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# Memory for Emotional Images: Mechanisms of Episodic Processing and its Psychophysiological Correlates

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Loma Linda University  
School of Science and Technology  
in conjunction with the  
Faculty of Graduate Students

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Memory for Emotional Images: Mechanisms of Episodic Processing and its  
Psychophysiological Correlates

by:

Gregory E. Devore

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A Dissertation submitted in satisfaction of  
the requirements for the degree of  
Doctor of Philosophy in Clinical Psychology

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September 2011

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Each person whose signature appears below certifies that this dissertation in his/her opinion is adequate, in scope and quality, as a dissertation for the degree of Doctor of Philosophy.

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## ABSTRACT OF THE DISSERTATION

Memory for Emotional Images: Mechanisms of Episodic Processing and its  
Psychophysiological Correlates

By

Gregory E. Devore

Doctor of Philosophy, Graduate Program in Clinical Psychology  
Loma Linda University, September 2011  
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Negative emotional stimuli are usually better remembered than neutral emotional stimuli. Previous examination of binding theory found no differences in recall for pure lists of taboo and neutral words. A similar result was found with equivalent recognition memory performance between pure lists of negative, positive, and neutral images. The current research is designed to test the predictions of binding theory using negative and neutral visual stimuli in mixed lists. A rapid serial visual presentation paradigm and recognition memory item-discrimination tasks are used. Binding theory predicts differences in recognition memory performance between arousing and neutral images in mixed lists, but not pure lists. Skin conductance and heart rate data are collected to understand the physiological counterparts of the psychological processes in episodic memory. Results found equivalent recognition memory performance between negative and neutral images in mixed and pure lists. A significant liberal response bias for negative over neutral images was observed across experiments. Skin conductance and heart rate measures did not correlate with recognition memory performance.

## Introduction

From an evolutionary perspective, automatic direction of attention toward emotional stimuli conveys an adaptive purpose in survival. Emotion's role in the prioritization of behavior necessary to survival increases the likelihood of the passing-on of genes. One of the key cognitive and physiological systems affecting behavior is emotion-linked memory. Emotion's role in the dynamics of memory has been widely studied in scientific literature (Cahill & McGaugh, 1998; Bradley et al., 1992; Gardiner, Ramponi, & Richardson-Klavehn, 2002; Hamann et al., 1999; Loftus & Burns, 1982). Supporting evolutionary theory, researchers generally agree that emotional information is better remembered than neutral information. A classic example of this comes from individuals who were alive when President Kennedy or Martin Luther King, Jr. was assassinated. Individuals typically remember the exact time, place, and what they were doing at the moment they heard the news. The strength of these memories differs in detail from other days on which important events did not occur (Brown & Kulik, 1977). Intuitively, it makes sense *why* emotion affects memory, but *how* it affects it is another question entirely. Understanding the fundamental cognitive mechanisms and the physiological correlates of how emotional information is processed in episodic memory is the goal of this literature review and research.

Two prominent theories explain the mechanisms of emotion-linked memory: arousal theory and binding theory. Arousal theory generally states that the strength of a memory is proportional to the importance of the stimulus and associated arousal level (Cahill & McGaugh, 1998). Binding theory, proposed by Hadley & MacKay (2006), generally states that the strength of a memory is based on the emotional salience of



concurrent and sequential contexts of a stimulus. Essentially this means that the process of encoding a memory (i.e., binding stimulus information in memory) and its relative strength is affected by multiple factors including other stimuli nearby and the order in which stimuli are presented over time. The temporal context of stimulus information is also stated to be bound by an episodic ‘peg’. Binding theory differs from arousal theory in the detail in which it explains the cognitive mechanisms of emotion-linked memory, although both theories explain enhanced memory performance for emotional stimuli through nearly identical physiological systems (Cahill & McGaugh, 1998; Kensinger & Corkin, 2004). The details of arousal theory and binding theory will be elaborated later in this review; however binding theory is the primary theory under investigation due to its predictive utility in the paradigm of the proposed research.

Also under investigation are the physiological correlates of emotion processing in the mind. Understanding the interplay between cognitive and physiological processes helps to explain the plasticity, adaptability, and variability in human experience and behavior. Analyzing the psychophysiology of a process also eliminates alternative hypotheses if the data comports with predictions about orchestrated actions of an organism. This helps to sharpen the remaining hypotheses and reduce error in conceptualization and measurement (Capioppo, Tassinari, & Bernston, 2007).

Conducting this research is important because it elucidates the fundamental mechanisms of how emotion affects memory. In a broader perspective, knowledge of this type informs theories of human information processing, which has commercial, military, and clinical utility. Examples may include how to organize and prioritize information in a car or plane heads-up display, or understanding how to provide interventions for clinical

populations involving memory-based trauma. In order to understand how the current research informs theories of human information processing, a review of the relevant literature on emotion, attention-mediated memory, physiological correlates of emotion, and arousal and binding theory is warranted. Following this review the proposed research's methodology in exploring emotion-linked processes in human memory will be discussed.

### **Emotion and the Biphasic Organization of Behavior**

Generally speaking, the human brain is a complex organ designed to remember information in order to decode patterns and predict outcomes necessary to maintain the processes of life. The brain prioritizes and organizes the importance of information through the primary mechanism of emotion. Intuitively, everyone knows what emotion is, but operationally defining it and its theoretical constructs present a greater challenge. Emotions are complex reactions involving not only subjective feelings such as joy, anger, or sorrow, but also physiological reactions such as a pounding heart, sweaty palms, tense muscles, facial flushing, frowning, and smiling. The link between emotional experience and bodily action is evident in the root of the word *emotion*. It comes from the Latin verb *motere*, which means "to move." Emotions motivate animals to act and react, and in animal research this action is described by two basic parameters: direction and intensity.

The first parameter is the direction of the action, where stimuli that promote survival (e.g., food, support) generate approach behaviors, and stimuli that threaten survival prompt withdrawal, escape, or avoidance. The dimensions of approach and avoidance in emotion research are known as the biphasic approach to emotion (Schneirla,

1959; Konorski, 1967; Lang, Bradley, & Cuthbert, 1990). The biphasic approach has been described in many ways (i.e., preservative and protective; appetitive and aversive), however emotion researchers agree that there are only two primary motivational systems. Since descriptors overlap significantly in their theoretical constructs, they will simply be referred to here as approach and avoidance.

The intensity of an approach or avoidance behavior is mapped by the continuums of valence (i.e., pleasant and unpleasant) and arousal (i.e., calm and excited) (Lang, Bradley, & Cuthbert, 1990). Valence essentially indexes which motivational system is activated by a stimulus or task (i.e., approach “pleasant,” or avoidant “unpleasant”), whereas judgments of arousal index the degree of activation in each motivation system depending on the context. Describing emotion as dimensions such as direction and intensity is different from classical views of specific emotional states such as fear, anger, or joy, or physiological reactions such as a pounding heart or sweaty palms. Studies of emotional states and their effect on a cognitive process (e.g., traumatic events and flashbulb memory studies) typically have methodological challenges that are not well-suited for the veridical study of what dimensions of emotion influence cognitive processes. A dimensional view of emotion allows researchers to understand the contribution of the valence dimension, arousal dimension, their interaction, and approach and avoidance behaviors to various cognitive processes. The literature reviewed here uses the principles of a biphasic approach of emotion in order to study the mechanisms underlying the effects of emotion on the cognitive process of memory, specifically episodic memory.

The proposed research uses a biphasic methodology to understand how emotion affects memory. A brief review of the history of the biphasic approach to emotion is presented here.

The biphasic organization of behavior was formerly proposed by Schneirla (1959). His orientation was biological and evolutionary:

In general, what we shall term the A-type of mechanism, underlying approach, favors adjustments such as food-getting, shelter-getting, and mating; the W-type, underlying withdrawal, favors adjustments such as defense, huddling, flight, and other protective reactions. Also, through evolution, higher psychological levels have arisen in which through ontogeny such mechanisms can produce new and qualitatively advanced types of adjustment to environmental conditions, (p. 4)

Konorski (1967, p. 9) also advocated a biphasic model. Unconditioned reflexes were organized into two classes, preservative (e.g., ingestive, copulation, and nurture of progeny) and protective (e.g., withdrawal from or rejection of noxious agents), based primarily on their biological, motivational role. He pointed out that both types of responses involved arousal. Dickinson and Dealing (1979) developed Konorski's dichotomy into two opponent motivational systems, aversive and attractive, each activated by a different but equally wide range of unconditioned stimuli. These systems were held to have reciprocal inhibitory connections that modulated learned responses and reactions to new, unconditioned input. Research following Dickinson and Dealing's work supported the biphasic approach to emotion by primarily studying verbal behavior (Ortony, Clore, & Collins, 1988; Shaver, Schwartz, Kirson, & O'Connor, 1987).

Lang, Bradley, and Cuthbert (1990) sought to extend the biphasic organization of emotion beyond the study of language to biobehavioral dimensions. By studying the role of emotion using a startle reflex paradigm, they found that the startle reflex was greater

during a fear state and diminished in a pleasant emotional context, and is determined by valence of the stimuli (i.e., pleasant to unpleasant). Affect was modulated using picture stimuli taken from the International Affective Picture System (IAPS) (Lang, Öhman, & Vaitl, 1988). Based on their data, they proposed that affective behavior is organized biphaseically at all levels of response complexity, from cognitive events to exteroceptive reflexes (Lang, Bradley, & Cuthbert, 1990). They concluded that emotional valence is a general information processing category, with sensory, central, and response processing implications, stating, however, that reflexes other than startle must be confirmed to be modulated by valence.

Although this study helped to understand the role of valence in startle modulation, they did not effectively explore the dimension of arousal, leaving the role of arousal in startle modulation unclear. To explore this Cuthbert, Bradley, and Lang (1996) used an acoustic startle probe during picture viewing and found that blink potentiation during unpleasant content and blink diminution during pleasant content were strongest for picture contents high in arousal. Like valence, they were able to conclude that arousal is a general information processing category. Through these experiments the role of arousal and valence in mapping approach and avoidance states were becoming clearer in emotion and motivation research, and will be covered in more detail later.

## **Emotion and Memory**

The relationship between emotion and memory has been studied extensively in cognitive science. Many laboratory studies have confirmed that emotional events are better remembered than neutral ones. Thus, if participants are shown a series of

emotional and neutral stimuli, they will later recall or recognize a greater proportion of the emotional stimuli than of neutral stimuli. This emotional memory enhancement effect has been replicated in studies in which real life events, pictures, words, sentences, and narrated slide shows have been used (see Buchanan and Adolphs, 2002; Hamann, 2001, for reviews). In assessing traumatic events, for example, several researchers have found that traumatic situations were better remembered than neutral ones (Brown and Kulik, 1977; Christianson & Loftus, 1987; Bohannon, 1988). The apparent clarity and stability of traumatic memories (e.g., JFK assassination, Space Shuttle Challenger explosion, 9/11 terrorist attacks) has led some researchers to posit the term “flashbulb memory,” or a memory that accurately records the details of an event. Recent examination of the purported clarity and stability of flashbulb memories revealed that they are not as stable as once thought. In a longitudinal memory study of the September 11<sup>th</sup>, 2001 terrorist attacks, strong emotional reactions elicited by the event were remembered more poorly over time than nonemotional features such as where and from whom someone learned of the event (Hirst et al., 2009). One of the primary methodological weaknesses of this study (and other emotional state studies) was that it could not identify what emotional dimensions accounted for the differences in memory performance over time. How do the effects of valence and arousal play a role in memory performance?

### **Contributions of Valence and Arousal**

Running parallel to data of improved memory for traumatic events or stimuli are a number of experiments have found that memory retrieval is most sensitive to differences in arousal. In a classic memory study highlighting the role of arousal in memory

performance (Loftus & Burns, 1982), two groups of participants saw either a violent or non-violent film. Details for neutral information in both recall and recognition tasks were lost following the violent film condition. The results indicated that the loss of information was due to a failure of encoding, rather than retrieval, and the authors stated that the distinctiveness of an event is not sufficient for failure to encode, it had to be arousing. A similar result was found for pleasant materials in experiments using verbal stimuli (Matlin & Stang, 1978). Bradley and colleagues (1992) found that in a recall task of picture stimuli the dimension of arousal (as indexed by verbal ratings and electrodermal responses) accounted for the most variability in remembering emotional stimuli. In a digit-parity task reaction times were significantly slower for sexually arousing words compared to threat and neutral words. Words' arousal ratings, but not their valence ratings, predicted the amount of interference (Aquino & Arnell, 2007). Moreover, parity reaction times for individual words were also related to memory for the word on a surprise memory test.

Ochsner (2000) proposed that the dimension of arousal is particularly important because some of the distinctiveness provided by emotion stems from the physiological responses resulting from the stimuli. Ochsner stated that emotional arousal is a critical mediator of the memory enhancement effect. Arousal can be manipulated in a variety of ways including pharmacological (see Cahill et al., 1994) and stimulus manipulations using visual images (Bradley, Greenwald, Petry, & Lang, 1992; Cahill & McGaugh, 1998). The importance of arousal, however, does not negate a contribution by valence.

Kensinger & Corkin (2003) found in a series of experiments using emotional words that recall rates were higher for emotional words that had low to moderate arousal

and high valence, as well as words with high arousal and low valence, although the magnitude of the effect was greater for words evoking arousal. The influence of valence can also be seen in the way threatening stimuli, such as snakes and angry faces, attract attention (Lang, Davis, & Öhman, 2000). Arousal has also been found to be an important predictor of memory performance using pictures (Bradley, Codispoti, Cuthbert, & Lang, 2001). There are many explanations for why arousal enhances memory performance. Lang and colleagues (1993) found that people tend to look at arousing pictures longer, suggesting that they process them more deeply. Bradley et al.'s (2003) finding that arousing stimuli produce more cortical activity also suggests that arousing stimuli are processed more deeply. An fMRI study conducted by Kensinger & Corkin (2004) suggested that there are two emotional routes to memory, each with distinct neural processes for arousal and valence. Correlations with memory performance found that arousing stimuli activated the amygdalar-hippocampal network, whereas neutral non-arousing and negative non-arousing stimuli activated the prefrontal cortex-hippocampal network. The general conclusion is that memory performance is enhanced by arousing stimuli, with valence providing contributory effects. In fact, all five sensory modalities (smell, taste, vision, hearing, and touch) have been found to affect the strength of memory associations as a function of arousal, with better memory performance for more arousing stimuli as determined by subsequent memory recall or recognition (D'Argembeau & Van der Linden, 2005; Koster et al., 2004; Miles & Hodder, 2005; Reales & Ballesteros, 1999; Wang & Chang, 2004). But how does arousal enhance memory performance?



