was well above chance, but did not differ between valence and arousal conditions. Error bars represent standard error of the mean.

### *Subsequent Memory Analyses*

Subsequent memory analyses were conducted as described for Experiment 1. Three separate repeated-measures ANOVAs were conducted, with box size (big vs. small), arousal (high vs. low), and subsequent memory (hit vs. miss) as independent variables, and participants as the random variable. The dependent variables were the number of fixations, duration of the longest fixation, and time fixating on the emotional side while viewing the IAPS slide during encoding.

For number of fixations, main effects of box size,  $F(1,47) = 8.8$ ,  $MS_e = .471$ ,  $p < .01$ ,  $d = .87$ , and arousal,  $F(1,47) = 19.2$ ,  $MS_e = .242$ ,  $p < .001$ ,  $d = 1.28$ , were again significant as in the initial analysis of eye movements at encoding. Overall, more fixations were made to subsequent hits (4.01) than subsequent misses (3.76), in a significant main effect of subsequent memory,  $F(1,47) = 18.9$ ,  $MS_e = .298$ ,  $p < .001$ ,  $d = 1.27$ . However, this effect was subsumed in a significant arousal by subsequent memory interaction,  $F(1,47) = 6.76$ ,  $MS_e = .341$ ,  $p < .05$ ,  $d = .76$ . Examining subsequent memory effects for low- and high-arousal slides separately as in Experiment 1, more fixations were made to low-arousal hits (4.19) than low arousal misses (3.80),  $F(1,47) = 22.7$ ,  $p < .001$ ,  $d = 1.39$ , replicating Experiment 1. Also as in Experiment 1, there was no subsequent memory effect for high-arousal slides (high-arousal hits = 3.82; high arousal misses = 3.73),  $F(1,47) = 1.2$ ,  $p > .25$ ,  $d = .32$ ; see Figure 9a. Greater numbers of fixations predicted subsequent visually-specific memory for low-arousal slides only, replicating Experiment 1. Critically, box size did not interact with these

subsequent memory effects,  $F(1,47) = 1.4$ ,  $p > .25$ ,  $d = .35$ , for the three-way box size by arousal by subsequent memory interaction.<sup>4</sup>

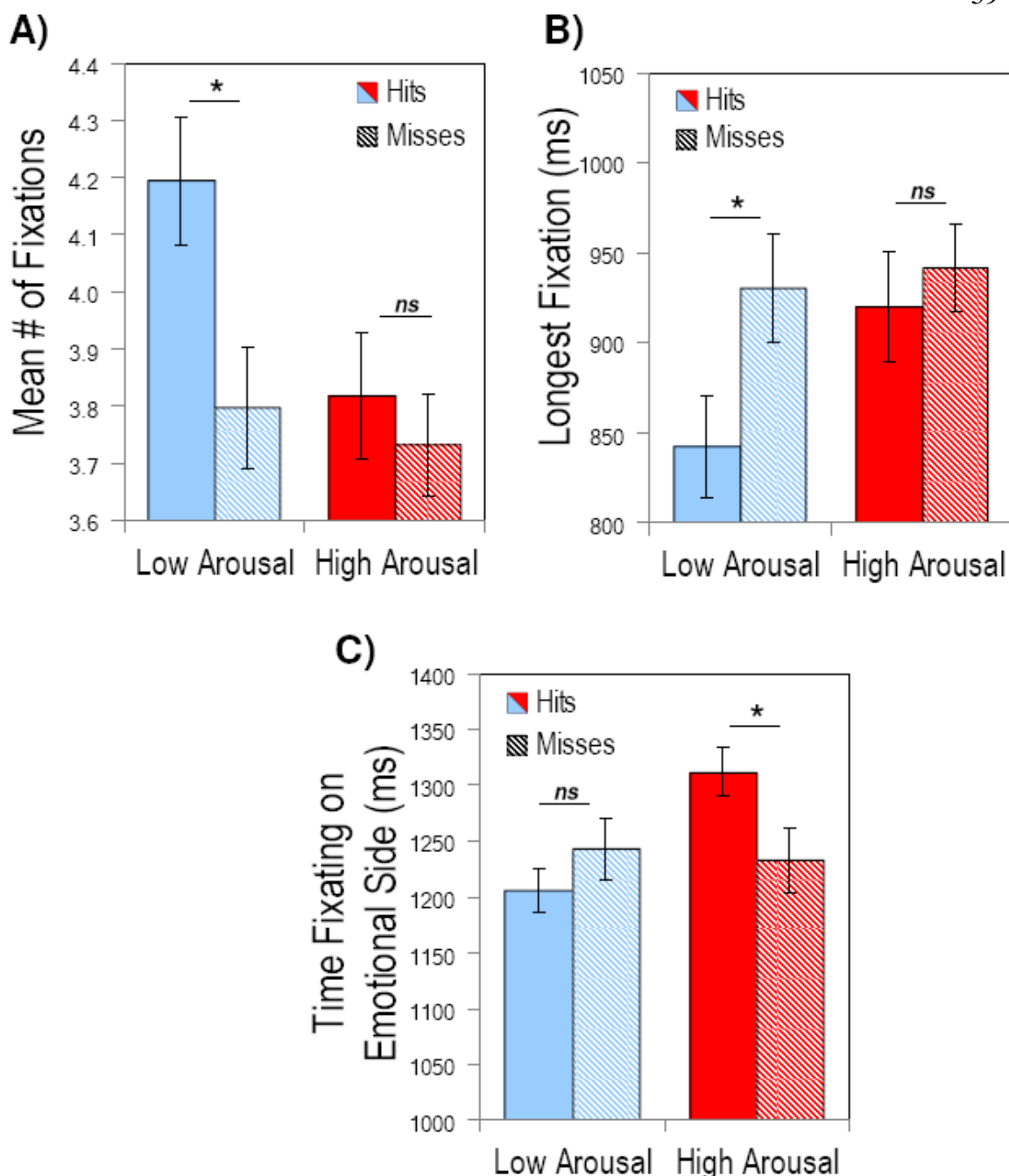
The pattern of effects for longest fixations was similar. The arousal main effect was again significant,  $F(1,47) = 8.21$ ,  $MS_e = 23303.2$ ,  $p < .01$ ,  $d = .84$ . Overall, shorter fixations are made to subsequent hits (881 ms), than subsequent misses (936 ms), in a significant main effect of subsequent memory,  $F(1,47) = 10.7$ ,  $MS_e = 27221.0$ ,  $p < .01$ ,  $d = .95$ . The arousal by subsequent memory interaction was trending,  $F(1,47) = 3.49$ ,  $MS_e = 30335.4$ ,  $p < .07$ ,  $d = .54$ . Examining subsequent memory effects separately for high- and low-arousal slides, shorter fixations were made to low-arousal hits (842 ms) than low-arousal misses (930 ms),  $F(1,47) = 11.6$ ,  $p < .001$ ,  $d = .99$ , as in Experiment 1. Also as in Experiment 1 there was no subsequent memory effect for high arousal hits (942 ms) versus high-arousal misses (920 ms),  $F(1,47) < 1$ , *ns*; see Figure 9b. Shorter fixations predicted subsequent visually-specific memory only for low-arousal slides. Critically, box size did not interact with these subsequent memory effects,  $F(1,47) < 1$ , *ns*, for the three-way interaction.

Lastly, for time fixating on the emotional side, the main effects of box size,  $F(1,47) = 28.8$ ,  $MS_e = 43218.7$ ,  $p < .001$ ,  $d = 1.57$ , and arousal,  $F(1,47) = 5.2$ ,  $MS_e = 42253.4$ ,  $p < .05$ ,  $d = .67$ , were again significant. Replicating Experiment 1, the arousal by subsequent memory interaction was significant,  $F(1,47) = 7.31$ ,  $MS_e = 44730.0$ ,  $p < .01$ ,  $d = .79$ . Examining low- and high-arousal slides separately, equal amounts of time

---

<sup>4</sup> As a more direct test of the match/mismatch hypothesis, I also performed each of these subsequent memory analyses by collapsing arousal and box size into a single two-level variable, with “match” including all high-arousal/small box plus all low-arousal/big box trials, and “mismatch” including all high-arousal/big box plus all low-arousal/small box trials. In no case was any match vs. mismatch effect significant.

were spent fixating on the emotional side for low-arousal hits (1205 ms) as low-arousal misses (1243 ms),  $F(1,47) = 1.2$ , *ns*. In contrast, more time was spent fixating on the emotional side for high-arousal hits (1311 ms) than high-arousal misses (1232 ms),  $F(1,47) = 5.72$ ,  $p < .05$ ,  $d = .70$ , replicating Experiment 1; see Figure 9c. However, box size did not interact with these subsequent memory effects,  $F(1,47) < 1$ , *ns*, for the three-way interaction.



*Figure 9* - Subsequent memory effects in eye movements. A,B) More fixations and shorter duration fixations during encoding predicts subsequent visually-specific memory for low-arousal slides, but not high-arousal slides, replicating Experiment 1. C) Time fixating on the emotionally salient side of the IAPS slide predicts subsequent visually-specific memory for high-arousal slides, but not low-arousal slides, replicating Experiment 1. Box size did not interact with any of these effects. Error bars represent standard error of the mean.

### *Discussion*

All eye movement, memory, and subsequent memory effects from Experiment 1 were replicated in Experiment 2. Fewer fixations of shorter duration were made when viewing high-arousal compared with low-arousal slides, and these fixations tended towards the emotionally salient side of the slide. Visually-specific memory was equivalent for high- and low-arousal slides. Lastly, different patterns of eye movements predicted subsequent visually-specific memory for high- and low-arousal slides, replicating results from Experiment 1. Broadening of attention at encoding (more fixations of shorter duration) predicted subsequent visually-specific memory *only* for low arousal scenes. In contrast, restriction of attention to the emotionally salient part of the slide predicted subsequent memory *only* for high-arousal scenes. However, of greater relevance, the box which preceded each picture – intended to induce a global or local processing bias – did not interact with valence or arousal in eye movements, visually-specific memory, or subsequent memory effects, unlike what was predicted by the global/local hypothesis. The box size manipulation did have effects: fewer fixations and longer fixations were made following small boxes than large boxes – but these effects did not interact with emotional arousal and/or subsequent memory effects as was predicted.

One reason no interactions between box size and arousal may have been observed is that global/local processing biases were induced on a trial-by-trial basis. Because of this, the induced effects may not have been particularly strong, or could have been weakened by rapid switching between local to global biases. Though local

and global biases can change on a trial-by-trial basis (e.g., Baumann & Kuhl, 2005), induction of a stronger processing bias might require using a blocked design where multiple global or local tasks are made consecutively, as used in past studies (e.g., Macrae & Lewis, 2002; Lin & Han, 2008). Inducing a stronger local or global bias through a blocked design was the goal of Experiment 3.

### **Experiment 3: Inducing Global/Local Processing in a Blocked Design**

Rather than the trial-by-trial method used for Experiment 2, in the current experiment, stronger and longer lasting global and local processing states were induced by having participants perform blocks of global or local Navon letter judgments (Navon, 1977; Macrae & Lewis, 2002) prior to viewing the IAPS slides.

As in Experiment 2, I hypothesize that when processing bias and emotional arousal are matched – local processing biases with high-arousal slides and global processing biases with low-arousal slides – visually-specific memory should be enhanced, and subsequent memory effects should be observed as in Experiment 1. In contrast, when processing bias and emotional arousal are *mismatched*, visually-specific memory should be poorer, and subsequent memory effects in eye movements should be lessened or abolished. However, if local and global biases do not underlie the subsequent memory effects in eye movements that were observed in Experiment 1, then the induced local/global processing bias will not affect eye movements, visually-specific memory, or subsequent memory effects in eye movements, and the results from Experiment 2 will be replicated.

#### *Method*

##### *Participants*

Forty-eight undergraduate students with normal or corrected-to-normal vision (half female) participated in exchange for course credit. Two subjects were replaced in the final analysis for excessive head movement that affected eye tracker calibration.



### *Materials*

The same set of 128 IAPS slides and counterbalancing lists were used as in Experiments 1 and 2. A total of 110 hierarchical Navon letters were created, featuring all possible large letter/small letter combinations of A, C, E, F, H, L, O, S, R, U, and P, excluding those in which the large and small letter were the same. Four pseudo-randomized ordered lists of the full set of Navon letters were created for counterbalancing purposes. The Navon letter lists were ordered such that no correct answer was repeated two trials in a row, and so that each letter occurred an equal number of times in the first half and last half of each list. Large letters varied in total size, but all fit within a 15 x 30 cm box, subtending a maximum of 22.5 x 45 degrees of visual angle. Following from past studies that used Navon letter judgments to induce processing biases (e.g., Lin, Lin, & Han, 2008; Lin & Han, 2008), I aimed for a roughly 1:1 correspondence between time spent making Navon letter judgments (thus inducing a processing bias), and the time spent viewing IAPS slides (while eye movements were recorded), roughly three minutes per block.

### *Procedure*

*Encoding Phase.* The encoding phase was divided into four blocks, each consisting of 110 Navon letter judgments and 32 IAPS slides with valence and arousal judgments (and including a filler IAPS slide at the beginning and end of each block to attenuate primacy and recency effects). For each participant, two consecutive blocks of Navon letter judgments required naming the *global* (large) letter in the hierarchical stimulus, the remaining two blocks required naming the *local* (small) letter; the order of

global/local letter judgment blocks was counterbalanced across participants.

Participants were first instructed how to perform Navon letter judgments and how to make valence and arousal judgments on the IAPS slides, then seated 55 cm from the computer screen (maintained by forehead rest). The eye tracking equipment was calibrated before the encoding phase began. For each Navon letter trial, a central fixation cross was presented for 500 ms. Then, a hierarchical Navon letter appeared on screen. Participants were instructed to name the large letter for global blocks, or the small letter for local blocks, and to speak this answer aloud. The letter remained on screen until participants made a verbal response. The next Navon letter judgment trial began 500 ms later. Immediately upon completion of a block of 110 Navon letter judgments, a block of 32 IAPS trials began. IAPS trials were conducted exactly as in Experiment 1.

For each participant, thirty-two IAPS slides were presented from each of the four valence by arousal categories; of these thirty-two, sixteen were presented following global Navon letter judgment blocks, and sixteen were presented following local Navon letter judgment blocks. Trial orders of IAPS blocks were pseudo-randomized such that no more than three consecutive trials represented the same arousal level (high vs. low), valence category (negative vs. positive), or target/distracter status at test (i.e., “old” vs. “new”). Navon-letter lists were rotated through global/local conditions and block position (1<sup>st</sup>, 2<sup>nd</sup>, 3<sup>rd</sup>, 4<sup>th</sup> block of letter judgments) so that each list represented each of these conditions an equal number of times.

*Test Phase.* The test phase was conducted as in Experiment 1. Trial orders were pseudo-randomized such that no more than three consecutive trials represented the same

arousal level (high vs. low), valence category (negative vs. positive), Navon condition at encoding (global or local letter judgment), or target/distracter status (old vs. new). The IAPS counterbalancing lists were rotated through the old/new conditions, original/enantiomorph conditions, and global/local conditions so that each slide represented each of these conditions an equal number of times across participants.

## *Results*

### *Eye Movements at Encoding*

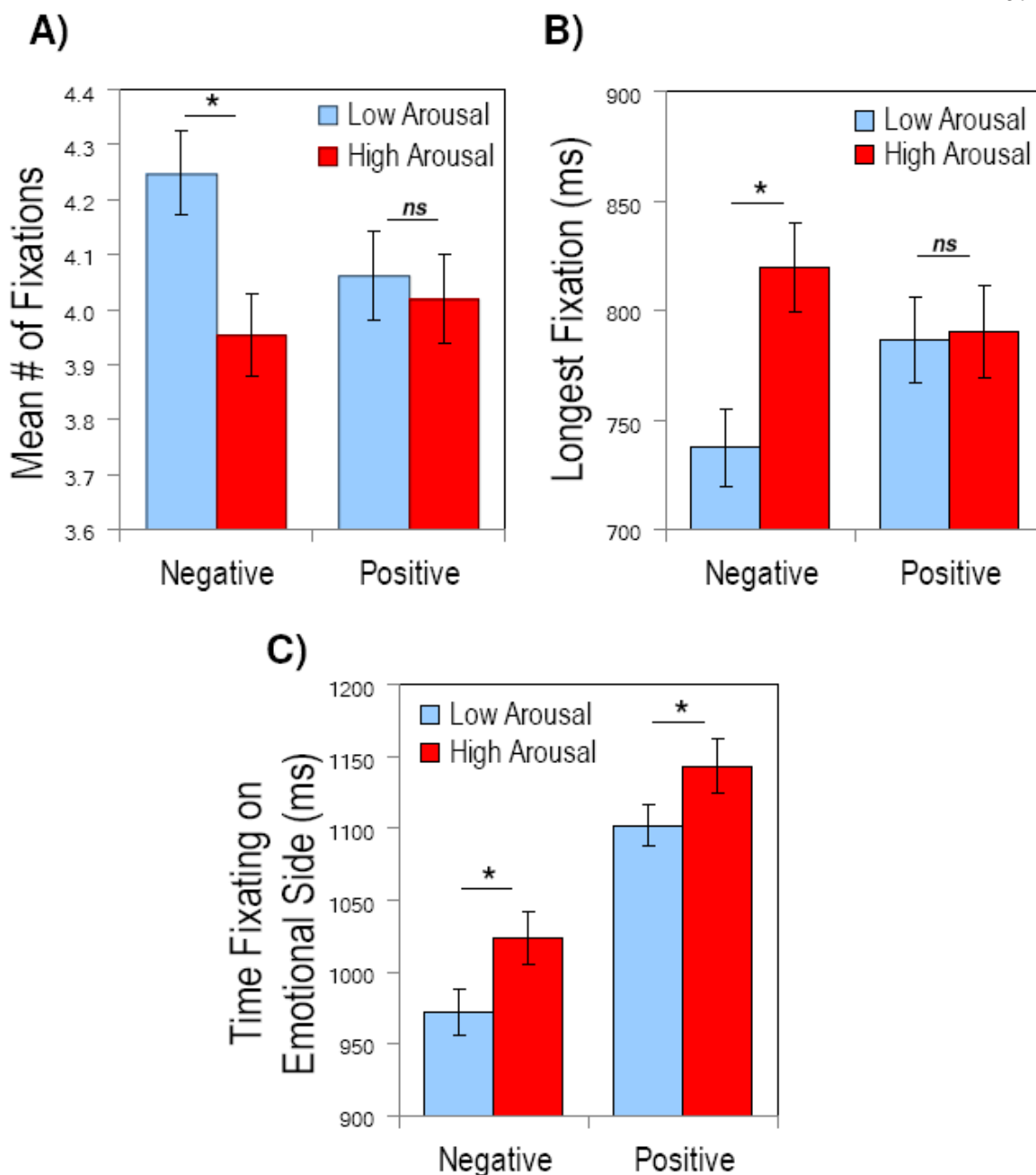
Navon condition (global vs. local), valence (positive vs. negative), and arousal (low vs. high) were within-subjects independent variables in three repeated-measures ANOVAs, with participants as the random variable. Fixations, longest looks, and time fixating on the emotional side were dependent measures used to examine attention-restricting effects in eye movements.

As in previous experiments, fewer fixations were made while viewing high-arousal (3.98) than low-arousal (4.16) slides, in a significant main effect of arousal  $F(1,47) = 34.5$ ,  $MS_e = .079$ ,  $p < .001$ ,  $d = 1.71$ . The main effect of valence was also significant,  $F(1,47) = 3.94$ ,  $MS_e = .089$ ,  $p = .053$ ,  $d = .58$ , as was the valence by arousal interaction,  $F(1,47) = 21.6$ ,  $MS_e = .098$ ,  $p < .001$ ,  $d = 1.36$ . Examining negative slides only, fewer fixations were made to high-arousal (3.95) than low-arousal (4.25) slides,  $F(1,47) = 52.0$ ,  $p < .001$ ,  $d = 2.10$ ; this was not true for positive slides. Equal numbers of fixations were made for high (4.02) and low (4.06) arousal positive slides,  $F(1,47) = 1.2$ ,  $ns$ ,  $d = .32$ , reflecting that overall attention restricting effects were driven by

negative slides; see Figure 10a. Navon condition did not have any effects on number of fixations made during encoding, all  $F_s < 2$ .

For fixation durations, a significant main effect of arousal was observed  $F(1,47) = 30.6$ ,  $MS_e = 5811.5$ ,  $p < .001$ ,  $d = 1.61$ , reflecting lengthier longest fixations to high-arousal (805 ms) than low-arousal slides (762 ms). The valence by arousal interaction was again significant,  $F(1,47) = 26.4$ ,  $MS_e = 5626.1$ ,  $p < .001$ ,  $d = 1.50$ . Similar to Experiments 1 and 2, longer fixations were made while viewing high-arousal negative slides (820 ms) than low-arousal negative slides (737 ms),  $F(1,47) = 56.7$ ,  $p < .001$ ,  $d = 2.20$ . However, for positive slides, fixation durations were equivalent for high (790 ms) and low (786 ms) arousals,  $F < 1$ ,  $ns$ ; reflecting that attention narrowing effects in fixation durations are driven by negative slides; see Figure 10b. Navon condition did not have any effects on the length of fixations made during encoding, all  $F_s < 2$ .

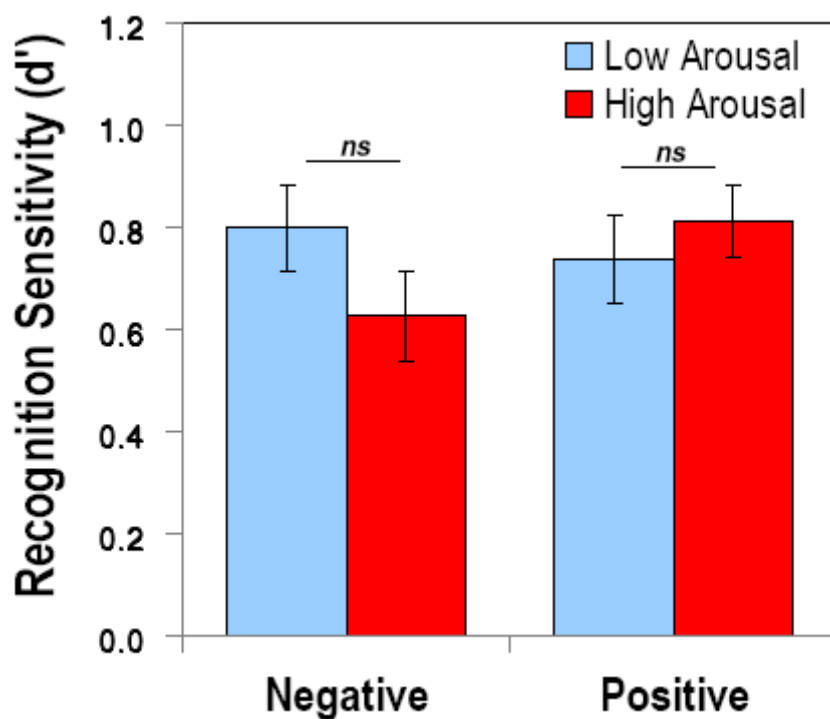
Examining time fixating on the emotional side, there was a significant main effect of arousal,  $F(1,47) = 13.0$ ,  $MS_e = 15815.8$ ,  $p < .001$ ,  $d = 1.05$ , with more time fixating on the emotional side for high-arousal slides (1083 ms) than for low-arousal slides (1037 ms). A positivity bias was again observed with a significant main effect of valence,  $F(1,47) = 128.0$ ,  $MS_e = 11615.7$ ,  $p < .001$ ,  $d = 3.30$ . Examining positive and negative slides separately, more time was spent fixating on the emotional side of negative high-arousal slides (1024 ms) compared with negative low-arousal slides (972 ms),  $F(1,47) = 7.47$ ,  $p < .01$ ,  $d = .80$ ; the same was true for positive high-arousal (1143 ms) compared with positive low-arousal (1102 ms) slides,  $F(1,47) = 5.21$ ,  $p < .05$ ,  $d = .67$ ; see Figure 10c. Navon condition did not have any effects on the time fixating on the emotional side, all  $F_s < 2$ .



*Figure 10* - Eye movements during encoding. A) Fewer fixations were made overall to high-arousal than low-arousal slides, though this effect was driven by negative slides. B) Longest looks were lengthier when viewing high-arousal compared with low-arousal slides, though this effect was observed only for negatively valenced slides. C) More time is spent fixating on the emotionally salient side of the IAPS slide for high-arousal slides compared with low-arousal slides. All three measures reflect a relative restriction of attention to emotionally salient parts of high-arousal slides. Navon letter condition (global or local) did not interact with any of these effects. Error bars represent standard error of the mean.

### *Recognition Memory*

To examine visually-specific memory, recognition sensitivity ( $d'$ ) estimates were obtained as in Experiments 1 and 2, and used as the dependent measure in a repeated-measures ANOVA, with participants as the random variable. Navon condition (global vs. local), valence (positive vs. negative) and arousal (low vs. high) were within-subjects independent variables. Overall, memory performance was again well above chance (overall  $d' = .74$ ;  $t(47) = 11.9$ ,  $p < .001$ ,  $d = 3.47$ ), but Navon condition did not influence memory; all Navon condition  $F$ s  $< 2$ . Unexpectedly, there was a valence by arousal interaction,  $F(1,47) = 4.03$ ,  $MS_e = .363$ ,  $p = .05$ ,  $d = .59$ . No simple effects were significant in unpacking this interaction, so after examining the data, I performed a post-hoc contrast comparing the condition with the lowest visually-specific memory performance (negative high-arousal slides,  $d' = .626$ ) to the remaining three valence-arousal conditions. This contrast was trending,  $F(1,47) = 3.87$ ,  $MS_e = .152$ ,  $p < .06$ ,  $d = .57$ , suggesting that visually-specific memory was lowest for negative high-arousal slides; see Figure 11.



*Figure 11* – Visually-specific memory performance. Visually-specific memory was significantly greater than chance in all conditions. Navon letter condition (global or local) did not interact with any of these effects. Error bars represent standard error of the mean.

#### *Subsequent Memory Analyses*

Subsequent memory analyses were performed as described previously. Three repeated-measures ANOVAs were conducted, with Navon condition (global vs. local), arousal (high vs. low), and subsequent memory (hit vs. miss) as independent variables, and participants as the random variable. The dependent variables were the number of fixations, duration of the longest fixation, and time spent fixating on the emotional side of the slide during encoding.