## **Emotion and Attention-Mediated Memory**

The general scientific consensus is that emotional arousal automatically directs attention toward stimuli to determine its relevance and subsequent importance. Over a hundred years ago William James (James, 1890) captured this when he wrote:

It is the taking possession by the mind, in clear and vivid form, of one out of what seem several simultaneous possible objects or trains of thought. Focalization, concentration of consciousness are of its essence. It implies withdrawal from some things in order to deal effectively with others. (p. 403-404)

William James noticed that the brain cannot possibly absorb all of the sensory information in our environment. The brain selectively attends to certain aspects of our environment while relegating others to the background because attention is a limited resource (Broadbent, 1958).

A classic theory on the relationship of arousal and human information processing is the Yerkes-Dodson Law, which states that a curvilinear relationship exists between arousal and performance (in this case, memory performance). It dictates that performance increases with arousal but only to a certain point. If arousal levels become too high, there is a decrement in performance (Yerkes & Dodson, 1908). This relationship affects a person's ability to remember and retrieve information. This has been supported by laboratory studies which have studied the effect of stress on memory (Mendl, 1999).

Biologically the structures of the brain primarily responsible for the processing of incoming stimuli as a function of attention are the reticular activating system, prefrontal cortex, amygdala, and the hippocampus. The reticular activating system (RAS) is the base of the attentional network, and is a system of structures that innervates the neural cortex to stay tuned in the waking state (Maruzzi & Magoun, 1949). The prefrontal cortex

(PFC), located right behind the eyes, is responsible for executive functions such as inhibition of behavior (e.g., regulation of emotion), planning, and selective attention. The amygdala (located deep within the temporal lobes) is considered the ‘emotional sentinel’ because of its ability to activate the ‘fight or flight’ response in animals. The ‘fight or flight’ response is a primitive survival reflex designed to assist rapid decision making to either run from danger, or to stay and fight. This reflex does not directly engage the more complex (and slower) higher order decision-making structures of the brain (LeDoux, 1992). This reflex response is in part due to the amygdala’s coordinated role with the endocrine system, which releases the neurochemicals epinephrine and norepinephrine. The release of these neurochemicals primes the body for action and also influences other brain regions, such as the hippocampus (located in the temporal lobes) to strengthen memory for what is happening. In essence, it is the hippocampus that initially stores things, but the amygdala is responsible for the flavor of those memories (the emotional context) (LeDoux, 2000). Understanding the dynamic processes that bind these three structures has led to the development of modern theories of attention, memory, and emotion. The two primary theories are arousal theory and binding theory.

### **Arousal Theory**

One of the leading theories of affective processing that explains the relationship between the RAS, PFC, amygdala, and hippocampus is arousal theory. Lang and colleagues examined experiential, behavioral, and physiological responses to affective pictures (Bradley, Codispoti, Cuthbert, & Lang, 2001; Bradley et al., 2003; Keil et al., 2002; Lang, 1995; Lang, Greenwald, Bradley, & Hamm, 1993). The evidence suggests

that responses to affective pictures form two factors that vary with the level of valence and the level of arousal of the pictures. Some index measures, such as experiences of pleasure and displeasure, facial expressions, the startle probe, and heart rate, vary with the valence of the picture. In contrast, interest ratings, voluntary exposure, skin conductance, the magnitude of initial heart rate deceleration after picture onset, the P300 in the event-related potential (ERP), and activation in the occipital cortex in functional magnetic resonance imaging scans vary with the arousal level of pictures.

The correlates of arousal have been linked to attention. For example, ratings of interest are likely to be related to attention because people attend more to interesting stimuli in their environments. Voluntary exposure is another important variable. Lang and colleagues (1993) noticed that when participants were allowed to watch pictures as long as they wanted, viewing time was longest for especially arousing pictures independent of their valence. That is, participants chose to look for a longer time at both erotic stimuli and gory pictures of mutilated bodies (Lang et al., 1993). Other studies suggest that arousal is also linked to attention when people are not voluntarily allocating attention to emotional stimuli. Gronau, Cohen, and Ben-Shakhar (2003) found that skin conductance, another correlate of arousal (Lang et al., 1993), was related to interference effects in the emotional Stroop task. Personally relevant words delayed response latencies in the emotional Stroop task and elicited a stronger skin conductance response than control stimuli.

Anderson (2005) provided further evidence for the importance of arousal in predicting performance on an attentional task, using the attentional-blink paradigm. Attentional blink is the phenomenon that people are often unable to report the second

target if it is presented 200–500 ms after the first target, and all stimuli are presented in a rapid sequence. In his experiment each word was presented for 100 ms. Participants had to detect two words that were marked by a specific color and report the two target words after all stimuli were presented. Anderson demonstrated that the attentional blink is attenuated if the second target is an affective word. Importantly, the affective modulation of the attentional blink was related to the arousal level of the word rather than to its valence.

In summary, several independent lines of research suggested that the arousal level of emotional stimuli is closely linked to the influence of emotional stimuli on attention. As negative stimuli and threatening stimuli tend to be more arousing than other stimuli (Lang et al., 1993), it is possible that the significant effects in these studies were also the result of arousal.

To test arousal theory, Lang and colleagues had all participants rate all stimuli on arousal. In addition, pictures of attractive male and female models were added to the stimulus set. These pictures fulfilled several important purposes. First, arousal is strongly correlated with the degree of unpleasantness of negative pictures (Bradley, Codispoti, Cuthbert, & Lang, 2001; Lang et al., 1993). That is, mild unpleasant pictures are less arousing than moderate unpleasant pictures, and strong unpleasant pictures are more arousing than moderate unpleasant pictures. Thus, it is virtually impossible to separate arousal from degree of unpleasantness. However, for positive pictures, the correlation between arousal and extremity of valence is weaker (Bradley, Codispoti, Cuthbert, & Lang, 2001; Lang et al., 1993). In particular, sexual pictures are more arousing than other pleasant pictures (e.g., a tropical beach). Thus, sexual pictures were needed to separate

effects of arousal from effects of valence. Second, sexual stimuli provided an opportunity to rule out artifacts that may arise from the use of ready-made stimuli that vary in other characteristics (e.g., familiarity, distinctiveness, complexity) that may influence attention (Harris & Pashler, 2004). For model pictures, arousal effects and artifacts were hypothesized to produce different effects. Whereas arousal effects should have depended on the match or mismatch of participants' sex and sex of model, artifacts should have produced main effects of the stimulus materials. As a result, only arousal predicted stronger effects for pictures of opposite-sex models than for pictures of same-sex models.

In sum, this body of research found that arousal theory predicts that affective influences on attention are predicted by arousal ratings of affective pictures. On the basis of previous studies of arousal, arousal theory also predicts that the strongest effects for strong unpleasant pictures and erotic pictures because these pictures elicit the highest level of arousal (Bradley, Codispoti, Cuthbert, & Lang, 2001). If higher arousal ratings of pictures influence attention, then arousal must also influence attention-mediated processes like memory.

Cahill and McGaugh (1998) found that emotionally arousing events predict lasting declarative memory. They explained better memory for emotional stimuli as a function of an emotional stimulus engaging the amygdala, whereupon it releases neurotransmitters or stress hormones that act on the hippocampus to facilitate encoding of that emotional stimulus. The strength of the memory is proportional to the importance of the stimulus and associated arousal level. This finding has subsequently been supported by a variety of studies. In a study of sex differences and memory processing, researchers found that emotional arousal enhances long-term memory for arousing stories differently

in men and women. Women tend to remember peripheral details of arousing stories with primary activation in the left amygdala/hemisphere function, and men remember central information with primary activation of the right amygdala/hemisphere function (Cahill & van Stegeren, 2003). In a positron emission tomography (PET) study examining the amygdala's role in memory performance using pleasant and aversive pictures, results indicated that bilateral amygdala activity during memory encoding was correlated with enhanced episodic recognition memory for both pleasant and aversive visual stimuli relative to neutral stimuli, and was specific to emotional stimuli. Enhancement of episodic memory was in part through modulation of the amygdala on the hippocampus (Hamann, Ely, Grafton, & Kilts, 1999). These findings were replicated by Kensinger & Corkin (2004) using fMRI and neutral, negative and nonarousing (e.g., sorrow, mourning, etc), or negative and arousing (e.g., rape, slaughter, etc) words. They found that arousing and negative nonarousing words were better remembered than neutral words, with arousing words activating an amygdala-hippocampal network and the negative nonarousing and neutral words activating a PFC-hippocampal network. The authors stated that the enhanced memory for arousing items is mediated by an amygdala-hippocampal network, which may reflect relatively automatic effects of emotion on memory, and may be specifically engaged when emotional stimuli elicit an arousal effect.

In summary, arousal theory posits that arousing stimuli automatically capture attention and affect attention-mediated processes such as memory. Several studies have demonstrated that memory for arousing items is enhanced due to the engagement of the amygdala-hippocampal network. Although it appears that the effect of arousal is general with respect to enhanced memory performance, several studies have demonstrated that

emotion-mediated attention processes are much more dynamic than previously thought.

The following review of binding theory elucidates the subtleties of how emotional stimuli affect attention-mediated processes.

## **Binding Theory**

Binding theory developed out of a vein of research using Stroop, rapid visual presentation tasks (RSVP), immediate memory, and lexical decision tasks. Binding theory seeks to explain the mechanisms of resource allocation of attention using data from several prominent studies that used these experimental paradigms. To understand the development of binding theory and its relationship to arousal theory, a brief review of the paradigms and the data in these studies is warranted.

The Stroop task is a demonstration of interference in the reaction time of a task using colored words. For example, subjects are asked to name the color of the text a word is printed in and not the word itself. Reaction time is slower in Stroop tasks where subjects must name a word printed in a different color than what is written (i.e.: RED printed in blue color). RSVP is a method of displaying information (generally text or pictures) using a limited space in which each item of information is displayed briefly in sequential order. Typically subjects are asked to search across the time-domain for a target rather than across space. Alternatively, subjects are asked to pay attention and try to remember all of the stimuli presented in the stream. Their memory is then tested for what was presented. The other two paradigms include the lexical decision and immediate memory task. The lexical decision task involves measuring how quickly people classify

stimuli as words or non-words. The immediate memory task involves measuring the accuracy in deciding if a stimulus was the same as a preceding stimulus.

The Stroop task has been incredibly successful in providing information facilitating the development of theories of parallel processing for studying emotion, attention, and memory (MacLeod, 1991). Its established empirical history makes it a good choice for studying the effect of emotional stimuli on reaction time and recall memory. For example, in clinical populations, particularly people with phobias, words associated with a particular phobia (i.e.: mouse, for people afraid of mice) took longer to color name than neutral control words (Dalgleish & Watts, 1990). These clinical Stroop effect experiments may be difficult to replicate and have constrained generalizability given the limited clinical populations and context of presentation (MacLeod and Hodder, 1998). In the general population, studies using unpleasant emotional words such as ‘death’, ‘fear’, ‘haunt’, and ‘holocaust’ have been shown to have a longer color naming times than neutral words. This emotional Stroop effect however, has not been consistently replicated and in order for the effect to be observed, time pressure (i.e.: response within 240 ms or less after presentation of a word) may be essential (Sharma & McKenna, 2001). It has also been argued that the emotional Stroop effect is caused by a threat-driven generic slowdown, instead of a selective attention mechanism usually associated with the classic Stroop phenomenon (Algom, Chajut, & Lev, 2004). An earlier study comports with this notion, reporting no emotional Stroop effect using pleasant words, and suggesting that instead of representing emotionality, the effect may be a result of negative affect (McKenna & Sharma, 1995). Supporting this perspective is the taboo Stroop effect, which occurs when people take more time to name taboo words than



neutral words (Siegrist, 1995). The finding that color naming for neutral words is shorter than for taboo words has been observed to be robust across individuals and contexts (Williams, Mathews, & MacLeod, 1996).

A number of theories have been proposed to explain the emotional Stroop effect. The first set of theories takes a resource-based perspective which suggests emotionally arousing stimuli automatically attract more attentional resources, limiting the capacity available for processing and responding to other stimuli (Bower, 1992). This in turn slows reaction time. This perspective leaves many relevant questions unanswered however. Primarily, what is the role or effect of reduced attentional resources in memory formation? A second theory suggests the emotionality of the words in the emotional Stroop task creates a threat-driven general state change in arousal. This explanation is offered because the emotional Stroop was found to only reliably occur in comparisons of trials blocked by emotion. Thus, the emotional Stroop effect is not found or is not nearly as strong in heterogeneous blocks containing both emotional and neutral word trials (Algom, Chajut, & Lev, 2004).

MacKay et al, (2004) addressed the resource-based perspective's questions by proposing a Binding theory using a Stroop task, a lexical decision task, and an immediate memory task. In a neutral and taboo word location-specific Stroop task, MacKay & Ahmetzanov (2005) found superior location memory for taboo relative to neutral words. The authors claim emotional reactions trigger binding mechanisms that link a specific source of emotion to salient contextual aspects such as location. In this experiment they hypothesized with respect to word location that attention and emotion 'represent the glue that helps bind features together' (MacKay & Ahmetzanov, 2005). Resource-allocation

reduction theories predict that lexical decision times will be faster for taboo than neutral words. However, in the lexical decision task, MacKay et al. (2004) found no difference in lexical decision time. The results indicated that allocation of limited-capacity attentional resources to taboo words is task specific, occurring for taboo Stroop tasks, but not for lexical decision tasks. This contradicted a resource-based allocation reduction hypothesis which would have predicted longer reaction times for taboo vs. neutral words. Binding theory however, which proposes that emotional information receives priority in processing and binds with contextual representations, predicts equivalent lexical decision time results for taboo vs. neutral words because lexical decision responses are unrelated to contextual aspects of word meaning. In contrast, the color-name responses in taboo Stroop tasks require processing the font color, a salient contextual aspect of a word that elicits the help of binding mechanisms. In a lexical decision task, the response is that a taboo word is a word; there is no requirement to process contextual information.

In a third experiment MacKay et al. (2004) found impaired immediate recall of neutral words immediately before and after a taboo word in rapidly presented lists. These word-before and word-after effects also supported the binding hypothesis that taboo words capture or preempt the binding mechanisms for encoding the context of occurrence. MacKay concluded that emotion-linked stimuli engage an emotional reaction system (i.e.: the amygdala to hippocampus) that prioritizes the activation of binding nodes (i.e., words in long-term memory) based on their emotional salience for both concurrent and sequential contexts (Doerksen & Shimamura, 2001; MacKay & Ahmetzanov, 2005). Essentially this means that at fast presentation rates the brain cannot consolidate each word with its episodic context before beginning to process the

subsequent word. In such cases, emotionally salient words receive priority processing. As a result, neutral words are lost from memory whereas taboo words (due to their salience) are remembered better during subsequent recall. Binding theory has since been supported by subsequent experiments using an RSVP task where memory for taboo words was better than neutral words when presented in heterogeneous lists, but not in homogeneous lists (Hadley and MacKay, 2006).

### **Generalizing the Predictions of Binding Theory: Beyond Taboo Words**

As reviewed, the predictions of binding theory have been empirically supported under paradigms that use taboo words. Hadley and MacKay (2006) posited a more general binding theory proposition that incorporates the priority-binding assumption and applies to emotion-linked stimuli other than taboo words and list recall. They stated that under binding theory, conceptual representations of emotion-linked stimuli engage an emotional reaction system that prioritizes the activation of binding nodes for linking the source of the emotion to salient aspects of both sequential and concurrent contexts, including the color and spatial location of the stimulus. Evidence for the generalization of binding theory beyond taboo words and list recall exists in the literature (for a review see McDaniel & Bugg, 2008). Within the scope of the current research, key experiments using pictures or recognition memory tasks will be discussed here.

Dewhurst and Parry (2000) conducted two experiments to investigate the effects of emotional stimuli on recollective experience in recognition memory. They utilized the *remember-know* procedure, where participants are given a test of recognition memory and instructed to assign their positive recognition decisions to either “remember” (R) or

“know” (K) response categories. They are asked to make an R response if they can recollect details of an item’s study presentation, or a K response if the item feels familiar but they cannot consciously recollect its earlier presentation. Findings from studies that have used the *remember-know* procedure indicate that R and K responses represent functionally distinct components of recognition memory (Rajaram & Roediger, 1997). This study also included a “guess” (G) option, as this has been found to remove guesses from the K response category (Gardiner, Java, & Richardson-Klavehn, 1996). In this experiment Dewhurst and Parry (2000) used emotional (positive and negative) and neutral words. They did not include taboo words. Their first experiment found that words judged to evoke a positive and emotional negative response were associated with more “remember” responses than emotional neutral words when presented in mixed lists. In experiment two the effects of emotional stimuli were eliminated when participants studied pure lists of either all emotional or all neutral words. This experiment parallels Hadley and MacKay’s (2006) mixed and pure list findings, generalizing the predictions of binding theory to a recognition memory paradigm using the remember-know procedure.

The temporal retention of information in memory using emotional visual stimuli was studied by D’Argembeau & Van der Linden (2005). In one non-RSVP task subjects viewed three sets of 21 images for 2000 ms each with a 750 ms inter-stimulus interval. Between each set a 3 minute break occurred where subjects performed arithmetic operations. Subjects were asked to remember the images but were not asked to remember which set any of the images appeared. When subjects confirmed that they recognized an image, a list-discrimination task was presented asking which image was in which set. The

researchers found emotionally arousing images had greater temporal memory accuracy than neutral images in the list-discrimination task. This was found for both negative and positive arousing images; however negative arousing images were remembered with the most temporal accuracy (D'Argembeau & Van der Linden, 2005). The results in this study cannot be directly attributed to binding theory however, because it did not employ a pure list condition. Without a pure list condition demonstrating equivalent memory performance for arousing and neutral stimuli, the predictions of arousal theory (i.e., enhanced memory for arousing stimuli) cannot be separated from the predictions of binding theory. What their study does suggest is that contextual parts of arousing stimuli (i.e., temporal information) may be encoded more strongly than neutral stimuli. A similar effect was found in an experiment assessing episodic memory for color information and spatial location (Doerksen & Shimamura, 2001). These results support the predictions of binding theory that sequential and concurrent (i.e., temporal) information of arousing stimuli are more strongly encoded over non-arousing stimuli, and that information is bound to an episodic 'peg'.

Gruhn and colleagues (2005) investigated age-related differences in memory performance between young and older adults using a RSVP mixed and pure list paradigm with emotional words. They found memory performance in a word recall task to be significantly better in a mixed list presentation than pure list. A follow-up experiment using picture stimuli with a recognition memory task found similar results, although older adults tended to remember fewer negative pictures than younger adults (Gruhn, Scheibe, & Baltes, 2007).

In 2008, I conducted two experiments to test the general priority-binding hypothesis in recognition and temporal (i.e., episodic) memory using an RSVP paradigm (500ms presentation, 500ms inter-stimulus interval). Experiment A used negative and neutral picture stimuli and experiment B used positive and neutral picture stimuli. All images were selected from the IAPS on the basis of arousal and valence (Lang et al., 1999). Each experiment was organized into three sets including two lists in each set; a high arousal list (negative images in experiment A, positive images in experiment B) and a neutral low arousal list (used in both experiments). Participants were streamed 18 images per set (9 arousing and 9 neutral images) in the encoding phase. Between each list a cancellation distractor task was used to prevent active image rehearsal. Between each set an arithmetic task was also used to delineate each set (along with a message prompt) as well as to prevent active image rehearsal. Following the encoding phase a recognition and temporal memory task were presented. In the recognition memory task participants were asked if they had seen the image before or not. This was then followed by a confidence rating. Information for temporal memory was assessed using a list discrimination task which occurred after all the images were viewed in the recognition task. Only images presented during the encoding phase were presented for the list-discrimination task. Participants were asked in which set each image was presented. This was followed by a confidence rating. Participants were not informed that they would be tested for temporal information prior to the list-discrimination task.

Results indicated equivalent recognition and temporal memory performance in both experiments for arousing (positive and negative) and neutral images. As expected, in both experiments participants mean confidence ratings for recognition memory

performance were higher for correct responses. Temporal confidence ratings were higher for correct responses with a main effect of valence (higher confidence for neutral over negative images) with no interaction. Overall, these results supported the predictions of binding theory and generalized the priority-binding hypothesis to recognition and temporal memory using picture stimuli in pure lists. The predictions of arousal theory did not comport with the observed results because arousal theory predicts enhanced memory performance for negative information, regardless of pure or mixed list presentation.

As reviewed, the generalized predictions of binding theory beyond taboo words and list recall has been supported in a number of studies. Confirming the results of Gruhn, Scheibe, & Baltes (2007) in a mixed list design is one goal of this research. By extending the predictions of binding theory to picture stimuli in mixed lists, increasing support for binding theory makes it the best theoretical explanation of emotional processing in the PFC-hippocampal and amygdala-hippocampal memory network.

### **Physiological Underpinnings of Emotion Processing**

Turning now to the physiological study of emotional processing, although arousal theory and binding theory may explain the cognitive mechanisms involved in emotion processing, the mind is viewed as having a biological substrate that interacts with the body. Understanding the interplay between these systems (both cognitive and physiological) helps to explain the plasticity, adaptability, and variability in human experience and behavior. Analyzing the psychophysiology of a process also eliminates alternative hypotheses if the data comports with predictions about orchestrated actions of an organism. This helps to sharpen the remaining hypotheses and reduce error in

conceptualization and measurement (Capioppo, Tassinari, & Bernston, 2007). Including psychophysiological methodology in the proposed research serves not only as a correlate to understanding the cognitive processes, but also to understand how the body responds to the demands of stimuli rapidly engaging the approach and avoidance systems (e.g., in a mixed list design of arousing and neutral stimuli). This section covers the theoretical and basic physiology of the approach and avoidance motivational systems, followed by the psychophysiological measures germane to the proposed research.

The modern study of the interplay between the mind and the body has been researched extensively for over a century, starting primarily with William James's hypothesis that physiological responses form the basis of emotional experience. He believed that the feelings of a physiological response were the emotion. In other words, a person is afraid because he runs. This hypothesis has not been supported despite several decades of experimentation, having been supplanted by the Cannon-Bard theory of emotion and later by the Schachter & Singer (1962) two-factor theory of emotion. Although the two-factor theory of emotion is intuitive for social psychological theory, its primary criticism is that it does not describe an emotional process in the central nervous system aside from the role of cognitive factors. The biphasic approach to emotion, as reviewed earlier, does account for emotional processes in the central nervous system by using the dimensions of arousal and valence to explain the approach and avoidance systems. As such, the literature reviewed in this section used a biphasic approach to emotion to explain the basic physiological correlates of the approach and avoidance systems.



The psychophysiological study of emotion has traditionally focused on autonomic and somatic outputs including heart rate, blood pressure, electrodermal, and muscle tension changes. These responses are proximally controlled by the peripheral nervous system and are innervated by nerves from the parasympathetic and sympathetic divisions. Although traditionally viewed as the mediator of the avoidance response, the sympathetic nervous system is now known to be activated in approach contexts such as sexual behavior and adventure seeking (Guyton & Hall, 1996; Zuckerman, 1982). These findings, among others, have informed modern psychophysiological research that has found both systems can be independently active, reciprocally controlled, or coactive (see Bradley & Lang, 2007).

The brain circuitry controlling sympathetic and parasympathetic activity occurs at every level of the central nervous system. Discussing in detail each of these structures and their associated pathways is beyond the scope of this review, however, briefly mentioning the primary physiological components and their known function serves as a useful framework to view the approach and avoidance systems. The hypothalamus controls sympathetic and parasympathetic responses involved in feeding, fleeing, fighting, and sexual activity. The periaqueductal central gray has been implicated in freezing and active defense behaviors such as attack or escape. One of the primary structures associated with emotion is the amygdala. It mediates associations involving motivationally relevant events, both positive and negative. Lesions of the amygdala eliminate fear behaviors and can create hypersexuality. Stimulation of the amygdala can produce rage, attack, and defense reactions (Aggleton, 1992). Extensive pathways connect to the amygdala from the thalamus (a sensory relay center), with outputs going to

the hypothalamus, periaqueductal central gray, the brainstem, the striatum, and cortical structures including the cingulate gyrus, frontal lobe, visual cortex, and more (Bradley & Lang, 2007). This neural organization highlights the central role of the amygdala in emotion processing, making it a key component of both approach and avoidance motivational systems.

Neurohormones play an integral role in approach and avoidance motivational systems, and are released by structures in the central nervous system. Examples of the effects by these two systems on different organs are mediated by the release of different neurotransmitters at the neuroeffector junction, with acetylcholine released by parasympathetic fibers (cholinergic) and noradrenaline released by sympathetic fibers (adrenergic). Subsequent actions (e.g., increase or decrease in heart rate) are also temporally differentiated by the fact that noradrenaline dissipates slowly whereas acetylcholine dissipates more rapidly. Thus, parasympathetic control will tend to activate specific organs with rapid, phasic effects, whereas sympathetic control is not only more diffuse but also somewhat longer-lasting (Bradley & Lang, 2007). Measuring the autonomic and somatic effects of sympathetic and parasympathetic function gives insight into the effects of pleasure and arousal on physiological response.

### **Measurement of Emotion**

One goal of this cognitive and psychophysiological study of emotion is to determine the relationship between perceptual inputs (varying in arousal and valence) and outputs (measured in a variety of different response systems such as electrodermal response, heart rate, and memory performance). Understanding the psychophysiology of

emotion relies on clearly defining the affective nature of the stimuli, determining the task context, and defining the measured output (Bradley & Lang, 2007). In the context of episodic memory, the affective nature of stimuli used in research predominantly involves words (e.g., taboo words, emotional words) and pictures taken from the IAPS (Lang, Bradley, & Cuthbert, 1999); this study will use pictures taken from the IAPS.

Determining task context is important because physiological reactions differ based on the paradigm being used, and extrapolating effects of emotion on psychophysiological response can be confusing if comparisons are not equivalent (Bradley & Lang, 2007). In the context of this research the comparison of physiological results to other perceptual studies (i.e., picture stimuli) will be used. Defining the measured output includes three systems: subjective report, overt action, and physiological response (Bradley & Lang, 2007). Subjective reports in this experiment include ratings of emotion (e.g., ratings of arousal, valence, dominance, and distinctiveness from 1 to 10). Overt behaviors such as freezing or running are frequently used in animal studies but not as often in human studies. In this study the overt behavior is a memory performance measure (e.g., accuracy). Physiological responses are measured in a variety of ways, including cardiovascular, electrodermal, gastric, reflex, and neurochemicals systems. This review covers the physiological changes of heart rate and electrodermal output to perceptual stimuli.

### **Physiological Reactions to Pictures: Heart Rate and Electrodermal Responding**

When viewing pictures, a classic triphasic pattern of heart rate response occurs that includes an initial deceleration followed by an acceleratory response and then a

secondary deceleration (Lang & Hnatiow, 1962). Affective valence is the primary contributor to the amount of initial deceleration and subsequent acceleratory activity, with unpleasant stimuli producing the greatest initial deceleration (Winton, Putnam, & Krauss, 1984). Pleasant pictures (e.g., erotic pictures) have been found to have the greatest peak acceleration that is not due to differential initial deceleration when comparing pleasant and unpleasant pictures. These findings demonstrate a consistent positive correlation between ratings of pleasure (unpleasant vs. pleasant) and heart rate change (Bradley & Lang, 2007). The heart's ability to engage in acceleration and deceleration is because it is dually innervated by the sympathetic and parasympathetic nervous systems.

The electrodermal system, in contrast, is innervated solely by the sympathetic nervous system. This makes it a useful measure of activation of this autonomic nervous system component. Measurement of this system is typically conducted using skin conductance, which is the measure of the electrical resistance of the skin. The amount of skin conductance activity increases with the rated arousal of an emotional picture increases, regardless of its emotional valence (Bradley & Lang, 2007). This finding suggests that sympathetic nervous system reactivity is greater for emotionally arousing than neutral stimuli. Repeated exposure to the same or different picture stimuli results in significant habituation effects, with the size of electrodermal changes rapidly decreasing (Bradley, Lang, & Cuthbert, 1993).

Taken together, data obtained in the picture perception paradigm demonstrated that motivational variables of affective valence and arousal predominate in organizing physiological and subjective reports of affective reactions. Supporting this, a factor

analysis conducted on self-report, physiological, and behavioral measures has consistently produced a strong two-factor solution of valence and arousal (Lang et al., 1993). Results in the proposed research should corroborate the valenced-based triphasic pattern of heart response and the variability of skin conductance as a function of arousal.

## **Preliminary Studies**

### **Major Hypotheses, Aims, and Significance**

Rationale: This study builds on the previous research of the writer by testing and expanding the predictions of binding theory to episodic memory using pure and mixed lists of visual images. By incorporating physiological measures such as heart rate and skin conductance, this research also documents the physiological correlates of emotional processing and their correlation with episodic memory performance.

Although several studies have utilized pure and mixed list designs, only the taboo word research of Hadley & MacKay (2006) has explicitly tested the predictions of arousal theory and binding theory. To date, the writer's previous research using negative and neutral images in pure lists is the only known use of an RSVP task using picture stimuli to test the predictions of a general priority-binding theory against the predictions of arousal theory. Testing the predictions of binding theory using picture stimuli is important because visual stimuli are more complex than words and binding theory may not apply in the same way.

Words are stimuli with at least three factors: phonology, orthography, and semantics. Binding theory clarifies that it is not the acoustics, phonology, or orthography factors that are bound to the episodic context, but the semantic representation of that word in memory (Hadley & MacKay, 2006). Binding theory further explains that emotional stimuli are better recalled or recognized as a function of priority binding in memory. According to binding theory emotional stimuli are more 'important' than neutral stimuli, and this importance is functionalized by previously established direct

amygdala to hippocampal links. This brief vignette explains some of the factors that may influence the ‘importance’ of emotional stimuli.