For number of fixations, the main effect of arousal was again significant,  $F(1,47) = 5.52$ ,  $MS_e = .283$ ,  $p < .05$ ,  $d = .69$ . Overall, more fixations were made to

subsequent hits (4.13) than subsequent misses (3.98),  $F(1,47) = 9.20$ ,  $MS_e = .239$ ,  $p < .01$ ,  $d = .88$ , in a significant subsequent memory effect. However, in contrast to both previous experiments, this effect was true for *both* low- and high-arousal slides,  $F(1,47) = .46$ ,  $MS_e = .347$ ,  $p = .50$ ,  $d = .20$ , for the arousal by subsequent memory interaction; see Figure 12a. Navon condition did not interact with any of these effects; all  $F_s < 2$ .

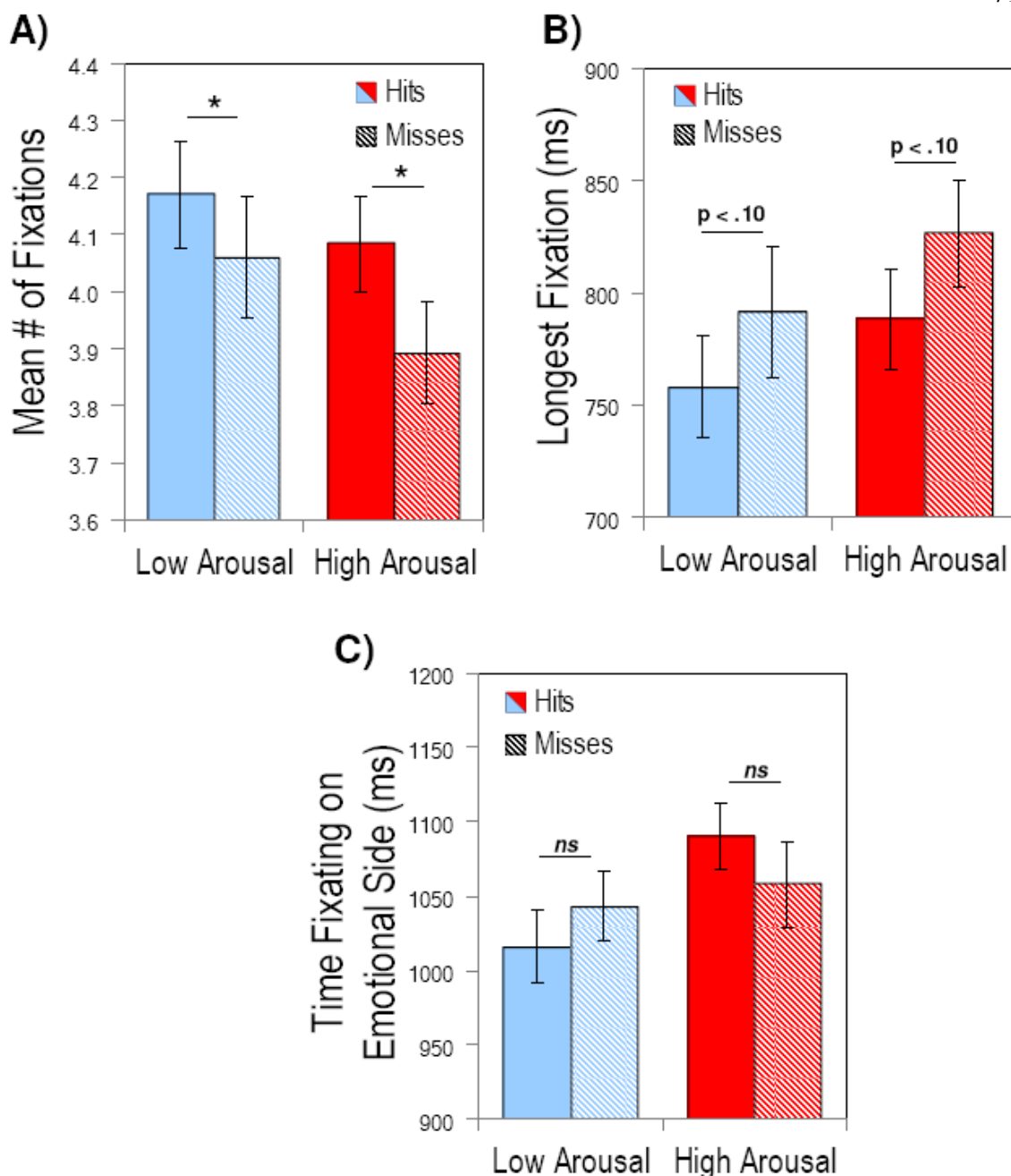
For longest fixations, the main effect of arousal was again significant,  $F(1,47) = 4.46$ ,  $MS_e = 22845.5$ ,  $p < .05$ ,  $d = .62$ . Overall, longest looks were shorter for subsequent hits (773 ms) than for subsequent misses (803 ms), in a significant subsequent memory effect,  $F(1,47) = 6.89$ ,  $MS_e = 17842.1$ ,  $p < .05$ ,  $d = .77$ . As with fixations, this effect was true for *both* low- and high-arousal slides,  $F(1,47) = .02$ ,  $MS_e = 28078.1$ ,  $p = .89$ ,  $d = .04$ , for the arousal by subsequent memory interaction; see Figure 12b. Navon condition did not interact with any of these effects; all  $F_s < 2$ .

For time fixating on the emotional side, the main effect of arousal was significant,  $F(1,47) = 4.76$ ,  $MS_e = 40291.6$ ,  $p < .05$ ,  $d = .64$ . However, in contrast to Experiment 1 and 2, no subsequent memory effects were observed for this dependent measure, all  $F_s < 2$ ; see Figure 12c. Navon condition did not interact with any of these effects; all  $F_s < 2$ .<sup>5</sup>

---

<sup>5</sup> As described in Experiment 2, I also conducted analyses by collapsing emotional arousal and local/global condition into a single “match/mismatch” independent variable. As in Experiment 2, these effects were not significant.





*Figure 12* - Subsequent memory effects in eye movements. A,B) More fixations and shorter duration fixations during encoding predicts subsequent visually-specific memory for *all* slides. C) Time fixating on the emotionally salient side of the IAPS slide does not predict subsequent visually-specific memory. Navon letter condition did not interact with any of these effects. Error bars represent standard error of the mean.

### *Discussion*

In Experiment 1, two different patterns of eye movements predicted subsequent visually-specific memory for emotional and non-emotional scenes. For low-arousal, relatively non-emotional slides, more fixations of shorter duration predicted subsequent memory. In contrast, for high-arousal emotional slides, restricting attention to the emotion-provoking side of the slide predicted subsequent memory. In Experiments 2 and 3, I tested whether local or global processing biases were responsible for these two opposing subsequent memory effects by inducing local or global processing biases on either a trial-by-trial basis (in Experiment 2), or with a blocked design (Experiment 3). Importantly, in neither experiment did these induced local or global processing biases interact with emotional arousal, either in the patterns of eye movements made while encoding IAPS slides, the degree of visually-specific memory that was exhibited, or the patterns of eye movements that predicted subsequent memory. Taken together, these results provide converging evidence that the subsequent memory effects observed in Experiment 1 are *not* the result of distinct local or global processing biases while encoding high- and low-arousal IAPS slides. There does not seem to be any relationship between the eye movements made while viewing IAPS slides and local or global processing state. However, the results from Experiments 2 and 3 differ in important ways.

Subsequent memory effects were altered in the Navon letter judgment experiment. Replicating results from the first two experiments, a relative broadening of attention when viewing low-arousal slides – fewer fixations of shorter duration – predicted subsequent visually-specific memory. However, unlike in the previous

experiments, the *same* effect was now true for high-arousal slides as well. Rather than a restriction of attention predicting subsequent memory, for high-arousal slides in the Navon experiment, a relative broadening of attention – more fixations of shorter duration – predicted subsequent visually-specific memory. In other words, subsequent memory effects in eye movements were equivalent for low- and high-arousal slides. Interestingly, this pattern of subsequent memory effects occurred even though, in terms of eye movements made during encoding, attention was restricted for high-arousal slides. Put simply, even though the patterns of eye movements made at encoding were similar in all three experiments, in the Navon experiment, the subsequent memory effects were altered. There may be a relatively simple explanation for why this could have occurred.

There is at least one important way in which the Navon letter judgments differed from the box size judgments used in Experiment 2. In Experiment 2, participants completed a simple box size comparison after viewing each IAPS slide. These size judgments were a simple task, completed easily, with a single correct answer, and requiring little or no deep, semantic, or post-visual processing of the boxes. Navon letter judgments, on the other hand, were likely more engaging, could have involved deeper, language-based (i.e., orthographic or phonological) processing of the letters, and involved selection of a correct response and suppression of an incorrect response in each trial. If this were the case, depth of processing may be an important factor. Recently, it has been demonstrated that when performing concurrent tasks, when the difficulty of the secondary task increases, emotional responses to IAPS slides decreases (Kellerman et al., 2011). Thus, it is likely that high-arousal slides in this experiment did

not elicit emotional reactions to the same extent as in Experiments 1 and 2, even though eye movements were restricted in a weapon-focus like manner when viewing them.

Experiment 4 was conducted to test whether decreased emotional reactivity explains the change in subsequent memory effects observed in the Navon experiment.

### Experiment 4: Free Viewing of IAPS Slides

In Experiment 3, subsequent memory effects in eye movements were the same for both high- and low-arousal slides, in contrast to previous experiments. One possibility is that the deeper processing of the Navon task lowered emotional reactivity to the high-arousal IAPS slides. One way to test whether this explanation is true would be to interpose an even more difficult or engaging task for participants to perform while they viewed IAPS. However, memory performance can be expected to decrease with substantially more difficult tasks (tasks would likely interfere with effective encoding of the IAPS slides), making subsequent memory effects more difficult to interpret when comparing across studies. Instead of dampening emotional reactions by using a secondary task in Experiment 4, participants simply viewed IAPS slides without making valence and arousal judgments. Free viewing of IAPS reduces the intensity of evoked emotional responses (when compared to making valence and arousal judgments; Liberzon, Taylor, Fig, Decker, Koeppel, & Minoshima, 2000), but should not be expected to decrement memory performance.

Experiment 4 tested whether decreased emotional reactions underlie the subsequent memory effects observed in Experiment 3. Participants viewed IAPS slides but made no valence or arousal judgments. If reduced emotional responses explain the subsequent memory effects in Experiment 3, then under free viewing conditions, these effects should be replicated: a relative broadening of attention (more fixations of shorter duration) should predict subsequent visually-specific memory for *all* slides, regardless of the normative arousal level. However, eye movements made at encoding should still reflect a restriction of attention to highly emotional parts of the scenes.

## *Method*

### *Participants*

Forty-eight undergraduate students with normal or corrected-to-normal vision (half female) participated in exchange for course credit.

### *Materials & Procedure*

The materials and procedure were exactly the same as in Experiment 1, with the exception that participants did not make valence and arousal judgments after viewing the IAPS slides. They were instructed only to look at and pay attention to each slide.

## *Results*

### *Eye Movements at Encoding*

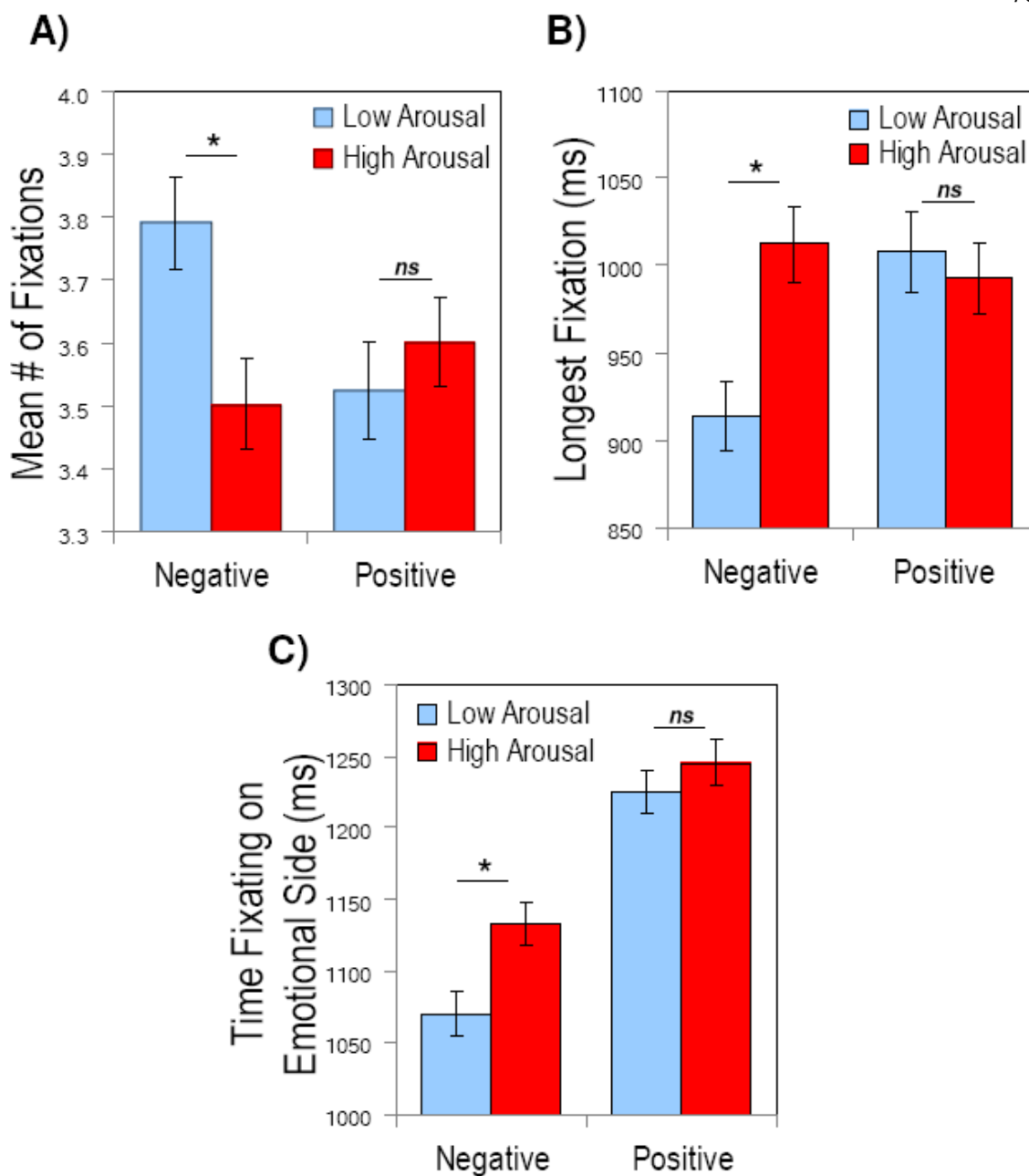
Valence (positive vs. negative) and arousal (low vs. high) were within-subjects independent variables in three repeated-measures ANOVAs, with participants as the random variable. Number of fixations, longest looks, and time fixating on the emotional side were dependent measures used to examine attention-restricting effects in eye movements during encoding.