If a young boy says a taboo word and is reprimanded by his parents, the emotional meaning of that word (as stressed by the parental reprimand) is characterized or ‘flavored’ by the amygdalo-hippocampal connections (also called the emotional reactive system) as ‘important’ and is then linked in the cortex as a part of lexical node representations (comprised of orthographic, phonological, and semantic features). When that boy subsequently encounters that word it activates the lexical node which is now linked to and activates the suprathreshold emotional reaction system as a part of the semantic representation.

Semantic representation of novel visual images in memory is significantly more complex than in words; however it is hypothesized that visual images activate semantic representations and engage the emotional reaction system in similar ways to words when image features are analyzed by the perceptual system.

Binding theory states that activation of the emotional reaction system gives processing priority of emotional stimuli in memory over ‘less important’ or neutral stimuli. Under temporal pressure, this results in delaying the processing of the neutral stimuli and creates a memory superiority effect for emotional stimuli. Temporal pressure in this context is defined as slow enough to prevent the attentional blink, but quick enough to prevent active rehearsal of presented stimuli before the presentation of the next stimulus. Moreover, Hadley and MacKay’s (2006) study using taboo words found this effect only exists in mixed lists of taboo and neutral words and not pure lists. This is explained by the fact that taboo and neutral words in mixed lists activate different binding

nodes, and it is the meaning of those nodes that activates the emotional reactive system and guides prioritization of emotional information for memory processing. In pure lists, no individual word gets relative priority because all words have similar emotional linkage.

Hadley & MacKay (2006) proposed a general priority-binding theory where emotionally linked stimuli activate an emotional reaction system which prioritizes the binding nodes in memory relative to the conceptual representation of the perceived stimuli (Hadley & MacKay, 2006). Thus, investigating whether or not binding theory generalizes to picture stimuli in mixed lists is one goal of this research. Supporting the previous research of equivalent recognition memory performance in pure lists is another. Of additional investigation is how pleasurable stimuli are processed under fast presentation rates (i.e., 500ms). Do positive stimuli receive priority binding in memory in mixed lists, parallel to the predictions for negative stimuli?

In summary, previous research using an RSVP paradigm and arousing and neutral picture stimuli in pure lists indicated that arousal theory cannot adequately explain the observed results of equivalent recognition memory performance. Binding theory is currently the best explanation for the observed results but must also be substantiated in mixed lists for positive and negative picture stimuli. Psychophysiological research has a large body of literature documenting typical patterns of physiological performance during exposure to picture stimuli. It is expected that the proposed research will comport with previous heart rate and skin conductance patterns, and it will also shed light on physiological correlates to episodic memory performance. Therefore, in line with the



predictions of binding theory and previous research on the physiological correlates of emotion processing, the major hypotheses of the current research are:

### **Hypotheses**

1. Binding theory predicts no statistically significant differences in recognition memory performance using an RSVP paradigm between:
  - a. Pure lists composed of high arousal negative images and low arousal neutral images
  - b. And pure lists of high arousal positive images and low arousal neutral images.
2. Binding theory predicts statistically significant differences in recognition memory performance using a RSVP paradigm consisting of:
  - a. Mixed lists composed of high arousal negative images and low arousal neutral images
  - b. And mixed lists of high arousal positive images and low arousal neutral images.
3. It is predicted that physiological measures will comport with previous research using picture stimuli. Skin conductance will vary as a function of image arousal rating (i.e., increasing levels of arousal will increase the magnitude of the skin conductance response) in both the study and recognition phase.
4. Heart rate should display the classic triphasic deceleration, acceleration, and secondary deceleration response, varying as a function of image valence rating during the study and recognition phase

5. Heart rate and skin conductance measures will not correlate with memory performance in pure lists.
6. Heart rate and skin conductance will correlate with memory performance in mixed lists.
7. Participant ratings of arousal and valence should correlate with standardized ratings from the IAPS (Lang, Bradley, & Cuthbert, 1999).
8. Participants should indicate more “Remember” responses for arousing (positive and negative) images than “Know” or “Guess” when compared to neutral images in mixed lists, but not pure lists.

To test these hypotheses a series of experiments were conducted using a rapid serial visual presentation paradigm using picture stimuli. Five experiments were planned, labeled A, B, C, D, and E. Experiments A & B examined pure lists because they are the counterintuitive predictions of binding theory. Experiments C, D, & E are designed to examine mixed lists, comparing performance on mixed versus pure lists within subjects. Positive and negative valences are to be compared separately to neutral stimuli and to each other. Data from experiments A, B, & C were collected prior to the beginning of this dissertation and are summarized in the preliminary studies section below because they guided subsequent experiment design. Conducting this research elucidates the fundamental mechanisms of how emotion affects memory and how the physiological correlates of emotion processing are related to memory performance. In a broader perspective, knowledge of this type informs theories of human information processing and provides a better understanding of how emotion affects attention-mediated processes.

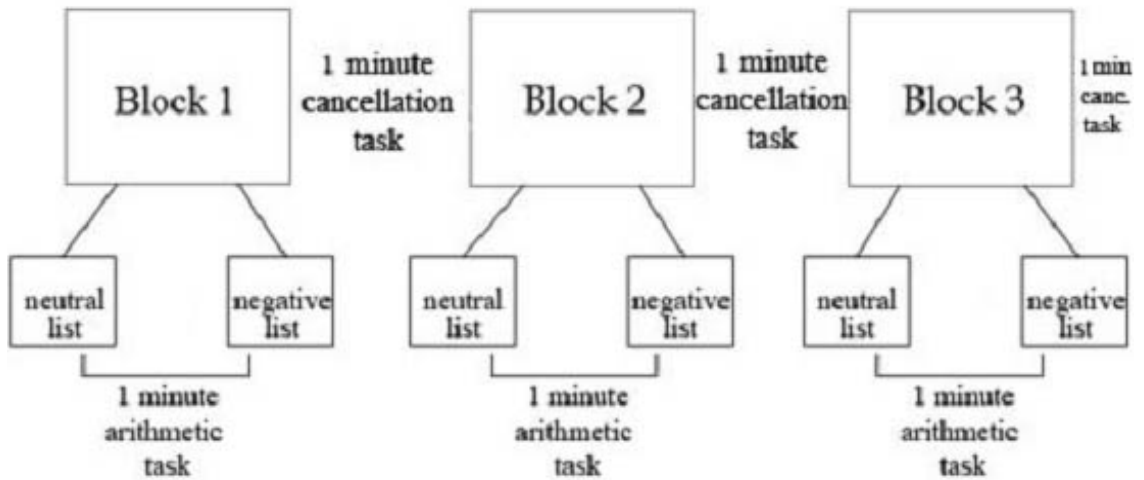
## **Preliminary Studies Introduction**

As with many experiments exploring the nature of cognition, multiple experiments are often needed to remove competing theories to support the most likely explanation. The proposed research is no different and multiple experiments were and continue to be necessary to explore the priority-binding hypothesis and the psychophysiological processing of emotion and memory. Experiment A and B were designed to explore the priority-binding hypothesis of pure lists with affective stimuli. Arousal theory predicts that emotional as compared to neutral information is better remembered. These two experiments explored the counterintuitive hypothesis for equivalent memory performance for emotional as compared to neutral stimuli. These experiments provided support for a general priority-binding hypothesis in pure lists for arousing stimuli (positive and negative) and are briefly reviewed in this section. Although arousal theory was ruled out for experiment's A & B, confirmation of binding theory could not be accepted without a mixed list design. Experiment C used a pure and mixed list design and although conducted prior to approval of my dissertation proposal, was planned as a part of the dissertation. Following preliminary data analysis, it was determined that experiment C did not adequately explore the questions posed by the aforementioned hypotheses and as a result, has been included in the preliminary studies section. An overview of experiments A, B, & C is provided here.

**Experiments A & B.** For a complete description and results of experiment A see Devore (2008). Experiments A & B were identical except that high-arousal negative images in experiment A were replaced with high-arousal positive images in experiment B. Both experiments compared recognition and temporal memory of high arousal

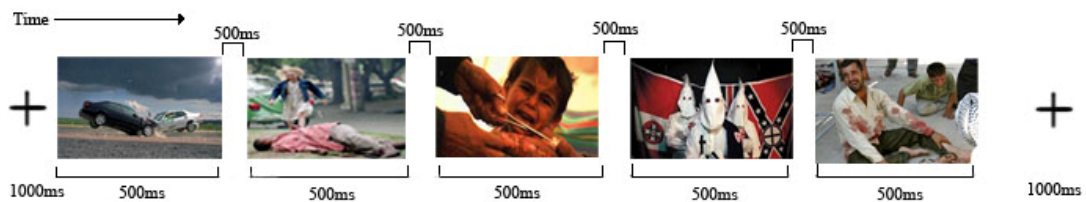
(negative or positive) versus neutral-only lists of rapidly presented visual images (500 ms/image + 500 ms ISI). The arousal hypothesis predicted better recognition and temporal memory performance for negative versus neutral images. Based on the predictions of binding theory, negative, positive, and neutral images should be recognized equivalently; with no better recognition or temporal memory for negative versus neutral images.

Each study consisted of a study and recognition phase. The study phase (see Figure 1) utilized an RSVP design, streaming six lists of nine neutral or valenced images (negative in experiment A, positive in experiment B) (see Figure 2). Between each list was a distracter cancellation task, and between each block was an arithmetic task. Following the study phase the recognition phase was presented (see Figure 3) and recognition memory was tested using all 54 images presented in the study phase as well as 54 new images as comparisons. Heart rate and skin conductance were measured during the study and recognition phases. Participants then rated each of the 108 images they viewed on valence and arousal using a Self-Assessment-Manikin derived scale (Lang et al, 1999). When compared to the IAPS normative ratings these ratings were a nearly exact match, verifying the emotional manipulation ( $p$ 's > 0.20).

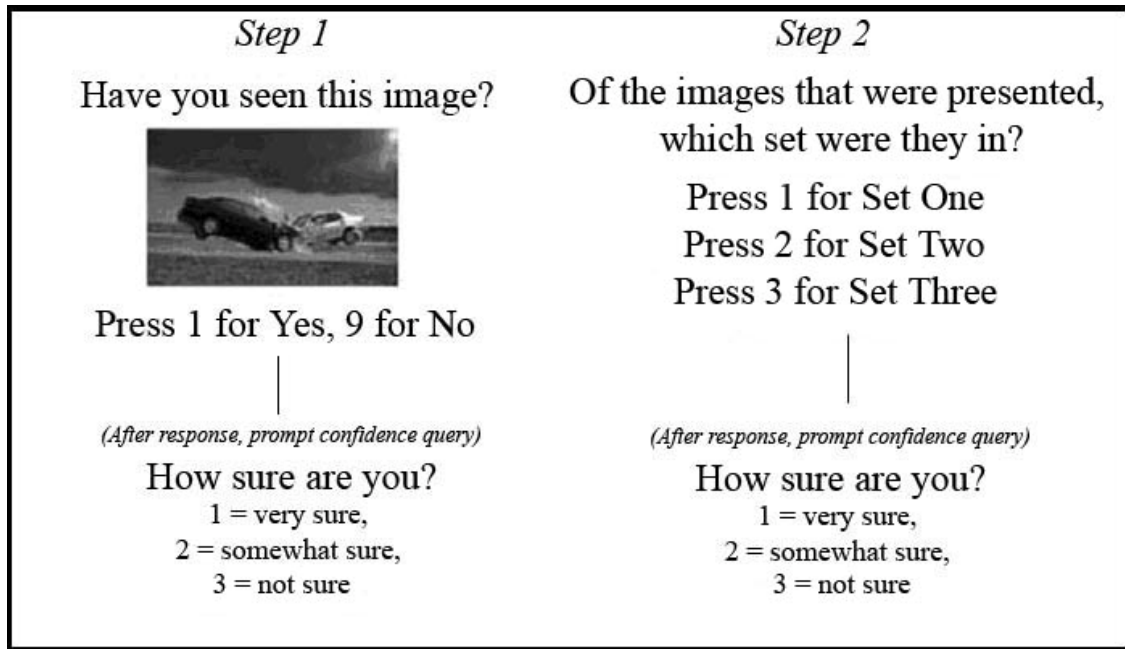


Block and list sequence are randomized.  
 Each subject will see 3 blocks, each block composed of two lists one negative and one neutral.  
 No picture is displayed more than once throughout the studied task.

*Figure 1.* Design of the study phase in Experiments A and B consisting of neutral and valenced images (negative or positive) in 3 randomized blocks. Each block consisted of a randomly presented neutral and valenced list containing 9 neutral or valenced images (6 lists consisting of 54 images total). Selection of images was random as was the order of each list within a pair.



*Figure 2.* Presentation of the RSVP Task (Note: In Experiments A and B, each list consisted of 9 images).



*Figure 3.* Recognition and List Discrimination Task in Experiments A and B. In Step 1 subjects' recognition memory was assessed and in Step 2 subjects' temporal memory was assessed.

The results of experiment A & B found that consistent with the predictions of binding theory for pure lists, neither the recognition memory task nor temporal memory tasks revealed significant differences between arousing (negative and positive) and neutral images (recognition memory:  $p$ 's > 0.10, and observed effect sizes  $d$ 's = 0.02, and 0.18 for experiments A & B, respectively; temporal memory:  $p$ 's > 0.44, and  $d$ 's = 0.08 and 0.08 for experiments A & B, respectively). Post-hoc power analysis suggested there was sufficient power to accept the null hypothesis in both. As expected, subjects were significantly more confident for correctly recognized images in both experiments ( $p$ 's < .001). Although emotional images (negative and positive) were not better recognized than neutral images, heart rate deceleration did indicate differential processing of negative valence lists during the study phase ( $p = 0.03$ ). Moreover, during

recognition, new (compared with old) emotional images elicited a sustained heart rate deceleration ( $p$ 's  $< 0.05$ ), indicative of the recognition of the new images as novel. Similarly, during the recognition phase, skin conductance activity was associated primarily with stimulus recognition (old and correctly recognized) rather than valence ( $p < 0.02$ ).

The predictions of arousal theory for enhanced memory performance in pure lists were not supported in experiments A & B. The results instead support the predictions of binding theory which predicts equivalent memory performance as was found in RSVP pure lists. Nevertheless, confirmation of binding theory cannot be supported without a mixed list design. Experiment C sought to test the predictions of the priority binding hypothesis using both pure and mixed lists in a within-subjects design.

**Experiment C.** Experiment C used a 2 (list-type: pure vs. mixed) x 2 (image type: negative vs. neutral) design to test the priority binding hypothesis of enhanced memory performance for negative images in a mixed list design. According to the predictions of binding theory and based on previous results, it was expected that for mixed list pictures, recognition memory would be enhanced for negative vs. neutral images. For pure list pictures, recognition memory was expected to be equivalent for both negative and neutral. Memory for temporal information was not included in this design because the focus of this investigation is on the application of the priority binding hypothesis to mixed lists and it was felt that too many memory evaluations would impair participant morale and subsequent task performance given the expanded number of pictures viewed and rated in experiment C.

**Participants.** Participants ( $N = 18$ ) were recruited from the undergraduate subject pool at California State University, San Bernardino (5 men and 13 women, aged = 18-36,  $M = 22$ ,  $SD = 2.8$ ). Participants spoke fluent English, reported normal-to-corrected vision, and received credit which could be applied toward their course in exchange for their participation in the study. All participants gave their informed consent and were told they were free to withdraw from the experiment with no penalty at any time. This study was reviewed and approved by the California State University, San Bernardino and Loma Linda University Institutional Review Boards (IRB).

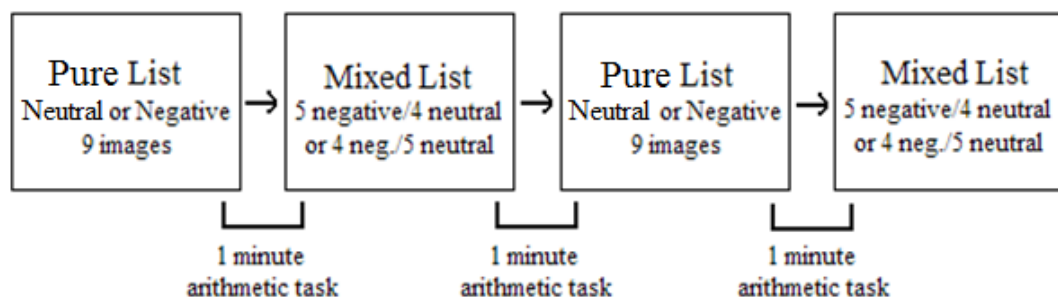
**Power analysis.** Using an effect size for recognition memory performance to guide expected outcomes (taken from Gruhn, Scheibe, & Baltes, 2007), a conservative power analysis for a repeated-measures ANOVA (within factors) was conducted to determine an appropriate sample size for this study. It was determined that 18 participants would be necessary to achieve a power of .9 with alpha set at .05 to detect significant results for a medium effect size of .5.

**Materials and design.** Stimuli were comprised of 108 negative and 108 neutral pictures taken from the International Affective Picture System (IAPS; Lang, Bradley, & Cuthbert, 1999). Selection of images was based on the normative ratings with negative images having unpleasant valence ( $< 4$ ) and high arousal ( $> 5$ ), and neutral images having intermediate valence ( $> 4.5$  and  $< 6.3$ ) and low arousal ( $< 3.5$ ). The mean valence for negative and neutral pictures was 2.43 ( $SD = 0.24$ ) and 5.24 ( $SD = 0.20$ ), respectively. The mean arousal for negative and neutral pictures was 5.74 ( $SD = 0.24$ ) and 2.84 ( $SD = 0.11$ ), respectively. The IAPS numbers for the pictures that were included in the study are shown in the Appendix.



Experiment C design consisted of three phases: the study phase, the recognition phase, and the ratings phase. The study and recognition phases were conducted during one session, and the ratings phase a week later. Two sets of images were constructed for experiment C (1 & 2), each set consisting of 54 negative and 54 neutral images. Half of the subjects received set 1 during the study phase and the other half received set 2. For each subject, the non-studied set was used as the new images during the recognition phase. Image sets were assigned in a counterbalanced order across participants.

The study phase consisted of 12 lists: 6 mixed and 6 pure with each list consisting of 9 images. There were 3 negative pure lists, 3 neutral pure lists, and 6 mixed lists. Three of the mixed lists consisted of 4 negative and 5 neutral images, and the other three consisted of 5 negative and 4 neutral images. List presentation was controlled such that no more than 2 mixed or 2 pure lists could be presented sequentially. Selection of images within each list was random and images in the study phase were displayed no more than once (see Figure 4 for details).



*Figure 4.* Experiment C design of the study task consisting of pure and mixed lists of negative and neutral images. This figure shows 4 lists but actual experiment consisted of 12 lists (6 mixed and 6 pure), and list presentation was pseudo-random so that no more than 2 of each list type (mixed or pure) were presented sequentially.

**Physiological measures.** Heart rate and skin conductance measures were identical to experiments A and B.

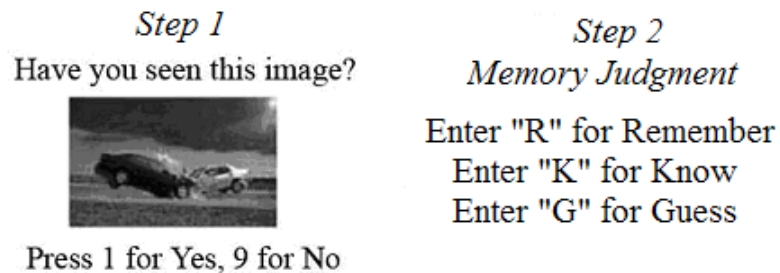
**Procedure.** Participants were tested individually while sitting eye level facing a computer monitor (Dell 17inch LCD, refresh rate 60 Hz) at approximately 60 centimeters distance in a quiet, air-conditioned room. The stimuli were presented with a full screen resolution display of 1028x786 with a viewing angle of 36.3°. To avoid emotional arousal or alert prior to the experiment no practice trials were presented. Participants were carefully instructed to ensure accurate comprehension of the task.

The task was presented using E-Prime 2.0 beta (Psychological Software Tools, Pittsburgh, PA). Each trial began with a 1000 ms centered fixation cross followed by the pictures with display duration of 500 ms for each picture. After each picture a black screen inter-stimulus interval of 500 ms was presented. At the end of each list another centered fixation cross was presented for 1000 ms (see Figure 2 from experiment A for details).

At the end of each list participants completed a 1-minute pen and paper arithmetic task (a series of multiplications involving 2-digit numbers) to prevent image rehearsal. After 55 seconds the computer sounded a 5 second warning beep that the next list was about to be presented.

Following the presentation of all 12 lists, a recognition memory discrimination task was presented. In this task each of the 208 images (both studied and new images) was displayed in random order and participants were asked to press 1 on the keyboard if they had seen the image before and 9 if they had not. After each recognition discrimination response a *remember-know* procedure was presented for all items.

Participants indicated one of three possible responses: “R” = remember, “K” = know, “G” = guess (See Figure 5 for details). A week later participants returned and rated all of the images they viewed on valence and arousal using the Self-Assessment Manikin (Lang et al, 1999). These ratings were then compared to the IAPS normative ratings.



*Figure 5.* Recognition memory and *Remember-Know* task. In Step 1 subjects’ recognition memory was assessed. In Step 2 subjects’ recollection or familiarity was assessed. Detailed instructions for the *remember-know* procedure were provided prior to Step 2.

**Results and discussion.** For each valence category and list condition, Table 1 provides percentages of hits and false alarms, the discrimination index  $d'$ , and the response bias  $C$ .

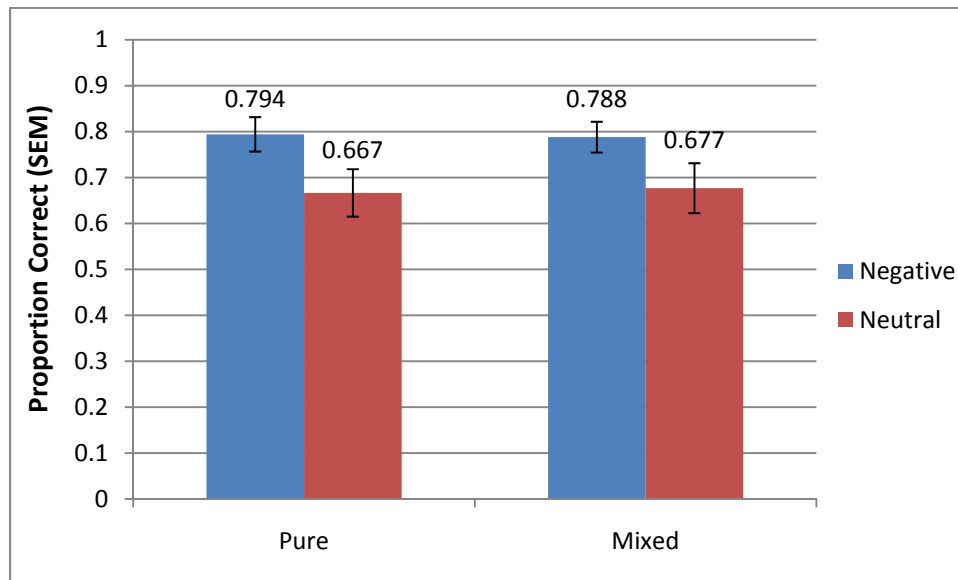
*Recognition memory proportion correct.* There was a significant effect of image type for correctly recognized “old” images, where negative images were better remembered than neutral images,  $F(1,17) = 9.64, p = 0.006, \eta^2 = 0.36$ , but this did not vary by list condition,  $F(1,17) = 0.04, p = 0.85, \eta^2 = 0.002$ . The interaction was not significant,  $F(1,17) = 0.07, p = 0.79, \eta^2 = 0.004$  (Figure 6). Neutral images were correctly identified as “new” significantly more than negative images,  $t(17) = -3.735, p = 0.002$  (Figure 7).

Table 1

*Experiment C: Recognition Performance in the Pure and Mixed List Conditions*

Index X Valence	<i>M</i>		<i>SD</i>	
	Pure	Mixed	Pure	Mixed
Hit Rates				
Negative	0.794	0.788	0.149	0.138
Neutral	0.667	0.677	0.213	0.224
False Alarms				
Negative	0.292	0.292	0.231	0.231
Neutral	0.153	0.153	0.169	0.169
<i>d'</i>				
Negative	1.551	1.529	0.527	0.548
Neutral	1.650	1.710	0.616	0.718
<i>C</i>				
Negative	-0.153	-0.143	0.588	0.568
Neutral	0.319	0.289	0.542	0.541

*Note.* Hit rates and false-alarm rates are in percentages. *C* = response bias.



*Figure 6.* Experiment C: Mean proportions of recognition memory performance for old images as a function of list condition and picture valence. Error bars represent standard error of the mean.

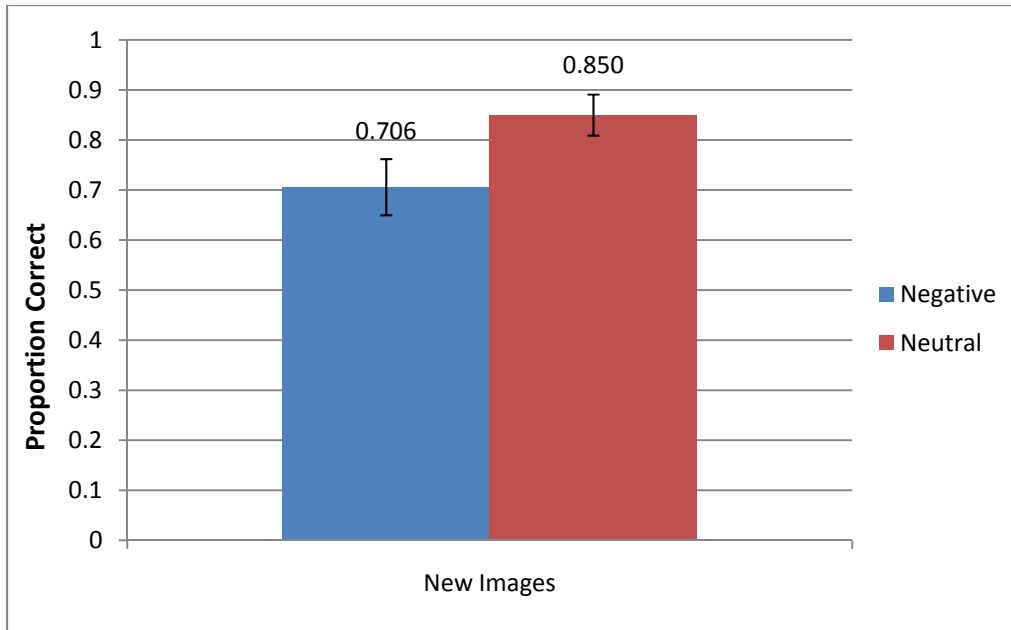


Figure 7. Experiment C: Mean proportions of recognition memory performance for new images as a function of picture valence. Error bars represent standard error of the mean.

*Signal detection measures.* Sensitivity index ( $d'$ ) was assessed to correct for proportion of hits to false alarms; the larger the  $d'$ , the better the participants' ability to discriminate between old and new items. The response bias  $C$  indicates whether participants show a liberal response bias, a tendency to report that a picture is "old" ( $C < 0$ ) or a conservative response bias, a tendency to report that a picture is "new" ( $C > 0$ ). Unfortunately, the structure of the E-Prime code written for data collection resulted in separate data being available for false alarms only by valence (i.e., negative or neutral images) but not by list condition (i.e., pure or mixed lists); however, valence and list condition data were available for the proportion of hits. Thus, the  $d'$  and  $C$  statistics in experiment C do not accurately reflect differences in false alarms across list condition and they should be interpreted with caution.

The sensitivity index  $d'$  was analyzed with a 2 x 2 (List condition X Valence) ANOVA. A trend toward participants being able to discriminate neutral over negative images was found, however this result was not statistically significant,  $F(1,17) = 3.48$ ,  $p = 0.08$ ,  $\eta^2 = 0.17$ , (see Figure 8). There was no effect of list condition.

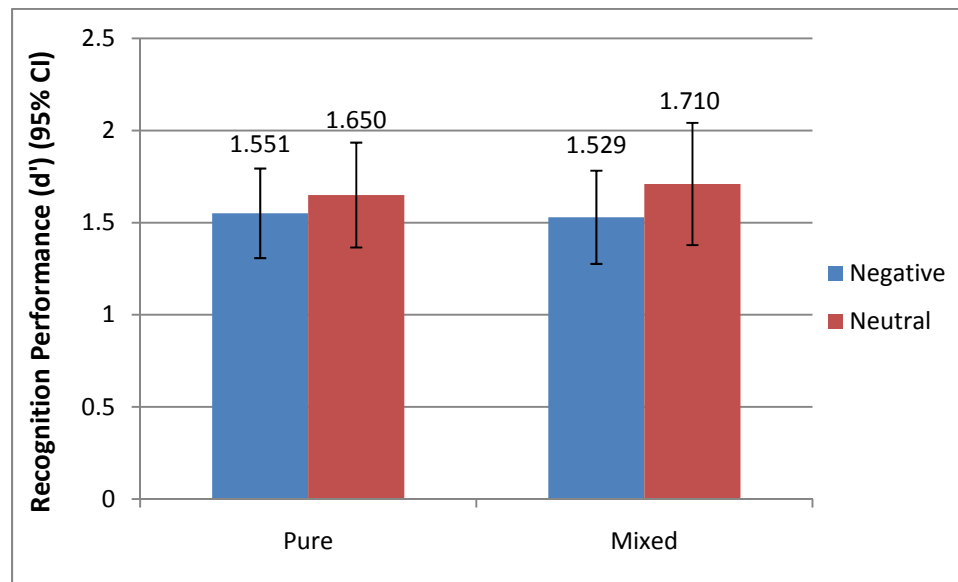


Figure 8. Recognition performance ( $d'$ ) as a function of picture valence. Higher numbers indicate greater sensitivity. Error bars represent 95% confidence intervals.