Replicating past experiments, fewer fixations were made to high-arousal (3.55) than low-arousal (3.66) slides, in a significant main effect of arousal,  $F(1,47) = 11.2$ ,  $MS_e = .049$ ,  $p < .01$ ,  $d = .98$ . The main effect of valence  $F(1,47) = 7.0$ ,  $MS_e = .048$ ,  $p < .05$ ,  $d = .77$ , and the valence by arousal interaction were also significant,  $F(1,47) = 38.6$ ,  $MS_e = .042$ ,  $p < .001$ ,  $d = 1.81$ . Examining negative valence slides only, fewer fixations were made while viewing high-arousal (3.50) than low-arousal (3.79) slides,  $F(1,47) =$

53.7,  $p < .001$ ,  $d = 2.14$ , for the test of simple effects. This effect was smaller for positive slides, with only a slight tendency for fewer fixations while viewing high-arousal (3.53) than low-arousal (3.60) slides,  $F(1,47) = 2.6$ ,  $p = .11$ ,  $d = .47$ ; see Figure 13a. As in previous experiments, overall attention narrowing effects in fixations for high-arousal slides derive primarily from negative valence slides.

Similar trends were observed for the duration of longest fixations. Overall, lengthier longest fixations were made while viewing high-arousal (1002 ms) than low-arousal (961 ms) slides, in a significant main effect of arousal,  $F(1,47) = 16.1$ ,  $MS_e = 5195.8$ ,  $p < .001$ ,  $d = 1.17$ . As with fixations, the main effect of valence,  $F(1,47) = 16.5$ ,  $MS_e = 4017.5$ ,  $p < .001$ ,  $d = 1.19$ , and the valence by arousal interaction,  $F(1,47) = 50.8$ ,  $MS_e = 3056.3$ ,  $p < .001$ ,  $d = 2.08$ , were significant. For negative slides, longer fixations were made to high-arousal (1012 ms) than low-arousal (913 ms) slides,  $F(1,47) = 57.3$ ,  $p < .001$ ,  $d = 2.21$ ; however, no attention-restricting effects were noted for positive slides, as fixation durations were similar for positive high-arousal (1008 ms) and positive low-arousal (993 ms) slides,  $F(1,47) = 1.3$ ,  $ns$ ; see Figure 13b. Once again, the attention narrowing effects of arousal are driven primarily by negative slides.

For time fixating on the emotional side, participants spent more time looking at high-arousal emotional sides (1189 ms) than low-arousal emotional sides (1147 ms), reflecting attention being restricted to emotional provoking aspects of scenes, in a main effect of arousal,  $F(1,47) = 6.49$ ,  $MS_e = 12828.4$ ,  $p < .05$ ,  $d = .74$ . As before, there was also a main effect of valence, with more time looking at positive emotional sides (1235 ms) than negative (1101 ms),  $F(1,47) = 103.8$ ,  $MS_e = 8328.6$ ,  $p < .001$ ,  $d = 2.97$ ; see Figure 13c. The valence by arousal interaction was not significant.



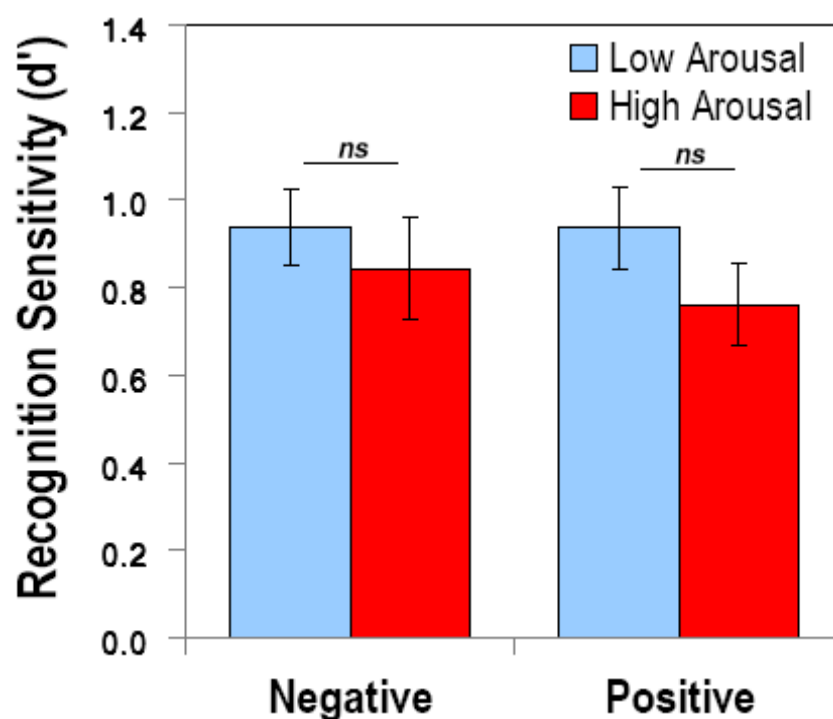
*Figure 13* - Eye movements during encoding. A) Fewer fixations were made overall to high-arousal than low-arousal slides, though this effect was driven by negative slides. B) Longest looks were lengthier when viewing high-arousal compared with low-arousal slides, though this effect was also only observed for negatively valenced slides. C) More time is spent fixating on the emotionally salient side of the IAPS slide for high-arousal slides compared with low-arousal slides. All three measures reflect a relative restriction of attention to emotionally salient parts of high-arousal slides. Error bars represent standard error of the mean.



### Recognition Memory

Estimates of recognition sensitivity ( $d'$ ) were obtained as in Experiments 1-3. Recognition sensitivity was the dependent measure in a repeated-measures ANOVA, using participants as the random variable. Valence (positive vs. negative) and arousal (low vs. high) were within-subjects independent variables.

Visually-specific memory performance was well above chance and similar to past experiments (overall  $d' = .87$ ;  $t(47) = 9.5$ ,  $p < .001$ ,  $d = 2.77$ ). Surprisingly, visually-specific memory was greater for low-arousal slides (.94) than for high-arousal slides (.80), in a significant main effect of arousal,  $F(1,47) = 6.6$ ,  $MS_e = .132$ ,  $p < .05$ ,  $d = .75$ ; see Figure 14.



*Figure 14* – Visually-specific memory performance. Visually-specific memory was significantly greater than chance in all conditions. Greater visually-specific memory was exhibited for low-arousal compared with high-arousal slides. Error bars represent standard error of the mean.

### *Subsequent Memory Analyses*

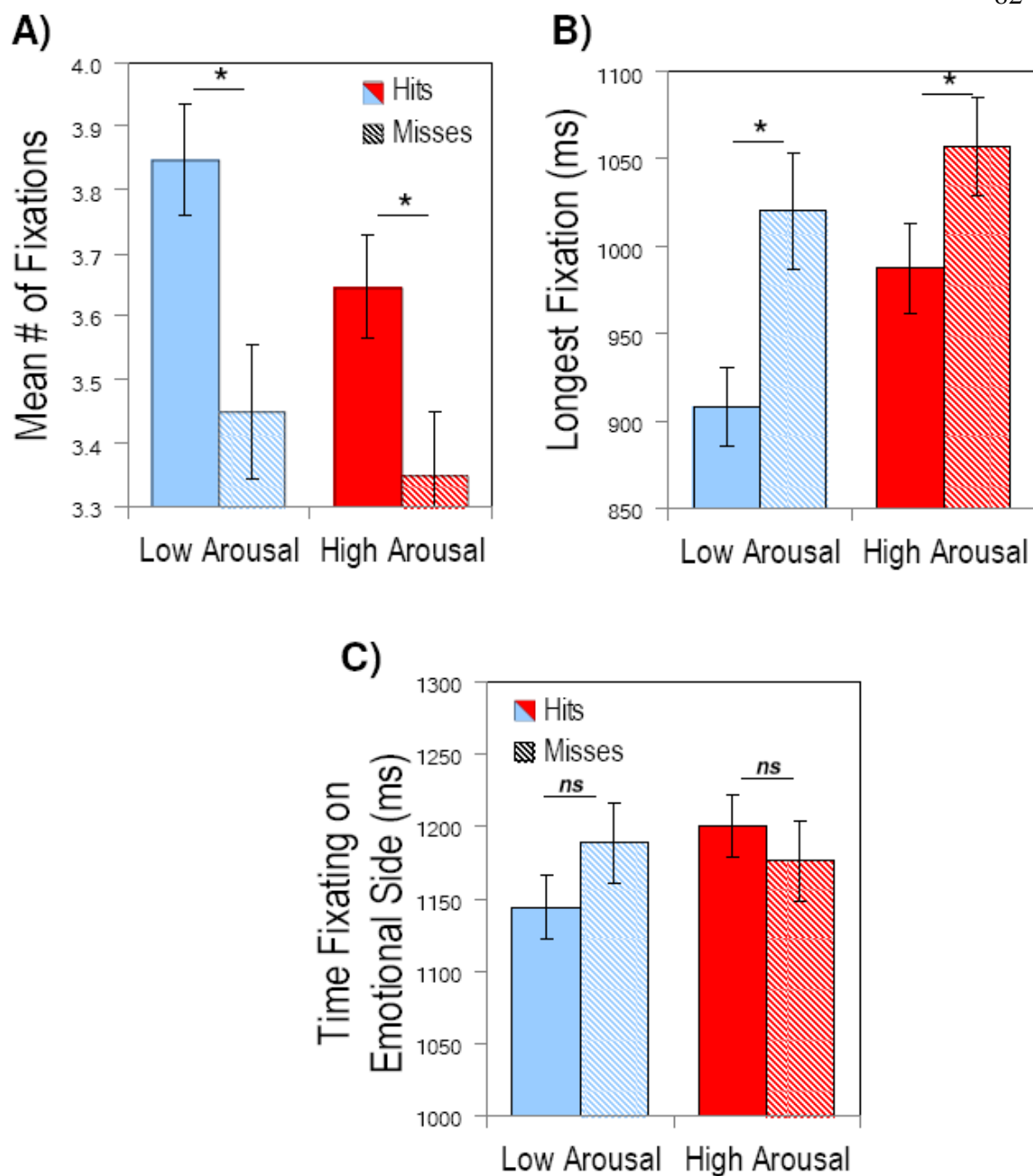
Analyses of subsequent memory were conducted as in Experiments 1-3. Three repeated-measures ANOVAs were conducted, with arousal (high vs. low) and subsequent memory (hit vs. miss) as independent variables, and participants as the random variable. The dependent variables were the number of fixations, duration of the longest fixation, and time fixating on the emotional side during encoding.

For number fixations, the main effect of arousal was again significant,  $F(1,47) = 6.29$ ,  $MS_e = .172$ ,  $p < .05$ ,  $d = .73$ . Overall, more fixations were made to subsequently remembered slides (3.75) than subsequently forgotten slides (3.40), in a significant subsequent memory effect,  $F(1,47) = 24.7$ ,  $MS_e = .234$ ,  $p < .001$ ,  $d = 1.45$ . Critically, the arousal by subsequent memory interaction was not significant,  $F(1,47) < 1$ , *ns*, replicating results from Experiment 3. Examining low-arousal slides only, more fixations were made to subsequent hits (3.85) than subsequent misses (3.45),  $F(1,47) = 17.4$ ,  $p < .001$ ,  $d = 1.22$ . High-arousal slides were similar to low-arousal slides: more fixations were made to subsequent hits (3.65) than subsequent misses (3.35),  $F(1,47) = 11.3$ ,  $p < .01$ ,  $d = .98$ ; see Figure 15a.

Similar patterns were observed for longest looks. The main effect of arousal was again significant,  $F(1,47) = 10.2$ ,  $MS_e = 15781.3$ ,  $p < .01$ ,  $d = .93$ . Overall, shorter longest looks are made to subsequent hits (948 ms) than subsequent misses (1039 ms), in a significant subsequent memory effect,  $F(1,47) = 19.8$ ,  $MS_e = 20011.0$ ,  $p < .001$ ,  $d = 1.30$ . Critically, the arousal by subsequent memory interaction was not significant,  $F(1,47) = 1.33$ , *ns*, as in Experiment 3. For low-arousal slides, shorter longest looks are made to subsequent hits (908 ms) than subsequent misses (1020 ms),  $F(1,47) = 15.2$ ,  $p$

$< .001$ ,  $d = 1.14$ ; the same is also true for high-arousal hits (987 ms) compared with high-arousal misses (1057 ms),  $F(1,47) = 7.12$ ,  $p < .01$ ,  $d = .78$ ; see Figure 15b.

Arousal and subsequent memory do not affect time fixating on the emotional side of the slides, all  $F$ s  $< 2$ ; see Figure 15c.



*Figure 15* - Subsequent memory effects in eye movements. A,B) More fixations and shorter duration fixations during encoding predicts subsequent visually-specific memory for *all* slides, as in Experiment 3. C) Time fixating on the emotionally salient side of the IAPS slide does not predict subsequent visually-specific memory, replicating Experiment 3. Error bars represent standard error of the mean.

### *Discussion*

Under free-viewing conditions, the results of Experiment 3 were replicated. Attention-restricting effects were observed for the eye movements made during encoding: fewer fixations of longer duration were made while viewing high-arousal slides than low-arousal slides, and these fixations tended towards the emotionally salient side of the slide. However, critically, emotional arousal did *not* influence the subsequent memory effects in eye movements. Similar to when participants made Navon letter judgments, a relative broadening of attention (more fixations of shorter duration) predicted visually-specific memories for *both* low- and high-arousal scenes.

Taken together with Experiment 3, these findings reflect two important boundary conditions on the arousal-dependent subsequent memory effects established in Experiments 1 and 2. First, when participants are not motivated to engage with the affective components of IAPS slides – when they are not required to make valence and arousal judgments, as in Experiment 4 – high-arousal slides do not engage emotional reactions to the same extent as when emotional judgments are made. Second, if attention is divided between encoding IAPS slides (even when making valence and arousal judgments) and another engaging task, even in a blocked, interleaved design, high-arousal slides do not engage emotional reactions to the same extent as when simpler tasks (e.g., the box size judgment of Experiment 2) are paired with valence and arousal judgments. In both cases, the result is that subsequent memory effects in eye movements are similar for high- and low-arousal slides, because, despite their normative arousal ratings, high-arousal slides are not effectively engaging emotional reactions.

Given that the arousal-dependent subsequent memory effects demonstrated in Experiments 1 and 2 were eliminated in the subsequent experiments, one concern is that such effects are not broadly applicable outside very specific laboratory contexts. There are several arguments that may assuage this concern. First, laboratory studies of emotion cannot engage emotional reactions to the same extent as a truly shocking event can – this is at least partially the reason why, despite their constraints, naturalistic studies of flashbulb memories are so common. In fact, there remains debate about whether “flashbulb memories” in naturalistic studies reflect a memorial process distinct from laboratory studies of emotional memory, or if flashbulb memories simply represent the far end of the spectrum of such emotional memory effects (see Talarico & Rubin, 2009, for a discussion). In short, laboratory studies of emotion, though they can be well controlled in ways that naturalistic studies cannot, likely measure only a slice of the overall effect of emotional arousal on memory. Second, IAPS slides in this experiment were chosen so that normative arousal ratings were equivalent across genders. As a practical matter, this required selecting slides that are not at the extremes of arousal from the IAPS set, meaning that high-arousal slides were not necessarily the most emotionally arousing slides available. Finally, emotional responses are lessened when completing concurrent tasks (Kellerman et al., 2011) or when performing tasks for which emotional information about the slide is irrelevant (Liberzon et al., 2000). Given that the arousal induced by the IAPS pictures in these experiments is weak, it is not surprising that the “motivation” and/or task-relevancy of valence and arousal judgments is needed to ensure that emotional reactions are engaged.

One additional important aspect of this experiment was that visually-specific memory for low-arousal scenes was *greater* than visually-specific memory for high-arousal scenes. This effect is discussed in more detail below.

## General Discussion

Theories of emotional memory often emphasize the importance of how attention is allocated when encoding emotional scenes, as in the weapon focus effect (e.g., Loftus et al., 1987). However, such attention-restriction theories of emotional memory have remained independent of the wealth of research on memory for non-emotional scenes (e.g., Henderson, 2003), and direct tests of the effect of “weapon focus-like” restriction of attention on emotional memory have not been conducted. In the preceding experiments, I examined how attentional allocation at encoding for emotional and non-emotional scenes influences the visual specificity of the memories that are stored.

### *Eye Movements and Visually-Specific Memory*

In Experiment 1, three important findings were established. First, as measured in eye movements, attention was restricted when viewing high-arousal, compared with low-arousal scenes. Fewer fixations of longer duration were made, and these fixations tended to land on emotionally salient parts of high-arousal slides. Importantly, this demonstrated that “weapon-focus-like” restriction of attention occurs for *all* emotional stimuli, not just those with weapons. Second, visually-specific memory was equivalent for emotional and non-emotional scenes, replicating a similar finding (Blank & Marsolek, 2006). However, most importantly, different patterns of eye movements predicted subsequent visually-specific memory for emotional and non-emotional scenes.

Distinct patterns of attentional allocation underlie effective encoding of emotional and non-emotional scenes in Experiment 1 and 2. For non-emotional scenes,



a relative broadening of attention across the scene, by making more fixations of shorter duration, led to visually-specific memory representations being stored. In contrast, a relative restriction of attention, by focusing eye movements on the emotionally salient side of the slide, led to a visually-specific memory representation being stored only when the scene is emotional. Even though the behavioral outcome was similar – a visually-specific memory was stored – the two types of scenes were encoded in vastly different ways.

### *Local and Global Processing*

In Experiments 2 and 3, I tested whether inducing local or global processing biases during encoding explained the eye movement effects from the first experiment. I hypothesized that the restriction of attention when viewing high-arousal slides was the result of local processing, and the broadening of attention when viewing low-arousal slides was the result of global processing. However, whether the local or global processing bias was induced on a trial-by-trial basis (Experiment 2), or in a blocked design (Experiment 3), local and global processing did *not* interact with eye movements during encoding, or subsequent memory effects in eye movements. Given these results, local and global processing did not appear to be related to the patterns of eye movements made when viewing emotional or non-emotional slides, or the subsequent memory effects that can be demonstrated in eye movements. However, results from these two experiments differed in important ways.

In Experiments 2 and 3, different subsequent memory effects were observed. In Experiment 2, when participants made box size judgments shortly after viewing each

IAPS slide, the same pattern of results was observed as in the first experiment.

Whereas a broadening of attention – more fixations of shorter duration – predicted subsequent memory for non-emotional scenes, a relative restriction of attention to the emotionally salient part of the slide predicted memory for emotional slides. In other words, the subsequent memory effect in eye movements was dependent on emotional arousal. However, this was not true in the blocked design Navon letter experiment. Instead, a broadening of attention – more fixations of shorter duration – predicted memory for *both* low- and high-arousal slides. Importantly, this occurred even though the same patterns of eye movements during encoding were observed as in previous experiments. Experiment 4 helped to explain this finding.

### *Boundary Conditions*

Experiments 3 and 4 provide boundary conditions on the subsequent memory effects observed for high-arousal slides in the first two experiments. There are two important effects to note in these two experiments. First, for high-arousal slides, attention was restricted at encoding in the same ways as in the first two experiments. Second, the subsequent memory effect for high-arousal slides was different than in the first two experiments – rather than a restriction of attention predicting memory, a *broadening* of attention predicted memory, just as for low-arousal slides. In tandem, these two effects highlight an important component of the subsequent memory effects observed in the first two experiments. Highly detailed representations of emotion-provoking objects are stored *only* when two conditions are met: when attention is restricted to emotion-provoking parts *and* when emotional arousal systems are engaged.

In Experiments 3 and 4, only the first condition was met. Eye movements, in terms of the number, length, and duration of fixations, were restricted in the same ways as in prior experiments. However, for both emotional and non-emotional scenes, greater numbers of fixations predicted subsequent memory. Possibly because attention was divided between Navon letter judgments in Experiment 3, or because there was no task-relevant necessity to attend to emotional information in Experiment 4, all pictures were treated as non-arousing, in terms of how eye movements predicted memory.

#### *Disentangling Valence and Arousal Effects in Emotional Memory and Attention*

One common theme in emotion research, and in the preceding experiments, concerns the nebulous effects of emotional valence on memory and attention. Whereas arousal effects on memory are so commonly found as to be generally accepted, there is still some debate about whether the occasionally found valence effects on memory are spurious (e.g., Mather & Sutherland, 2009), or reflect a real, if small, effect (e.g., Kensinger, 2009). In the current experiments, for example, the attention-restricting effects of arousal on eye movements were largely due to negative slides. Across all experiments, the average effect size  $d$  for attention-restricting effects in eye movements was 2.1 for negative slides (ranging from .8 to 3.04) and .51 for positive slides (ranging from .32 to .67). Although generally arousal effects in eye movements occur for both negative and positive slides, in the experiments reported here, the effect is larger and more stable for negatively valenced slides. Possibly in part because of this uncertainty about the effects of positive and negative valence, a continuing issue in many studies of emotion and memory is that they use only negative stimuli (e.g., Kensinger et al., 2006),

even though most theories of emotional effects on memory are arousal-based (e.g., Cahill & McGaugh, 1998).

One explanation for the uncertainty of valence effects on memory involves the extent to which approach and withdrawal emotional systems are activated by emotional stimuli. Generally, arousal responses to positively valenced pictures are more state-dependent than to negatively arousing pictures. For example, smokers who have abstained from smoking prior to study rate pictures of cigarettes as more positively arousing than smokers who do not abstain prior to study, pointing to a role for desire and satiation in responses to positive stimuli (Engelmann, 2010). Similar effects have been demonstrated when comparing the responses to pictures of food made by participants who have recently eaten and those who have not (Harmon-Jones & Gable, 2009), or via electrophysiological and fMRI measures of emotional arousal (Engelmann, 2009; Harmon-Jones & Gable, 2009). In some sense, this is not surprising – most of us have likely experienced the monetary consequences of visiting the grocery store when hungry. The negative, aversive emotional system, in contrast, is relatively more immune to state changes, because threatening stimuli should *always* be threatening. Not being frightened of a venomous snake in front of you because you just saw one five minutes earlier would not be an evolutionarily adaptive response; indeed, it is difficult to conceptualize what it means to be “satiated” with threat. Because of the state-dependent nature<sup>6</sup> of the appetitive system, positively arousing emotional pictures should be expected to be much more volatile in effectively eliciting emotional

---

<sup>6</sup> Of course, *trait*-dependent differences can be observed for all types of stimuli. Doctors might be relatively inured to mutilation, and arachnophobics are sensitive to spiders. Dessert chefs might not find cakes to be arousing regardless of their current motivational state; it is perhaps best left to the imagination what types of stimuli an adult film director no longer finds arousing.

responses, an effect that could become exacerbated if small numbers of participants or stimuli are used.

Unfortunately, this is also a difficult issue to experimentally control. First, such effects are content-specific. Abstaining smokers *only* rate smoking-related pictures more positively than non-abstinent smokers, not all positive pictures (Engelmann, 2010). For studies employing a broad range of emotional pictures, there is likely no single measure of motivational state that can account for the individual, state-dependent differences in arousal induced by the different categories of positive pictures. One solution would be to only use pictures from a particular category (e.g., Harmon-Jones & Gable, 2009), thus allowing for an easier control (e.g., using food pictures and requiring a fast before the experiment). However, this approach does not work for broad ranges of stimuli, and measures of emotional arousal (e.g., ERP, fMRI, skin conductance, pupillometry, even participant arousal ratings) are likely too noisy to provide confirmation of emotional engagement on a trial-by-trial basis. Valence effects may continue to prove problematic to clarify.

#### *Varied Influences of Emotional Arousal on Cognitive Processing*

Theories of emotional memory should take into consideration the various ways in which emotion can influence both the encoding and storage of memories. In brief, emotion influences visual perception and the locus of visual selective attention in the short-term, and in the long-term influences the consolidation of emotional memories. These effects are all important in determining the information that is stored, and the detail with which it is encoded, in emotional memories.