A significant liberal criterion bias was found. Subjects had a tendency to report false alarms for negative images across both pure and mixed lists, which appeared as a main effect of valence,  $F(1,17) = 15.59$ ,  $p = 0.001$ ,  $\eta^2 = .48$  (see Figure 9). Once again, because  $C$  was computed by collapsing false alarms across list conditions, it was expected that if the criterion bias statistic ( $C$ ) was significant it would be for both list conditions. Higher rates of false alarms for negative stimuli have been reported using words (Maratos, Allan, & Rugg, 2000), and may be explained through the semantic

cohesion hypothesis of Phelps et al. (1998), in which negatively valenced stimuli share higher levels of inter-item associations than do stimuli of neutral valence.

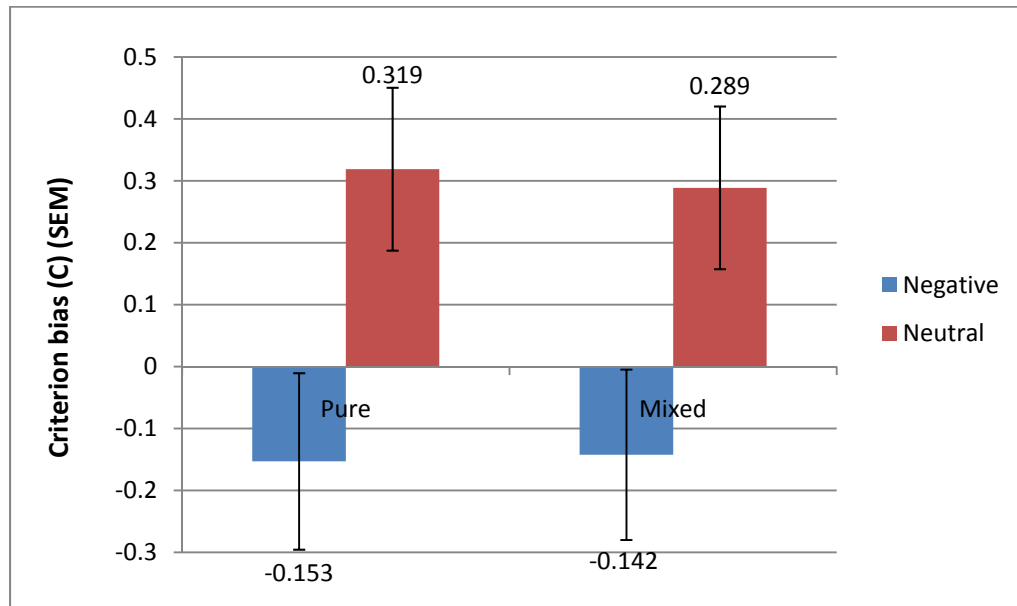


Figure 9. Experiment C: Criterion bias (C) as a function of list condition and picture valence. Lower numbers (i.e.,  $C < 0$ ) indicate a liberal bias to report more false alarms and higher numbers (i.e.,  $C > 0$ ) indicate a conservative bias.

*Remember-Know-Guess (RKG)*. Planned comparisons expected more *remember* than *know* or *guess* responses. Pure lists were expected to have an equivalent number of *remember* responses across valence while mixed lists were expected to have more *remember* responses for negative than neutral images. Figure's 10 and 11 present the mean proportions for *RKG* responses for hits and false alarms (respectively) as a function of list condition and picture valence. A  $3 \times 2 \times 2$  (*remember-know-guess* x List condition x Valence) ANOVA for hits revealed a main effect of response type (i.e., *remember*, *know*, or *guess*),  $F(2,17) = 86.36, p < 0.001, \eta^2 = 0.92$ , and valence,  $F(2,17) = 9.48, p =$

0.007,  $\eta^2 = 0.36$ . The interaction of response type X valence was significant,  $F(2,16) = 5.28, p = 0.02, \eta^2 = 0.39$ ; there were no other significant main effects or interactions.

Separate ANOVAs for *remember* and *know*, and *know* and *guess* verified that there were more *remember* responses than *know*,  $F(2,17) = 130.52, p < 0.001, \eta^2 = 0.89$ ; and more *know* responses than *guess*,  $F(2,17) = 179.43, p < 0.001, \eta^2 = 0.91$ . There were more *remember* responses for negative images in both pure and mixed lists,  $F(1,17) = 5.70, p = 0.03, \eta^2 = 0.25$ . For *know* responses there was an interaction (List condition X Valence), with more *know* responses for hits of negative images in the pure condition,  $F(1,17) = 4.61, p = 0.046, \eta^2 = 0.21$ . There were no significant effects for *guess* responses.

Analysis of *remember-know-guess* data for false alarms was collapsed across list conditions. In addition to the main effect of response type,  $F(2,16) = 12.65, p = 0.001, \eta^2 = 0.61$ , there was also an effect of valence,  $F(1,17) = 12.97, p = 0.002, \eta^2 = 0.43$ . The interaction of response type X valence was significant,  $F(2,16) = 9.30, p = 0.002, \eta^2 = 0.54$ . Separate ANOVAs for *remember* and *know* and *know* and *guess* revealed there were more *remember* than *know*,  $F(1,17) = 5.000, p = 0.039, \eta^2 = 0.23$ , and more *know* than *guess* responses,  $F(1,17) = 11.18, p = 0.004, \eta^2 = 0.39$  (Figure 11). This result means that participants falsely recognized more negative over neutral images.



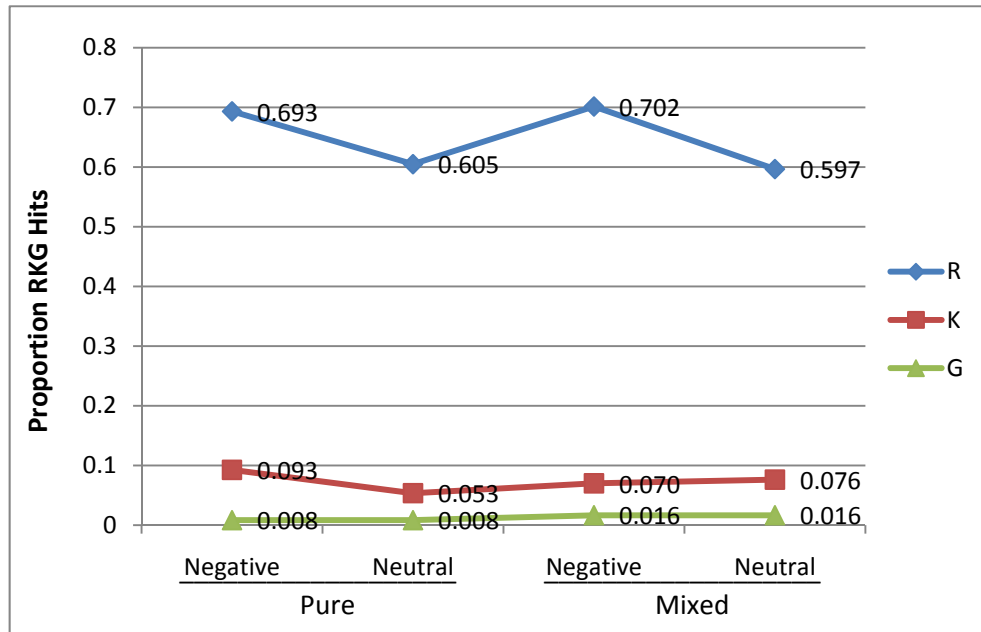


Figure 10. Experiment C: Proportion of *Remember-know-guess* hit responses as a function of list condition and picture valence. Proportion is out of 1 (hits + false alarms).

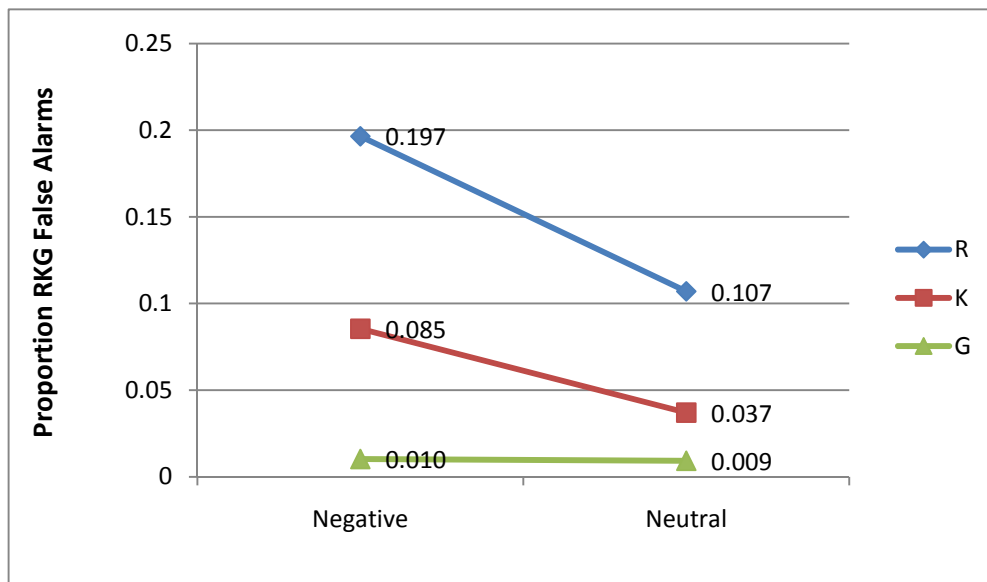


Figure 11. Experiment C: Proportion of *Remember-know-guess* false alarm responses as a function of picture valence.

Experiment C found that negative images were associated with better recognition memory than neutral. This effect appeared as greater proportions of correctly recognized negative over neutral images in both list conditions. This conclusion was undercut by the signal detection analysis revealing a bias for participants to falsely indicate they had previously seen a new negative image in combination with marginally better sensitivity for neutral than negative images. This result does not support binding theory, which would predict better memory for negative images in mixed but not pure lists. It is likely the observed results are due to the pseudo-random alternation of mixed and pure lists in experiment C and the delay of the recognition memory task after the end of all presented lists. This is substantiated by the finding that the proportion of correctly recognized negative images in mixed lists was no better than negative images in pure lists,  $t(17) = -.232, p = 0.82$  ( $M = 0.788, 0.794$  for mixed and pure lists, respectively). A similar result was found for neutral image comparisons between pure and mixed lists,  $t(17) = .293, p = 0.77$  ( $M = 0.677, 0.667$  for mixed and pure lists, respectively). Moreover, this result lends support to both arousal and binding theory, and does not meet the experimental goals of testing the priority-binding hypothesis because the pseudo-random alternation of mixed and pure lists likely prevented precision encoding of list information.

Physiological and image ratings data are not reported for Experiment C because they would not assist in testing the proposed hypotheses. Thus, experiment D alters the study list structure to distinguish the pure lists and mixed lists more effectively. Additionally, a separate recognition task is presented after the pure as well as the mixed lists. The goal is to create an encoding process and retrieval context with sufficient precision to test the predictions of priority-binding theory.

## **Experiment D**

### **Major Hypotheses, Aims, and Significance**

Although arousal theory was not supported in Experiment A, the priority-binding hypothesis could not be confirmed without a mixed list design. Experiment C was designed to integrate the pure and mixed list design, replicating experiment A's results for pure lists with the additional goal of finding enhanced memory performance for negative over neutral images in mixed lists. Experiment C's design apparently encouraged subjects to encode information as one large mixed list, due in part to the alternating mixed and pure list presentation and delayed recognition memory task. This design caused enhanced recognition memory for negative over neutral information. Building on the lessons of experiments A & C, experiment D was designed to test the priority-binding hypothesis using a block design for pure and mixed lists.

To achieve this, experiment D replicated some aspects of experiment A's design by using a blocked pure and mixed list presentation, such that either a series of 6 mixed lists followed a series of 6 pure lists, or vice versa. All lists consisted of 9 images, with the mixed lists varying in structure such that there were 3 mixed lists consisting of 4 neutral and 5 negative images, and 3 mixed lists consisting of 5 neutral and 4 negative images. Both list presentation within each block as well as the block presentation order was randomized across participants. A design for one large mixed list and one large pure list similar to Gruhn, Scheibe, & Baltes (2007) was considered but not selected because I wanted to replicate and maintain generalizability with the results of experiment A, which used several pure lists. To help avoid the encoding and retrieval set problems discussed in

experiment C, separate recognition memory tasks for mixed and pure lists followed immediately after the completion of each block.

**Hypotheses.** The following experimental hypotheses cover the domains of recognition memory, physiological data, and subjective arousal and valence ratings.

**Recognition measures.** This design was chosen to test the priority-binding hypothesis for pure and mixed RSVP lists. It was expected that for pure lists there will be equivalent recognition memory performance between negative and neutral images. Although the actual content of each image may differ, similar arousal levels create equivalent priority in attention-mediated memory, rendering equivalent recognition memory performance. Previous research has found that arousal is the primary predictor of subsequent memory performance (Bradley, Greenwald, Petry, & Lang, 1992; Cahill & McGaugh, 1998), and both neutral and negative images were chosen to have similar within-category arousal levels.

Within mixed lists it is expected that there will be significantly enhanced memory performance for negative over neutral images. Binding theory states that activation of the emotional reaction system gives processing priority of emotional stimuli in memory over 'less important' or neutral stimuli. Under temporal pressure (i.e., 500 ms presentation duration, 500ms inter-stimulus interval), this results in delaying the processing of the neutral stimuli and creates a memory superiority effect for emotional stimuli. The significantly different arousal and valence ratings between negative and neutral images in this experiment should be sufficient to engage the emotional reaction system and guide priority processing of negative over neutral images at the 500ms presentation and 500ms inter-stimulus interval rate.

Using the logic of the priority-binding theory, there should be greater sensitivity ( $d'$ ) for negative over neutral images in mixed lists, but not pure lists. These predictions are based on the results of several studies (Devore, 2008; Gruhn, Scheibe, & Baltes, 2005; Gruhn, Scheibe, & Baltes, 2007; Hadley & MacKay, 2006).

Similarly, there should be more *remember* than *know* or *guess* responses for hits and false alarms in mixed lists, but not in pure lists. This result would comport with the predictions of priority-binding theory and the findings of Dewhurst & Parry (2000). If participants indicate more *remember* and *know* responses than *guess* in both pure and mixed lists for negative stimuli, this result would support arousal theory.