Emotion often enhances or facilitates visual perception and attention. Contrast sensitivity is enhanced briefly following the presentation of an emotional (but not neutral) face (Phelps, Ling, & Carrasco, 2006). When an emotionally arousing white-noise blast is heard shortly before viewing a series of high- and low-contrast letters, reporting of high-contrast letters is increased compared to when no noise precedes the letters (Mather & Sutherland, 2011). ERP components such as the early posterior negativity (Schupp et al., 2004) or late positive potential (Dolcos & Cabeza, 2002) that are of larger amplitude when viewing emotional stimuli are thought to reflect enhanced visual or semantic processing of emotional stimuli. Generally, mechanistic explanations for these effects are lacking, though some current theories hold that the “enhancing” effects of emotion on visual processing arise due to the increased release of norepinephrine elicited by arousing stimuli (see e.g., De Martino, Strange, & Dolan, 2008). Emotion has other effects on cognitive processing as well.

Emotion influences where attention is directed. One of the primary aspects of “weapon focus” theories is that attention is spatially directed towards weapons or other arousing objects in the environment. This is true in terms of eye movements for scenes with weapons (e.g., Loftus et al., 1987), and eye movements were restricted when viewing all types of emotional slides in each of the four experiments described here. In addition, emotional objects are found more quickly than neutral objects in visual search tasks (e.g., Öhman et al., 2001). Thus, emotion-provoking stimuli both guide attention to a particular location *and* enhance or facilitate the processing of objects at that location. But emotion can also influence memory in the long-term.

Emotional arousal influences the consolidation of emotional memories in the long-term. Though the hippocampus is largely responsible for consolidation of non-emotional episodic memories (see e.g., Squire & Zola-Morgan, 1991), consolidation of *emotional* memories seems to rely on a long-term interaction between the hippocampus and amygdala (Cahill & McGaugh, 1998; McGaugh, 2000; 2004). Emotional stimuli (in particular, negatively valenced stimuli) should activate the amygdala and release a cascade of neurotransmitters and stress hormones. Over time, as the memory is stored, an amygdala-hippocampal interaction serves to “stamp-in” the memory. Indeed, the amygdala is a critical structure for gist-based enhancements in emotional memory (e.g., LaBar & Phelps, 1998; Hamann, Cahill, McGaugh, & Squire, 1997; Adolphs, Tranel, & Denburg, 2000).

These three major influences of emotion on cognitive processing all help to explain emotional memory. In one sense, the effects of emotional arousal on perception and attention can be thought to influence how emotional scenes may be *encoded* in different ways than neutral scenes. This happens both in terms of facilitated visual processing of emotional parts, and a spatial restriction of attention to emotionally salient locations. In contrast, consolidation theories suggest a mechanism by which emotional memories are *stored* differently than non-emotional memories. Emotional effects on memory need to be considered from both perspectives: *what* is stored in memory, *how* it is consolidated, and perhaps most importantly, in what ways the two effects are intertwined or distinct. The experiments described here focused on encoding processes while explicitly avoiding long-term consolidation effects, but allow for a description of how emotional memories are initially encoded.

*A Scene-Representation Based Conception of Emotional Memory*

Crucially, the subsequent memory effects observed in these experiments provide a framework for understanding the varying effects of emotion on memory from a scene representation perspective. When viewing an emotionally arousing scene, attention is spatially restricted to emotion provoking aspects of the scene (e.g., a weapon), but not at most other elements of the scene (e.g., the weapon holder). When emotional reactions are engaged *and* attention is restricted to those emotion-provoking parts, a highly-detailed visually-specific object representation can be stored. Encoding of other objects in the scene is impaired either because attention is never oriented to them at all, or because the emotion provoking elements in the scene draw processing resources even when they are ignored (e.g., Schimmack, 2005). In contrast, for emotionally neutral scenes, attention is more evenly distributed across the scene, yielding roughly equivalent object representations, in which no particular aspect is highlighted. Thus, the stored memory representations underlying emotional and non-emotional memories are distinct, in that emotional memories are relatively more “parts-based” and non-emotional representations are relatively more “whole-scene” based.

This model makes clear several effects of emotion on memory. The central-peripheral memory tradeoff occurs because attention is allocated towards emotion-provoking elements at the expense of peripheral elements (and, in part, because the emotional element, even when ignored, should impair processing of peripheral aspects). More detailed object representations are encoded for those areas where attention is allocated, and less detailed representations are encoded for the peripheral areas. This



also explains why memory for single emotional objects (without the context of a scene) is more visually specific than memory for neutral objects (e.g., Kensinger et al., 2006; 2007): emotional arousal provides some “boost” to processing that allows for a more detailed object representation to be stored. Finally, it can also explain why memory for emotional and non-emotional scenes is similarly visually specific, as in the current experiments. If the central-peripheral tradeoff is a perfect tradeoff in terms of information, then any information lost from peripheral details is made up for by the more detailed representation of the central object. In other words, visually specific memory for an emotional scene is truly driven by a single object representation, whereas visually specific memory for neutral scenes relies on multiple, less detailed object representations. Memory representations of emotional and non-emotional scenes are qualitatively distinct, but, importantly, both representations are capable of supporting visually-specific memory.

This explanation of emotional memory effects also helps clarify an interesting memory effect in Experiment 4. In Experiment 4, visually-specific memory for low-arousal pictures was *greater* than visually-specific memory for high-arousal scenes. Why might this happen? If a lack of task demands caused high-arousal scenes to elicit less emotional arousal than in past experiments, then, for those high-arousal slides, participants were engaging in relatively *ineffective* encoding strategies. Attention was restricted to individual parts, but they were not experiencing high levels of emotional arousal – thus, there was no “boost” to the visual processing of those objects. In other words, something like a parts-centric representation was being stored for what were, in practice, non-emotional scenes. Such an encoding strategy would be expected to

decrease visually-specific memory relative to low-arousal scenes, as it did in Experiment 4.

### *Limitations*

Several methodological limitations should be taken into account when interpreting these results. First, in this series of studies, visually-specific memory was operationalized by using a mirror-reflection manipulation. Though this is a common method in memory research (e.g., Standing et al., 1970; Lawson, 2004), there are many other picture manipulations that can also be used to test for visually-specific memory, including size changes (e.g., Cooper et al., 1992), color changes (Cave, Bost, & Cobb, 1996), contrast or illumination changes (Srinivas, 1996), and token changes or object deletions within a scene (e.g., Hollingworth & Henderson, 2002). A reflection manipulation has the benefit of maintaining the same visual details, such that normative ratings on IAPS slides should be the same for original and mirror-reversed versions of the picture; emotional reactions to the slide could be altered when the color, contrast, or size of the slide is changed. Despite this, it may be important to consider different approaches for testing visual specificity of memory in future studies.

A second limitation is the use of “emotional sides” in analyzing restriction of attention. Though using the time spent fixating on the emotional side of the slide is especially useful in controlling for noise in eye tracking calibration and/or degradation of calibration during the experiment, it is also a very coarse measurement. An underlying assumption of using this measure is that when participants spend more time fixating on the emotional side of an IAPS slide, they are fixating on emotion-provoking

elements within the scene. But this assumption is not necessarily true. A participant may be fixating on the “emotional side” of the slide, but *not* fixating on an emotional part (e.g., a gun). Similarly, because some emotional scenes have more than one emotion-provoking part, even when a participant is *not* fixating on the “emotional side,” they may still be fixating on an emotionally arousing part of the scene. Defining more restricted locations of emotionally salient objects would help to alleviate these concerns.

A final limitation is the memory test procedure. Because recognition performance for pictures is typically near ceiling, brief presentation times (33 ms) were used during the test phase to reduce performance and generate the incorrect trials necessary for subsequent memory analyses. However, these brief presentations may lower recognition performance because the task is perceptually difficult, not necessarily because memory itself is decremented. However, other methods that might typically be used to lower recognition performance may prove even more problematic. Increasing the delay between the encoding and test phases would reduce memory performance, but also introduce consolidation effects. Decreasing the presentation time during encoding would also reduce the number of eye movements made. Finally, adding a secondary task during the encoding phase would make interpretations of eye movements difficult.

### *Future Directions*

One interesting question raised by these results is the role of consolidation in emotional memory. As discussed above, there are significant differences in how emotional memories are consolidated when compared with emotionally neutral memories. In the current experiment, I focused on how emotional and non-emotional

memories might differ in terms of how they are encoded, and minimized any consolidation effects by conducting the memory test immediately after the encoding phase was completed. It would be interesting to examine how the subsequent memory effects demonstrated here play out over a long-term consolidation of the memory. One possibility is that only those emotional memories for which attention was restricted during encoding will receive the “benefit” of the enhanced consolidation, meaning that the arousal-dependent subsequent memory effects found here with short-delay memory tests would be replicated over longer delays. On the other hand, the “stamping in” of emotional memories may occur independently of the way attention was allocated at encoding, meaning that over the long-term, the eye movement based subsequent memory effects observed here could be diminished.

fMRI measures might help clarify the ways that encoding of emotional and non-emotional memories differ. There is some evidence that, with regard to object processing, the functions of the fusiform gyrus are lateralized. The right fusiform seems to respond more strongly to specific details about objects, such as the size, color, orientation, and the like; the left fusiform gyrus, in contrast, responds to more general object features (such as category information; see e.g., Garoff, Slotnick, & Schacter, 2005). Given this, greater activity in the right fusiform may underlie the encoding of highly-detailed object representations in emotional memory, an especially interesting concept given theories that emotion processing is biased towards the right hemisphere (see e.g., Damasio, 1995 for a review).

### *Conclusion*

In conclusion, the current experiments provide insight into the role of attention and eye movements in encoding visually-specific memories. Importantly, the results from the first two experiments demonstrate that there are two distinct “pathways” by which visually-specific memories can be stored, depending on whether a scene is emotionally arousing or emotionally neutral. In Experiments 2 and 3, there was no evidence that these patterns of eye movements underlying visually-specific memory are the result of local or global processing biases for the scenes. Lastly, in Experiments 3 and 4, boundary conditions were established on these effects, demonstrating that for high-arousal scenes, attention must be spatially restricted to a particular location while systems of emotional reactivity are also engaged, in order to store a visually-specific memory. Future research should focus on the way these effects of attentional allocation at encoding interact with known mechanisms for long-term consolidation of emotional memories, and work to specify a mechanism by which such attention restricting and facilitating effects occur.

## References

- Adolphs, R., Cahill, L., Schul, R., & Babinsky, R. (1997). Impaired declarative memory for emotional material following bilateral amygdala damage in humans. *Learning & Memory, 4*, 291-300.
- Adolphs, R., Denburg, N. L., & Tranel, D. (2001). The amygdala's role in long-term declarative memory for gist and detail. *Behavioral Neuroscience, 115*, 983-992.
- Adolphs, R., Tranel, D., & Buchanan, T.W. (2005). Amygdala damage impairs emotional memory for gist but not details of complex stimuli. *Nature Neuroscience, 8*, 512-518.
- Adolphs, R., Tranel, D., & Denburg, N. (2000). Impaired emotional declarative memory following unilateral amygdala damage. *Learning & Memory, 7*, 180-186.
- Anderson, A.K., & Phelps, E.A. (2001). Lesions of the human amygdala impair enhanced perception of emotionally salient events. *Nature, 411*, 305-309.
- Antes, J.R., & Penland, J.G. (1981). Picture context effects on eye movement patterns. In D.F. Fisher, R.A. Monty, & J.W. Senders (Eds.), *Eye movements: Cognition and visual perception* (pp. 157-170). Hillsdale, NJ: Erlbaum.
- Baumann, N., & Kuhl, J. (2005). Positive affect and flexibility: Overcoming the precedence of global over local processing of visual information. *Motivation and Emotion, 29*, 123-134.
- Berntsen, D., & Thomsen, D.K. (2005). Personal memories for remote historical events: accuracy and clarity of flashbulb memories related to World War II. *Journal of Experimental Psychology: General, 134*, 242-257.

- Biederman, I. (1987). Recognition-by-components: A theory of human image understanding. *Psychological Review*, 94, 115-147.
- Blank, M.P. & Marsolek, C.J. (2006, April). Making a “picture perfect” memory: How do affective responses to emotion provoking scenes affect the visual specificity of subsequent memory? Presented at the Cognitive Neuroscience Society Annual Meeting, San Francisco, CA. *Journal of Cognitive Neuroscience*, 17. (Suppl.), 179.
- Bohn, A., & Berntsen, D. (2007). Pleasantness bias in flashbulb memories: Positive and negative flashbulb memories of the fall of the Berlin Wall among East and West Germans. *Memory & Cognition*, 35, 565-577.
- Bradley, M.M., Cuthbert, B.N., & Lang, P.J. (1996). Picture media and emotion: Effects of a sustained affective context. *Psychophysiology*, 33, 662-670.
- Bradley, M.M., Greenwald, M.K., Petry, M.C., & Lang, P.J. (1992). Remembering pictures: Pleasure and arousal in memory. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, 18, 379-390.
- Brewer, J. B., Zhao, Z., Desmond, J. E., Glover, G. H., & Gabrieli, J. D. E. (1998). Making memories: Brain activity that predicts how well visual experience will be remembered. *Science*, 281, 1185-1187.
- Bridgeman, B., Hendry, D., & Stark, L. (1975) Failure to detect displacements of the visual world during saccadic eye movements. *Vision research*, 15, 719-722.
- Brohawn, K.H., Offringa, R., Pfaff, D.L., Hughes, K.C., & Shin, L.M. (2010). The neural correlates of emotional memory in posttraumatic stress disorder. *Biological Psychiatry*, 68, 1023-1030.

- Brown, J.M. (2003). Eyewitness memory for arousing events: Putting things into context. *Applied Cognitive Psychology, 17*, 93-106.
- Brown, R., & Kulik, J. (1977). Flashbulb memories. *Cognition, 5*, 73-99.
- Buchanan, T.W. & Tranel, D. (2008). Stress and emotional memory retrieval: Effects of sex and cortisol response. *Neurobiology of Learning and Memory, 89*, 134-141.
- Burke, A., Heuer, F., & Reisberg, D. (1992). Remembering emotional events. *Memory & Cognition, 20*, 277-290.
- Cahill, L., Gorski, L., & Le, K. (2003). Enhanced memory consolidation with post-learning stress: Interaction with the degree of arousal at encoding. *Learning & Memory, 10*, 270-274.
- Cahill, L., & McGaugh, J.L. (1995). A novel demonstration of enhanced memory associated with emotional arousal. *Consciousness and Cognition, 4*, 410-421.
- Cahill, L., & McGaugh, J.L. (1998). Mechanisms of emotional arousal and lasting declarative memory. *Trends in Neuroscience, 21*, 294-299.
- Cave, C.B., Bost, P.R., & Cobb, R.E. (1996). Effects of color and pattern on implicit and explicit picture memory. *Journal of Experimental Psychology: Learning, Memory, & Cognition, 22*, 639-653.
- Center for the Study of Emotion and Attention [CSEA-NIMH]. (1999). The international affective picture system: Digitized photographs. Gainesville: University of Florida, Center for Research in Psychophysiology.
- Christianson, S. Å. (1987). Emotional and autonomic responses to visual traumatic stimuli. *Scandinavian Journal of Psychology, 28*, 83-87.



- Christianson, S. Å. (1989). Flashbulb memories: Special but not so special. *Memory & Cognition*, *17*, 435-443.
- Christianson, S. Å., & Loftus, E. F. (1991). Remembering emotional events: The fate of detailed information. *Cognition & Emotion*, *5*, 81-108.
- Christianson, S., Loftus, E.F., Loftus, G.R., & Hoffman, H. (1991). Eye fixations and accuracy in detail memory of emotional versus neutral events. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *17*, 693-701.
- Cohen, G., Conway, M. C., & Maylor, E. A. (1994). Flashbulb memories in older adults. *Psychology and Aging*, *9*, 454-463.
- Colgrove, F. (1899). Individual memories. *American Psychologist*, *10*, 228-235.
- Conway, A. R. A., Skitka, L. J., Hemmerich, J. A., & Kershaw, T. C. (2009). Flashbulb memory for September 11, 2001. *Applied Cognitive Psychology*, *23*, 605-623.
- Cooper, L.A., Schacter, D.L., Ballesteros, S., & Moore, C. (1992). Priming and recognition of transformed three-dimensional objects: Effects of size and reflection. *Journal of Experimental Psychology: Learning, Memory, & Cognition*, *18*, 43-57.
- Curci, A., & Luminet, O. (2009). Flashbulb memories for expected events: a test of the emotional integrative model. *Applied Cognitive Psychology*, *23*, 98-114.
- Damasio, A.R. (1995). Toward a neurobiology of emotion and feeling: Operational concepts and hypotheses. *The Neuroscientist*, *1*, 19-25.
- De Martino, B., Strange, B., & Dolan, R.J. (2008). Noradrenergic modulation of human attention for emotional and neutral stimuli. *Psychopharmacology*, *197*, 127-136.

- Dolcos, F., & Cabeza, R. (2002). Event-related potentials of emotional memory: Encoding pleasant, unpleasant, and neutral pictures. *Cognitive, Affective, and Behavioral Neuroscience*, 2, 252-263.
- Dodson, C. S., Johnson, M. K., & Schooler, J. W. (1997). The verbal overshadowing effect: Source confusion or strategy shift? *Memory & Cognition*, 25, 129-139.
- Easterbrook, J.A. (1959). The effect of emotion on cue utilization and the organization of behavior. *Psychological Review*, 66, 183-201.
- Engelmann, J.M. (2010). Psychophysiological and fMRI investigations of tobacco cue reactivity. Unpublished doctoral dissertation, University of Minnesota, Minneapolis, MN.
- Engelmann, J.M., Radke, A.K., & Gewirtz, J.C. (2009). Potentiated startle as a measure of negative affective consequences of repeated exposure to nicotine in rats. *Psychopharmacology*, 207, 13-25.
- Fabiani, M., Karis, D., & Donchin, E. (1986). P300 and recall in an incidental memory paradigm. *Psychophysiology*, 23, 298-308.
- Farah, M.J., Wilson, K.D., Drain, M., & Tanaka, J.W. (1998). What is “special” about face perception? *Psychological Review*, 105, 482-498.
- Findlay, J.M. (2005). Covert attention and saccadic eye movements. In L. Itti, G. Rees, & J. Tsotsos (Eds.), *Handbook of the Neurobiology of Attention* (pp. 114-117). San Diego, CA: Elsevier.
- Friedman, A. (1979). Framing pictures: The role of knowledge in automatized encoding and memory for gist. *Journal of Experimental Psychology: General*, 108, 316-355.

- Gable, P.A., & Harmon-Jones, E. (2008). Approach-motivated positive affect reduces breadth of attention. *Psychological Science, 19*, 476-482.
- Garoff, R.J., Slotnick, S.D., & Schacter, D.L. (2005). The neural origins of specific and general memory: The role of fusiform cortex. *Neuropsychologia, 43*, 847-859.
- Green, D.M., & Swets, J.A. (1966). *Signal detection theory and psychophysics*. New York: Wiley.
- Grimes, J. (1996). On the failure to detect changes in scenes across saccades. In A.A. Kathleen (Ed.), *Perception: Vancouver studies in cognitive science* (pp. 89-110). New York: Oxford University Press.
- Hamann, S.B., Cahill, L., McGaugh, J.L., & Squire, L.R. (1997). Intact enhancement of declarative memory for emotional material in amnesia. *Learning & Memory, 4*, 301-309.
- Hamann, S.B., Cahill, L., & Squire, L.R. (1997). Emotional perception and memory in amnesia. *Neuropsychology, 11*, 104-113.
- Harmon-Jones, E., & Gable, P.A. (2009). Neural activity underlying the effect of approach-motivated positive affect on narrowed attention. *Psychological Science, 20*, 406-409.
- Henderson, J. M. (1997). Transsaccadic memory and integration during real-world object identification. *Psychological Science, 8*, 51-55.
- Henderson, J.M., & Hollingworth, A. (1999). The role of fixation position in detecting scene changes across saccades. *Psychological Science, 10*, 438-443.
- Henderson, J. M., & Hollingworth, A. (2003a). Eye movements, visual memory, and scene representation. In M. A. Peterson and G. Rhodes (Eds.), *Analytic and*

*holistic processes in the perception of faces, objects, and scenes* (pp. 356-383).

New York: Oxford University Press.

- Henderson, J.M., & Hollingworth, A. (2003b). Eye movements and visual memory: Detecting changes to saccade targets in scenes. *Perception & Psychophysics*, *65*, 58-71.
- Hirst, W., Phelps E. A., Buckner R. L., Budson A. E., Cuc A., Gabrieli J. D. E., et al. (2009). Long-term memory for the terrorist attack of September 11: Flashbulb memories, event memories, and the factors that influence their retention. *Journal of Experimental Psychology: General*, *138*, 161 – 176.
- Hollingworth, A. (2005). The relationship between online visual representation of a scene and long-term scene memory. *Journal of Experimental Psychology: Learning, Memory, & Cognition*, *31*, 396-411.
- Hollingworth, A., & Henderson, J.M. (2002). Accurate visual memory for previously attended objects in natural scenes. *Journal of Experimental Psychology*, *28*, 113-136.
- Hollingworth, A., Williams, C.C., & Henderson, J.M. (2001). To see and remember: Visually specific information is retained in memory from previously attended objects in scenes. *Psychonomic Bulletin & Review*, *8*, 761-768.
- Hsiao, J., & Cottrell, G.W. (2009). Not all visual expertise is holistic, but it may be leftist. *Psychological Science*, *20*, 455-463.
- Itti, L., & Koch, C. (2000). A saliency-based search mechanism for overt and covert shifts of visual attention. *Vision Research*, *40*, 1489-1506.

- Itti, L., & Koch, C. (2001). Computational modeling of visual attention. *Nature Reviews Neuroscience*, 2, 194-203.
- James, W. (1890). *The principles of psychology*. New York: Henry Holt.
- Kaestner, E.J., & Polich, J. (2011). Affective recognition memory processing and event-related brain potentials. *Cognitive, Affective, and Behavioral Neuroscience*, 11, 186-198.
- Kellermann, T.S., Sternkopf, M.A., Schneider, F., Habel, U., Turetsky, B.I., Zilles, K., & Eickhoff, S.B. (2011). Modulating the processing of emotional stimuli by cognitive demand. *Social Cognitive and Affective Neuroscience*. Advance online publication. Retrieved from <http://www.scan.oxfordjournals.org>
- Kensinger, E.A. (2009). Remembering the details: Effects of emotion. *Emotion Review*, 1, 99-113.
- Kensinger, E.A., & Choi, E.S. (2009). When side matters: Hemispheric processing and the visual specificity of emotional memories. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, 35, 247-253.
- Kensinger, E.A., Garoff-Eaton, R.J., & Schacter, D.L. (2006). Memory for specific visual details can be enhanced by negative arousing content. *Journal of Memory and Language*, 54, 99-112.
- Kensinger, E.A., Garoff-Eaton, R.J., & Schacter, D.L. (2007a). Effects of emotion on memory specificity: Memory trade-offs elicited by negative visually arousing stimuli. *Journal of Memory and Language*, 56, 575-591.

- Kensinger, E.A., Garoff-Eaton, R.J., & Schacter, D.L. (2007b). Effects of emotion on memory specificity in young and older adults. *Journal of Gerontology: Psychological Sciences, 62B*, 208-215.
- Kensinger, E.A., Garoff-Eaton, R.J., & Schacter, D.L. (2007c). How negative emotion enhances the visual specificity of a memory. *Journal of Cognitive Neuroscience, 19*, 1872-1887.
- Kensinger, E.A., Piquet, O., Krendl, A.C., & Corkin, S. (2005). Memory for contextual details: Effects of emotion and aging. *Psychology and Aging, 20*, 241-250.
- Kimchi, R. (1992). Primacy of wholistic processing and global/local paradigm: A critical review. *Psychological Bulletin, 112*, 24-38.
- Kimchi, R., & Palmer, S.E. (1982). Form and texture in hierarchically constructed patterns. *Journal of Experimental Psychology: Human Perception and Performance, 8*, 521-535.
- Koster, E.H.W., Crombez, G., Van Damme, S., Verschuere, B., & De Houwer, J. (2004). Does imminent threat capture and hold attention? *Emotion, 4*, 312-317.
- LaBar, K. S., & Cabeza, R. (2006). Cognitive neuroscience of emotional memory. *Nature Reviews Neuroscience, 7*, 54-64.
- LaBar, K.S., & Phelps, E.A. (1998). Arousal-mediated memory consolidation: Role of the medial temporal lobe in humans. *Psychological Science, 9*, 490-493.
- Lang, P. J., Bradley, M. M., & Cuthbert, B. N. (1997). Motivated attention: Affect, activation, and action. In P. Lang, R.F. Simons, & M. Balaban (Eds.), *Attention and orienting: Sensory and motivational processes* (pp. 97-136). Hillsdale, NJ: Erlbaum.

- Lang, P. J., Bradley, M. M., & Cuthbert, B. N. (1999). *International affective pictures system (IAPS): Instruction manual and affective ratings* (Tech. Rep. No. A-4). Gainesville: University of Florida, The Center for Research in Psychophysiology.
- Lang, P.J., Greenwald, M.K., Bradley, M.M., & Hamm, A.O. (1993). Looking at pictures: Affective, facial, visceral, and behavioral reactions. *Psychophysiology*, *30*, 261-273.
- Lawson, R. (2004). Depth rotation and mirror-image reflection reduce affective preference as well as recognition memory for pictures of novel objects. *Memory & Cognition*, *32*, 1170-1181.
- Liberzon I., Taylor, S.F., Fig, L.M., Decker, L.R., Koeppe, R.A., & Minoshima, S. (2000). Limbic activation and psychophysiologic responses to aversive visual stimuli: Interaction with cognitive task. *Neuropsychopharmacology*, *23*, 508-516.
- Lin, Z., & Han, S. (2008). Self-construal priming modulates the scope of visual attention. *The Quarterly Journal of Experimental Psychology*, *62*, 802-813.
- Lin, Z., Lin, Y., & Han, S. (2008). Self-construal priming modulates visual activity underlying global/local perception. *Biological Psychology*, *77*, 93-97.
- Loftus, E.F. (1979). *Eyewitness testimony*. Cambridge, MA: Harvard University Press.
- Loftus, E. F., & Burns, T. E. (1982). Mental shock can produce retrograde amnesia. *Memory & Cognition*, *10*, 318–323.
- Loftus, E. F., Loftus, G., & Messo, J. (1987). Some facts about “weapon focus.” *Law and Human Behavior*, *11*, 55–62.