***Physiological data.*** It is predicted that heart rate data during the study and recognition phase will comport with the triphasic deceleration, acceleration, deceleration response seen in similar picture studies (Lang, Bradley, & Cuthbert, 1999; Bradley & Lang, 2007). The greatest change in mean beats per minute is expected to occur during negative-valence images. For skin conductance in the study phase it is expected that mean amplitude and number of SCR responses will be greater for negative over neutral images as a function of arousal. SCR for recognition memory will not be included due to practical considerations of the study design (i.e., speed of participant responses tends to be faster than the length of time necessary for SCR responses to be measured accurately). These expected physiological results are well supported by the literature in emotion and motivation research (Bradley et al., 2001).

Recognition memory performance should not correlate with heart rate changes in pure lists, but should in mixed lists. A result of this type would suggest that recognition memory performance is independent of measures of physiological arousal (Devore et al.,

2008). In the broader context of approach and avoidance systems, this suggests that sustained and consistent levels of arousal would not affect motivational systems due to equivalent levels of attention-mediated processes. Rather, for motivational systems to engage in adaptive behavior, differing levels of arousal and valence must occur in order to engage the emotional reaction system to give priority processing to relevant stimuli.

***Arousal and valence ratings.*** It is predicted that participants will rate the selected IAPS images similarly to the standardized IAPS ratings. Arousal ratings should be higher and valence ratings lower for negative images. Arousal ratings should be low and valence intermediate for neutral images. A result to the contrary would suggest that participants were not affected in the same way as the population in the standardized IAPS ratings, and consideration of this would be important in interpreting all relevant data. To explain a contrary result, it is possible that increased media exposure to violence, gore, and sexually explicit material in the participant population has desensitized their subjective experience of the material, rendering negative stimuli not as arousing.

## **Research Design and Methods**

**Participants.** Participants ( $N = 24$ ) were recruited from undergraduate subject pools at California State University, San Bernardino (23 women and 1 male, aged = 19-40 y,  $M = 26$ ,  $SD = 5.9$ ). Participants spoke fluent English, were right-handed, reported normal-or-corrected vision, and received credit which could be applied as extra credit toward their course in exchange for their participation in the study. All participants in the experiment gave informed consent; to comply with ethical guidelines, the consent form explicitly mentioned that they would be seeing potentially disturbing and graphic pictures

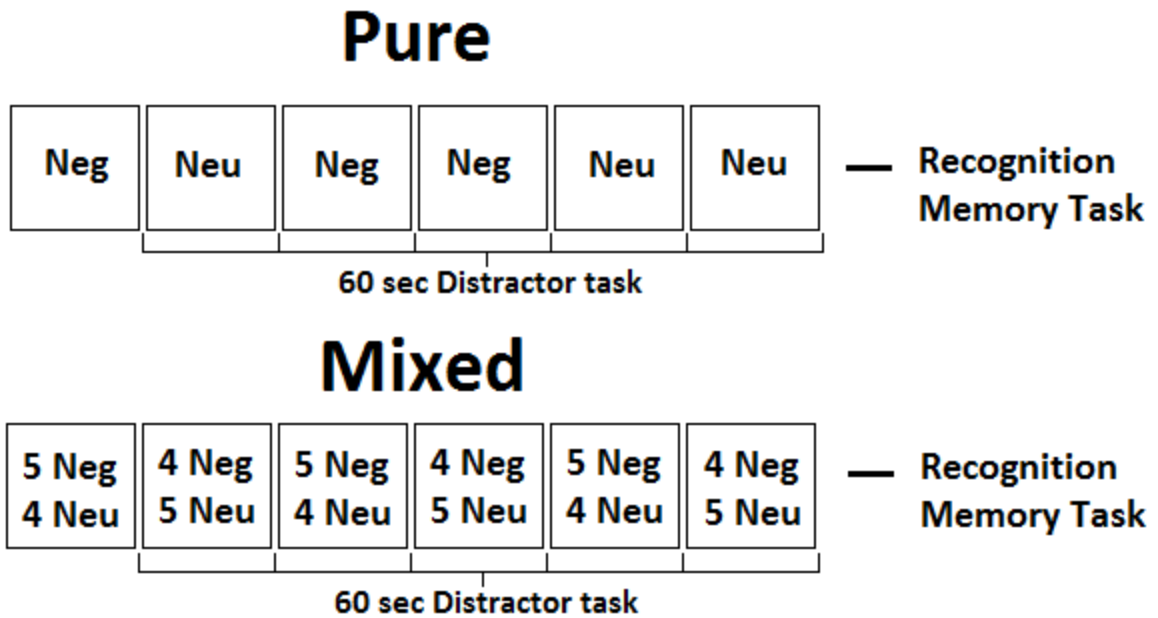
and were told they were free to withdraw from the experiment with no penalty at any time. No participant in this experiment reported having a history of neurological or mental illness.

**Power analysis.** The power analysis, identical to experiment C, determined that 18 participants would be necessary to achieve a power of .9 with alpha set at .05 to detect significant results for a medium effect size of .5.

**Physiological measures.** Heart rate and skin conductance measures were identical to experiment C.

**Materials.** The materials were identical to experiment C.

**Procedure and design.** Procedure was identical to experiment C except that a recognition memory task was presented following the end of each block (see Figure 12). Each recognition memory task consisted of the 54 studied images presented in the block and 54 new, unstudied images to be used as foils. The order of image presentation in the recognition memory task was random. A 60 second arithmetic task followed presentation of each list. Following the recognition phase, participants were asked to rate the valence and arousal of all of the images they viewed using a Self-Assessment-Manikin-derived scale (Lang et al, 1999). These ratings were then compared to the IAPS normative ratings.



*Figure 12.* Experiment D design. Each block consisted of either 6 pure or 6 mixed lists. Within the pure block, 3 of the lists consisted of only negative images and 3 of neutral images. Within the mixed block, 3 of the lists consisted of 4 negative and 5 neutral, and the other 3 consisted of 5 negative and 4 neutral. Each list consisted of 9 images and an arithmetic task was presented between each list. A recognition memory task was presented at the end of each block.

## Results

**Recognition memory task.** For each valence category and list condition, Table 2 provides percentages of hits and false alarms, the discrimination index  $d'$ , and the response bias  $C$ .



Table 2

*Recognition Performance in the Pure and Mixed List Conditions*

Index X Valence	<i>M</i>		<i>SD</i>	
	Pure	Mixed	Pure	Mixed
Hit Rates				
Negative	0.789	0.765	0.119	0.135
Neutral	0.750	0.755	0.180	0.147
False Alarms				
Negative	0.194	0.221	0.133	0.181
Neutral	0.162	0.188	0.129	0.157
<i>d'</i>				
Negative	1.813	1.693	0.584	0.530
Neutral	1.916	1.845	0.636	0.474
<i>C</i>				
Negative	0.048	0.047	0.338	0.501
Neutral	0.160	0.135	0.476	0.548

*Note.* Hit rates and false-alarm rates are in proportion of total number of hits and misses.

**Recognition memory proportion correct.** The proportion of correctly recognized “old” images was not affected by image valence or list condition,  $F$ 's(1,23) < 1.26,  $p$ 's > 0.27 and the interaction was not significant,  $F(1,23) = 0.46$ ,  $p = 0.51$  (Figure 13). Similarly, there were no significant valence effects for correctly recognized “new” images,  $t(23) = -1.48$ ,  $p = 0.15$  (Figure 14). Data for “new” images across list condition was not available due to programming errors.

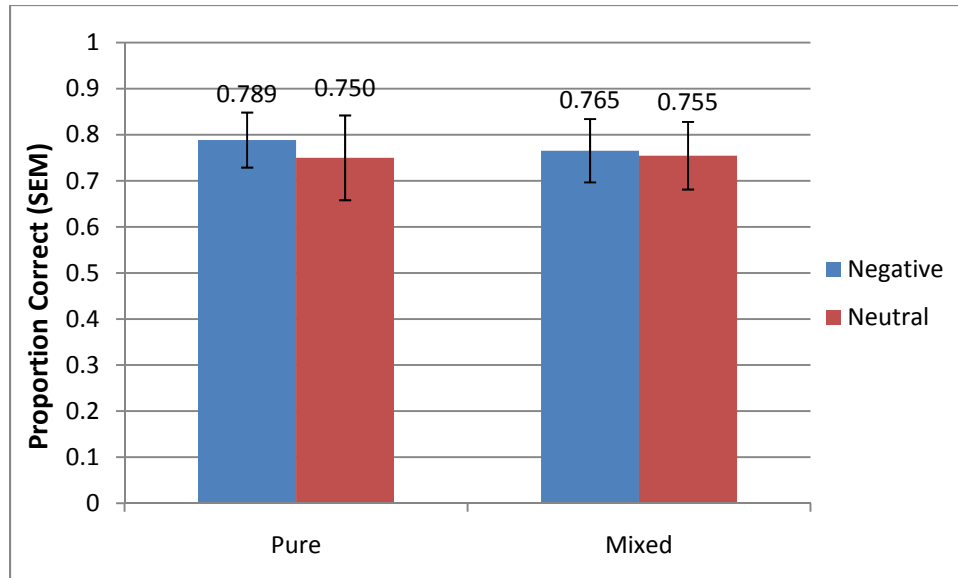


Figure 13. Experiment D: Mean proportions of recognition memory performance for old images as a function of list condition and picture valence. Error bars represent standard error of the mean.

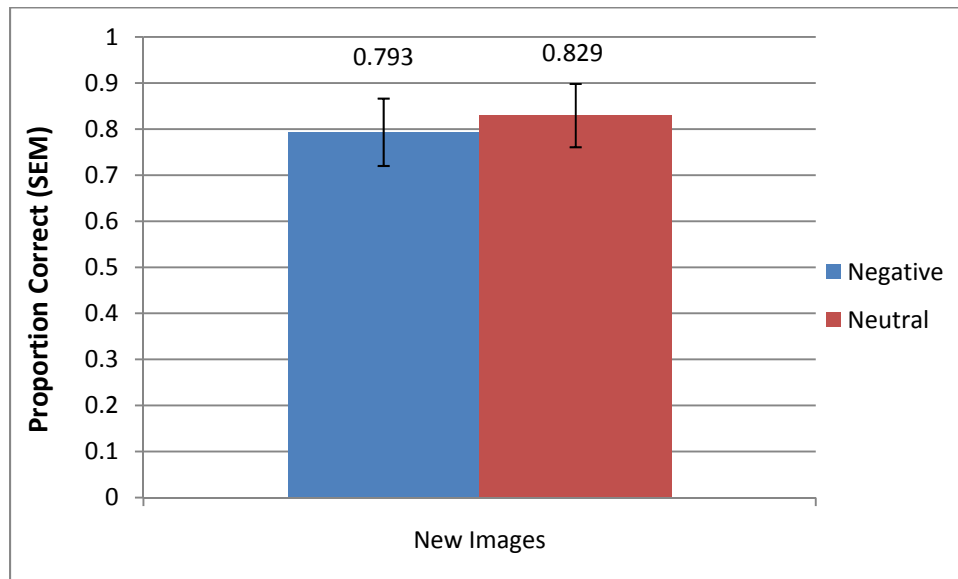


Figure 14. Experiment D: Mean proportions of recognition memory performance for new images as a function of picture valence. Error bars represent standard error of the mean.

**Signal detection measures.** The sensitivity index  $d'$  was analyzed with a 2 x 2 (List condition X Valence) ANOVA. Participants did not recognize negative images better than neutral images in either list condition; neither the main effects of list condition or valence, nor their interaction were significant,  $F$ 's < 1 (see Figure 15).

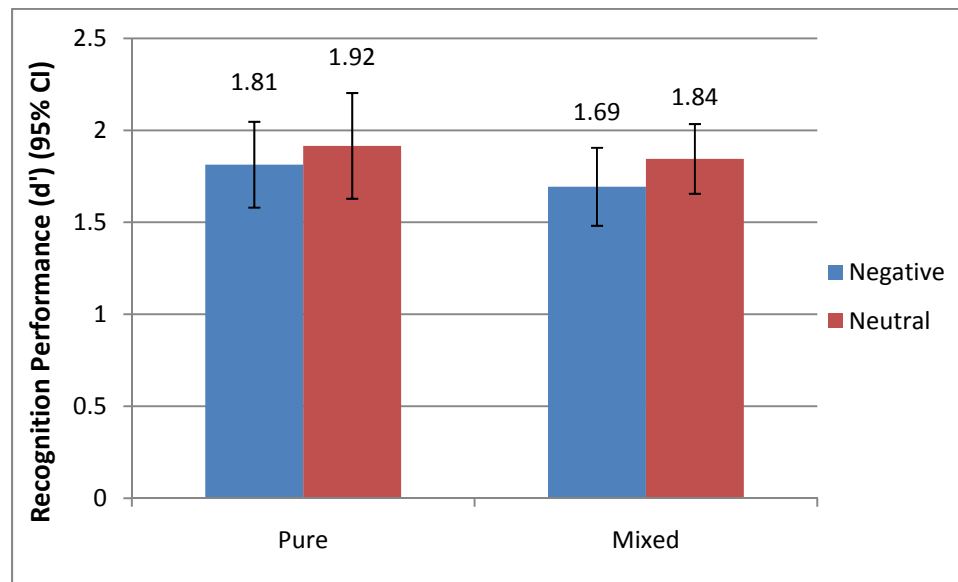


Figure 15. Experiment D: Recognition performance ( $d'$ ) as a function of list condition and picture valence. Higher numbers indicate greater sensitivity. Error bars represent 95% confidence intervals.

No significant criterion bias ( $C$ ) was found, meaning that participants did not respond to any image type or list condition better than another. A slight trend was observed for valence in which participants tended to make more false alarms for negative over neutral images,  $F(23) = 3.04$ ,  $p = 0.09$ ,  $\eta^2 = .12$  (Figure 16). There was no effect of list condition and the interaction was not significant,  $F$ 's < 1.

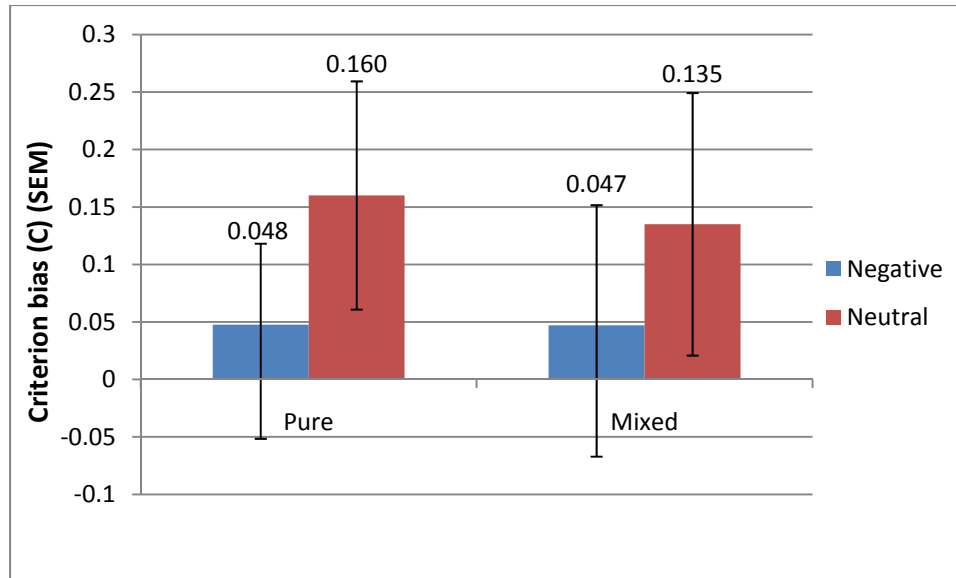


Figure 16. Experiment D: Criterion bias (C) as a function of list condition and picture valence. Lower numbers (i.e.,  $C < 0$ ) indicate a liberal bias to report more false alarms and higher numbers (i.e.,  $C > 0$ ) indicate a conservative bias.