- Loftus, G.R. (1972). Eye fixations and recognition memory for pictures. *Cognitive Psychology*, 3, 525-551.
- Loftus, G.R., & Mackworth, N.H. (1978). Cognitive determinants of fixation location during picture viewing. *Journal of Experimental Psychology: Human Perception and Performance*, 4, 565-572.
- Lundqvist, D., & Öhman, A. (2005). Emotion regulates attention: The relation between facial configuration, facial emotion, and visual attention. *Visual Cognition*, 12, 51-84.
- Mackworth, N.H., & Morandi, A.J. (1967). The gaze selects informative details within pictures. *Perception & Psychophysics*, 2, 547-552.
- Macrae, C.N., & Lewis, H.L. (2002). Do I know you? Processing orientation and face recognition. *Psychological Science*, 13, 194-196.
- Mather, M., & Sutherland, M. (2009). Disentangling the effects of arousal and valence on memory for intrinsic details. *Emotion Review*, 1, 118-119.
- Matin, E. (1974). Saccadic suppression: A review and an analysis. *Psychological Bulletin*, 81, 899-917.
- McCloskey, M., Wible, C. G., & Cohen, N. J. (1988). Is there a special flashbulb-memory mechanism? *Journal of Experimental Psychology: General*, 117, 171-181.
- McConkie, G.W., & Currie, C.B. (1996). Visual stability across saccades while viewing complex pictures. *Journal of Experimental Psychology: Human Perception and Performance*, 22, 563-581.
- McGaugh, J.L. (2000). Memory – A century of consolidation. *Science*, 287, 248-251.



- McGaugh, J.L. (2004). The amygdala modulates the consolidation of memories of emotionally-arousing experiences. *Annual Reviews of Neuroscience*, 27, 1-28.
- Navon, D. (1977). Forest before the trees: The precedence of global features in visual perception. *Cognitive Psychology*, 9, 353-383.
- Neisser, U., & Harsch, N. (1992). Phantom flashbulbs: False recollections of hearing the news about Challenger. In E. Winograd & U. Neisser (Eds.), *Affect and accuracy in recall: Studies of "flashbulb" memories* (Vol. 4, pp. 9–31). New York: Cambridge University Press.
- Ochsner, K. N. (2000). Are affective events richly “remembered” or simply familiar? The experience and process of recognizing feelings past. *Journal of Experimental Psychology: General*, 129, 242–261.
- Öhman, A., Flykt, A., & Esteves, F. (2001). Emotion drives attention: Detecting the snake in the grass. *Journal of Experimental Psychology: General*, 130, 466-478.
- Öhman, A., Juth, P., & Lundqvist, D. (2009). Finding the face in a crowd: Relationships between distractor redundancy, emotion, and target gender. *Emotion*, 24, 1216-1228.
- O'Regan, J.K. (1992). Solving the “real” mysteries of visual perception: The world as an outside memory. *Canadian Journal of Psychology*, 46, 461-488.
- O'Regan, J.K., Deubel, H., Clark, J.J., & Rensink, R.A. (2000). Picture changes during blinks: looking without seeing and seeing without looking. *Visual Cognition*, 7, 191-211.

- Otten, L.J., Henson, R.N., & Rugg, M.D. (2001). Depth of processing effects on neural correlates of memory encoding: Relationship between findings from across- and within-task comparisons. *Brain, 124*, 399-412.
- Paller, K.A., Kutas, M., & Mayes, A.R. (1987). Neural correlates of encoding in an incidental learning paradigm. *Electroencephalography and Clinical Neurophysiology, 67*, 360-371.
- Palomba, D., Angrilli, A., & Mini, A. (1997). Visual evoked potentials, heart rate responses and memory to emotional pictorial stimuli.
- Parkhurst, D., Law, I., & Niebur, E. (2002). Modeling the role of salience in the allocation of overt visual selective attention. *Vision Research, 42*, 107-123.
- Phelps, E.A., Ling, S., & Carrasco, M. (2006). Emotion facilitates perception and potentiates the perceptual benefits of attention. *Psychological Science, 17*, 292-299.
- Pillemer, D.B. (1984). Flashbulb memories of the assassination attempt on President Reagan. *Cognition, 16*, 63-80.
- Posner, M.I., & Petersen, S.E. (1990). The attention system of the human brain. *Annual Review of Neuroscience, 13*, 25-42.
- Pratto, F., & John, O.P. (1991). Automatic vigilance: The attention-grabbing power of negative social information. *Journal of Personality and Social Psychology, 61*, 380-391.
- Reingold, E.M. (2002). On the perceptual specificity of memory representations. *Memory, 10*, 365-379.

- Reisberg, D., Heuer, F., McLean, J. and O'Shaughnessy, M. (1988). The quantity, not the quality, of affect predicts memory vividness. *Bulletin of the Psychonomic Society*, 26, 100-103.
- Rensink, R.A. (2000). The dynamic representation of scenes. *Visual Cognition*, 7, 17-42.
- Rensink, R.A., O'Regan, J.K., & Clark, J.J. (1997). To see or not to see: The need for attention to perceive changes in scenes. *Psychological Science*, 8, 368-373.
- Riggs, L., McQuiggan, D.A., Farb, N., Anderson, A.K., & Ryan, J.D. (2011). The role of overt attention in emotion-modulated memory. *Emotion*. Advance online publication. Retrieved from <http://www.psycnet.apa.org>
- Rugg, M.D. (1995). ERP studies of memory. In MD Rugg, MGH Coles (Eds.), *Electrophysiology of Mind: Event-Related Brain Potentials and Cognition*. Oxford University Press.
- Ryan, J.D., & Cohen, N.J. (2004). The nature of change detection and online representation of scenes. *Journal of Experimental Psychology: Human Perception and Performance*, 30, 988-1015.
- Salvucci, D.D., & Goldberg, J.H. (2000). Identifying fixations and saccades in eye-tracking protocols. In *Proceedings of the Eye Tracking Research and Applications Symposium* (pp. 71-78). New York: ACM Press.
- Schaefer, A., Fletcher, K., Pottage, C.L., Alexander, C., & Brown, C. (2009). The effects of emotional intensity on ERP correlates of recognition memory. *Neuroreport*, 20, 319-324.

- Schimmack, U. (2005). Attentional interference effects of emotional pictures: Threat, negativity, or arousal? *Emotion, 5*, 55-66.
- Schneider, W., Eschman, A., & Zuccolotto, A. (2002). E-Prime: User's Guide. Pittsburgh: Psychology Software Tools Inc.
- Schupp, H.T., Junghöfer, M., Weike, A.I., & Hamm, A.O. (2004). The selective processing of briefly presented affective pictures: An ERP analysis. *Psychophysiology, 41*, 441-449.
- Scott, D., & Ponsoda, V. (1996). The role of positive and negative affect in flashbulb memory. *Psychological Reports, 79*, 467-473.
- Shafer, A., Iordan, A., Cabeza, R., & Dolcos, F. (2011). Brain imaging investigation of the memory-enhancing effect of emotion. *Journal of Visualized Experiments, 51*, doi:10.3791/2433
- Simons, D.J., & Levin, D.T. (1997). Change blindness. *Trends in Cognitive Sciences, 1*, 261-267.
- Snodgrass, J.G., & Corwin, J. (1988). Pragmatics of measuring recognition memory: Applications to dementia and amnesia. *Journal of Experimental Psychology: General, 117*, 34-50.
- Soares, S.C., Esteves, F., Lundqvist, D., & Öhman, A. (2009). Some animal specific fears are more specific than others: Evidence from attention and emotion measures. *Behavioral Research Therapy, 47*, 1032-1042.
- Squire, L.R., & Zola-Morgan, S. (1991). The medial temporal lobe memory system. *Science, 253*, 1380-1386.

- Srinivas, K. (1996). Contrast and illumination effects on explicit and implicit measures of memory. *Journal of Experimental Psychology: Learning, Memory, & Cognition*, 22, 1123-1135.
- Standing, L. (1973). Learning 10,000 pictures. *Quarterly Journal of Experimental Psychology*, 25, 207-222.
- Standing, L., Conezio, J., & Haber, R.N. (1970). Perception and memory for pictures: Single-trial learning of 2500 visual stimuli. *Psychonomic Science*, 19, 73-74.
- Talarico, J.M., & Rubin, D.C. (2003). Confidence, not consistency, characterizes flashbulb memories. *Psychological Science*, 14, 455-461.
- Talarico, J. M. & Rubin, D. C. (2009). Flashbulb memories result from ordinary memory processes and extraordinary event characteristics. In O. Luminet and A. Curci (Eds.), *Flashbulb Memories: New Issues and New Perspectives*. New York: Psychology Press.
- Tanaka, J.W., & Farah, M.J. (1993). Parts and wholes in face recognition. *Quarterly Journal of Experimental Psychology: Human Experimental Psychology*, 42, 225-245.
- Tanaka, J.W., & Sengco, J.A. (1997). Features and their configuration in face recognition. *Memory & Cognition*, 25, 583-589.
- Thompson, P. (1980). Margaret Thatcher: A new illusion. *Perception*, 9, 483-484.
- Tooley, V., Brigham, J.C., Maass, A., & Bothwell, R.K. (1987). Facial recognition: Weapon effect and attentional focus. *Journal of Applied Social Psychology*, 17, 845-859.

- Torralba, A., Oliva, A., Castelhana, M.S., & Henderson, J.M. (2006). Contextual guidance of eye movements and attention in real-world scenes: The role of global features in object search. *Psychological Review, 113*, 766-786.
- Underwood, G., & Foulsham, T. (2006). Visual saliency and semantic incongruency influence eye movements when inspecting pictures. *Quarterly Journal of Experimental Psychology, 59*, 1931-1949.
- Walther, D., & Koch, C. (2006). Modeling attention to salient proto-objects. *Neural Networks, 19*, 1395-1407.
- Waring, J.D., & Kensinger, E.A. (2009). Effects of emotional valence and arousal upon memory trade-offs with aging. *Psychology and Aging, 24*, 412-422.
- Waring, J.D., Payne, J.D., Schacter, D.L., & Kensinger, E.A. (2010). Impact of individual differences upon emotion-induced memory trade-offs. *Cognition and Emotion, 24*, 150-167.
- Wessel, I., & Merckelbach, H. (1998). Memory for threat-relevant and threat-irrelevant cues in spider phobics. *Cognition and Emotion, 12*, 93-104.
- Wolfe, J.M. (1997). In a blink of the mind's eye. *Nature, 387*, 756-757.
- Yarbus, A.L. (1967). *Eye movements and vision*. New York: Plenum Press.

## Appendix

Complete list of IAPS slides used in all experiments.

### *Negative High-Arousal Slides*

### *Negative Low-Arousal Slides*

<u>IAPS Slide</u>	<u>Description</u>	<u>IAPS Slide</u>	<u>Description</u>
1030	Snake	1112	Snake
1040	Snake	1230	Spider
1070	Snake	2230	Sad face
1080	Snake	2520	Elderly man
1220	Spider	2590	Old woman
1301	Dog	2682	Billy club
1302	Dog	2700	Woman
2661	Baby	2750	Bum
3160	Pussy eyes	2752	Alcoholic lady
3210	Surgery	2753	Alcoholic man
3250	Chest cavity	2810	Boy
3280	Dentist	3300	Wheel chair
5940	Lava	6000	Prison
6020	Electric chair	6010	Jail
6200	Aimed gun	6241	Gun
6211	Gun	7920	Car accident
6242	Gang	9000	Cemetery
6244	Military man	9001	Cemetery
6410	Aimed gun	9010	Barbed wire
6571	Car jacking	9041	Scared girl
6940	Tank	9080	Wires
7380	Pizza roaches	9101	Cocaine
8230	Boxer	9110	Puddle
9042	Stick through lip	9190	Woman
9120	Oil fires	9265	Hung man
9160	Soldier	9280	Smoke
9230	Oil fire	9290	Garbage
9411	Boy	9330	Garbage
9490	Corpse	9390	Dishes
9620	Shipwreck	9404	Soldiers
9621	Ship	9440	Skulls
9630	Bomb	9830	Cigarettes

*Positive High-Arousal Slides**Positive Low-Arousal Slides*

<u>IAPS Slide</u>	<u>Description</u>	<u>IAPS Slide</u>	<u>Description</u>
1560	Hawk	1500	Dog
1650	Jaguar	1510	Dog
1811	Chimps	1540	Cat
4599	Couple	1590	Horse
4606	Couple	1600	Horse
4609	Couple	1601	Giraffes
4610	Couple	1660	Gorilla
4640	Couple	1721	Lion
4641	Couple	1740	Owl
4650	Couple	1920	Porpoise
4653	Couple	2170	Feeding
4669	Couple	2250	Neutral Baby
4672	Couple	2311	Mom & child
4680	Nudes	2510	Old woman
4690	Nudes	2540	Mother/baby
5260	Water falls	2650	Boy
5270	Niagara Falls	4700	Couple
5450	Space shuttle	5300	Galaxy
5470	Astronaut	5593	Clouds
5480	Fireworks	5594	Clouds w/ sun
5623	Windsurfers	5820	Mountains
5626	Hang glider	5990	Clouds
5700	Mountains	5991	Clouds
8040	Diver	7200	Brownie
8130	Pole vaulter	7280	Wines
8161	Hang glider	7286	Pancakes
8200	Water skier	7352	Pizza
8210	Boat	7390	Popsicles
8300	Plane	7470	Pancakes
8380	Athletes	8032	Ice skaters
8470	Gymnast	8330	Trophy
8531	Red car	8461	Running teens