**Arousal and valence ratings.** According to the ratings data, participants subjectively reacted to the images as intended. Negative pictures (as compared to neutral) were rated as significantly more negative and arousing,  $t(23) = -14.84, p < .001$ ;  $t(23) = 8.26, p < .001$ , respectively. Compared to the normative IAPS ratings, participants rated the viewed negative and neutral images as more arousing,  $t's(23) > 2.56, p's < 0.02$ . There were no significant differences between the normative IAPS ratings and participant ratings for valence ( $p's > 0.10$ ). These results suggest that this study's participants may have experienced greater levels of subjective arousal to the images than the normative IAPS participants although their rated valence was equivalent to the norm (see Table 3). Additionally, analyses with gender-based (females only) IAPS norms were conducted and did not alter the results or interpretations.

Table 3.

*Mean Ratings of IAPS Images displaying Means, Standard Deviations, Confidence Intervals, and Standard Errors*

	Mean	Mean Diff.	Std. Dev.	CI 95%	Std. Error
<i>Valence</i>					
Negative	2.161	-0.277	0.755	0.323	0.169
Neutral	5.637	0.393	0.733	0.314	0.164
<i>Arousal</i>					
Negative	6.475	0.726*	1.402	0.599	0.313
Neutral	3.581	0.737*	1.202	0.514	0.269

Note: Valence ratings are rated unpleasant to pleasant (1-9); Arousal ratings are rated calm to excited (1-9); Ratings are from 40 subjects. Mean Difference is difference of selected images from the normative IAPS ratings. \* $p < 0.02$

**Remember-Know-Guess.** Planned comparisons expected more *remember* than *know* or *guess* responses. Pure lists were expected to have an equivalent number of *remember* responses across valence while mixed lists were expected to have more *remember* responses for negative than neutral images. Figure's 17 and 18 present the mean proportions for *remember-know-guess* responses for hits and false alarms (respectively) as a function of list condition and picture valence. A 3 X 2 X 2 (Response type x List condition x Valence) Omnibus ANOVA revealed only one main effect, that of response type (i.e., *remember*, *know*, or *guess*),  $F(2,22) = 649.29$ ,  $p < 0.001$ ,  $\eta^2 = 0.98$ . Separate ANOVAs for *remember* and *know*, and *know* and *guess* verified that there were more *remember* responses than *know*,  $F(2,23) = 459.12$ ,  $p < 0.001$ ,  $\eta^2 = 0.95$ , and more *know* responses than *guess*,  $F(2,23) = 41.80$ ,  $p < 0.001$ ,  $\eta^2 = 0.64$ . None of the other main effects or interactions were significant in any of the ANOVAs,  $F$ 's  $< 1.396$ ,  $p$ 's  $> 0.25$ ,  $\eta^2 < 0.06$ .

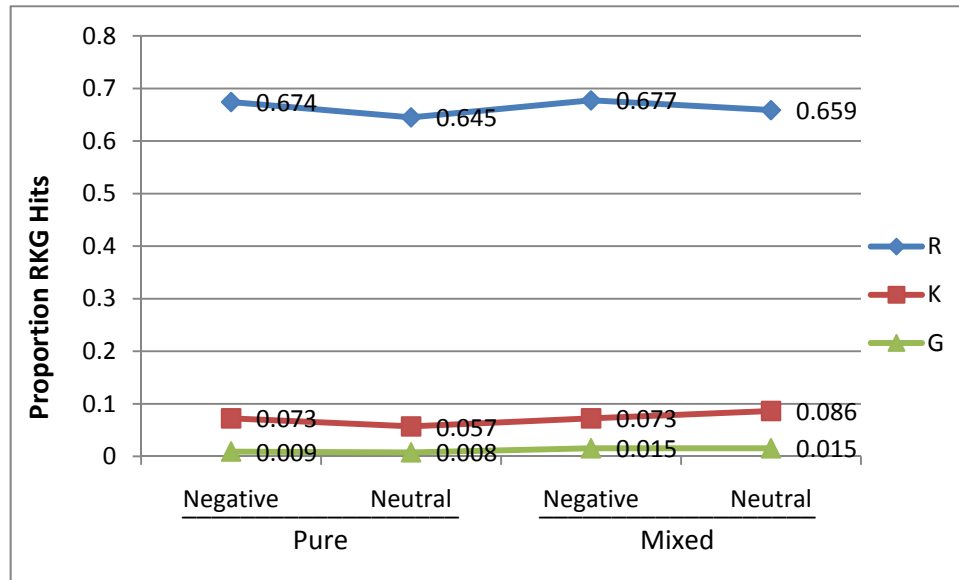


Figure 17. Experiment D: Proportion of *Remember-know-guess* hit responses as a function of list condition and picture valence.

Analysis of *remember-know-guess* data for false alarms began using a 3 X 2 X 2 (Response type X List condition X Valence) Omnibus ANOVA. In addition to the main effect of response type,  $F(2,22) = 164.77, p < 0.001, \eta^2 = 0.94$ , there was also an effect of valence,  $F(2,23) = 1057.25, p < 0.001, \eta^2 = 0.98$ . There were significant interaction effects for Response type X List condition,  $F(2,22) = 4.59, p = 0.02, \eta^2 = 0.29$ ; Response type X Valence,  $F(2,22) = 7.45, p = 0.003, \eta^2 = 0.40$ ; and List condition X Valence,  $F(2,23) = 263.92, p < 0.001, \eta^2 = 0.92$ . No other effect reached significance, including the Response type X List condition X Valence,  $F(2,22) = 1.896, p = 0.174, \eta^2 = 0.147$ .

Separate ANOVAs for *remember* and *know*, and *know* and *guess* responses verified that there were more *remember* responses than *know*,  $F(2,23) = 269.24, p < 0.001, \eta^2 = 0.92$ , and more *know* responses than *guess*,  $F(2,23) = 275.05, p < 0.001, \eta^2 = 0.92$ . However, inspection of Figure 18 suggests that the greater number of *remember* than *know* responses was due to more false alarms for negative than for neutral images. This

explanation was supported in the ‘*remember* and *know*’ ANOVA by main effects of list,  $F(23) = 13.26, p = 0.001, \eta^2 = 0.37$ , and valence,  $F(23) = 583.21, p < 0.001, \eta^2 = 0.96$  and by follow-up paired-sample  $t$ -tests indicating more *remember* responses negative over neutral images in both pure and mixed list conditions,  $t(23) = 2.23, p = 0.04, t(23) = 2.48, p = 0.02$  respectively). A similar ANOVA for *know* responses revealed no main effects and no significant interactions. Paired-sample  $t$ -tests revealed no significant differences for *know* or *guess* responses for either list condition or valence. The proportion of *guess* responses did not warrant further analysis.

Although recognition memory performance ( $d'$ ) did not differ significantly across list condition or valence, participants reported that they recognized old negative images better than they actually did, and committed more false alarms for the *remember* responses than *know* or *guess*.

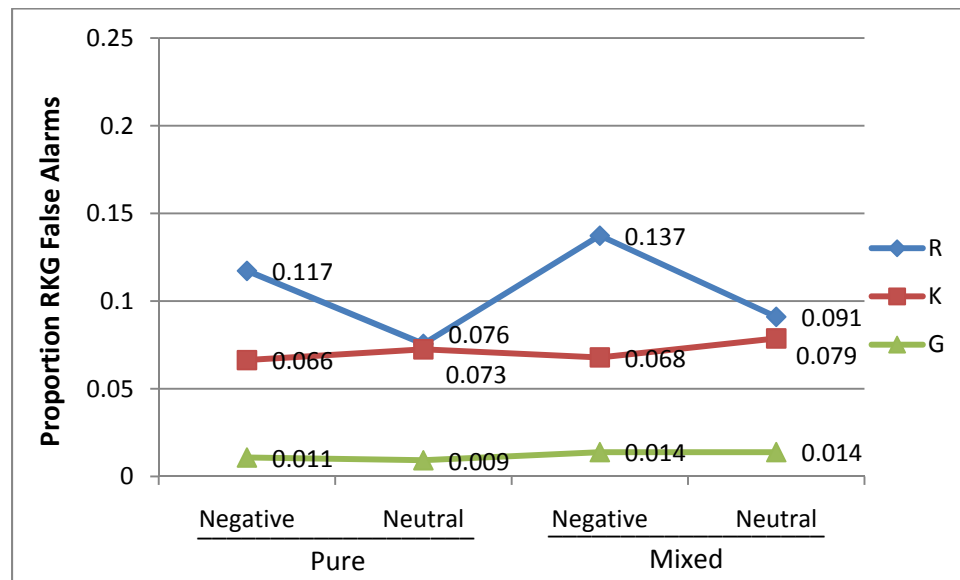


Figure 18. Experiment D: Proportion of *Remember-know-guess* false alarm responses as a function of list condition and picture valence.

**Physiological results in studied lists.** This section outlines the results for the physiological data in the studied list phase.

**Skin conductance.** A repeated measures ANOVA was conducted to determine if the mean amplitude of responses varied by list condition. It was expected that participants would demonstrate increased amplitude to negative images in both pure and mixed lists; however, the greatest amplitude was observed in neutral images in pure lists.

Nevertheless, statistical analyses revealed no significant differences in electrodermal responding across list conditions,  $F(2,18) = 1.37$ ,  $p = 0.28$ ,  $\eta^2 = 0.13$  (Figure 19).

Similarly, there was no effect of list condition on the number of responses produced,  $F(2,18) = 0.81$ ,  $p = 0.46$ ,  $\eta^2 = 0.08$  (Figure 20).

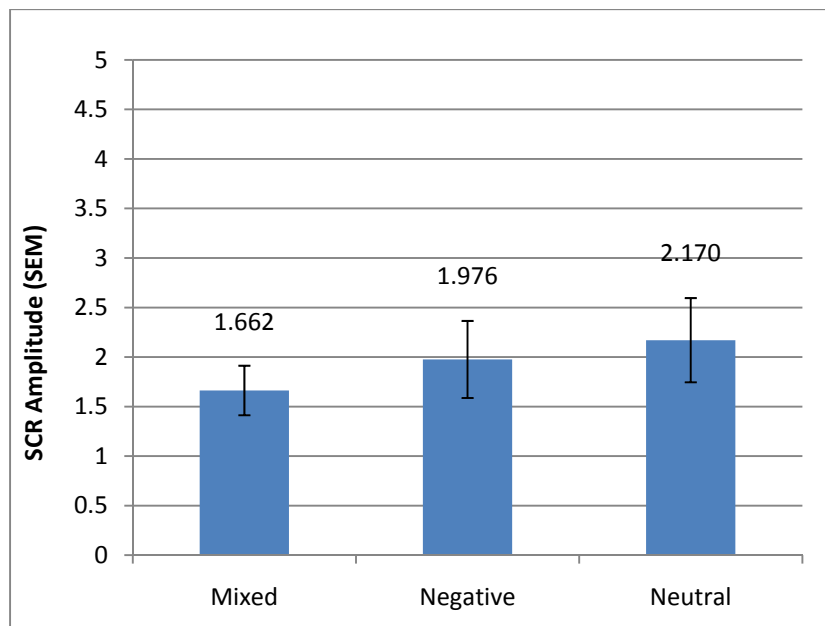


Figure 19. Experiment D: Skin conductance amplitude as a function of list condition. Error bars represent standard error of the mean.



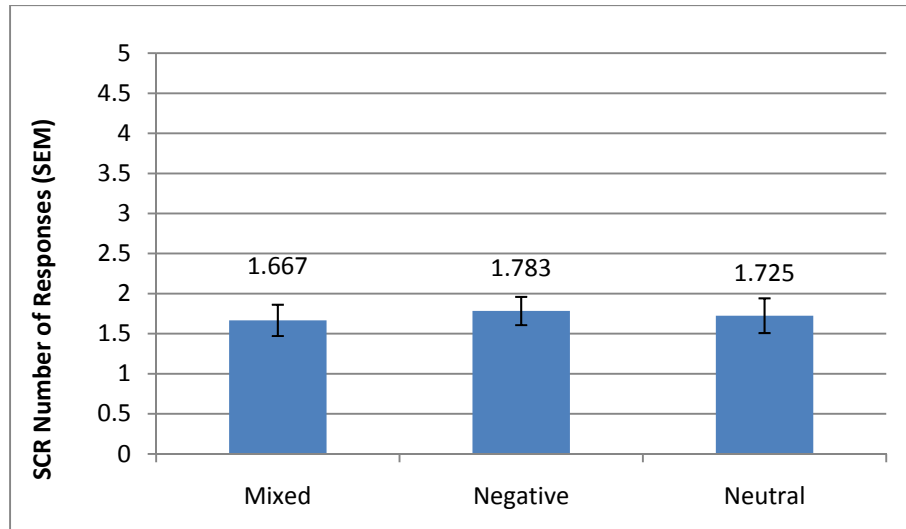


Figure 20. Experiment D: Number of skin conductance responses as a function of list condition. Error bars represent standard error of the mean.

**Heart rate in study phase.** As may be observed in Figure 21, following onset of the first image in the list, a triphasic heart rate response occurred consisting of a small acceleration, a deceleration, and a final acceleration above baseline. These data were analyzed with a 3 X 28 (List condition X ½-second Time Bins, beginning with bin 4) repeated measures ANOVA. The classic triphasic heart rate response to novel stimuli is supported by the significant main effect of Time,  $F(2,27) = 9.83, p < 0.001, \eta^2 = 0.32$  with quadratic and cubic effects,  $F's(1,21) > 20.122, p's < 0.001, \eta^2's > 0.49$ . However, heart rate did not vary across list condition as neither the main effect,  $F(2,20) = 1.63, p = 0.22, \eta^2 = 0.14$ , nor the interaction was significant,  $F(2,54) = 0.91, p = 0.65, \eta^2 = 0.96$ . Based on the established literature (Bradley & Lang, 2007), it was expected that heart rate would decelerate in negative pure or mixed list conditions more than in the neutral pure list condition. Although Figure 21 shows a trend for greater heart-rate deceleration for the negative and mixed list condition, their differences were not significant. This issue

will be explored later in the discussion section of experiment D. Nevertheless, the valence and arousal ratings data, taken together with the triphasic heart rate response demonstrate that the participants were responding to the image lists as expected.

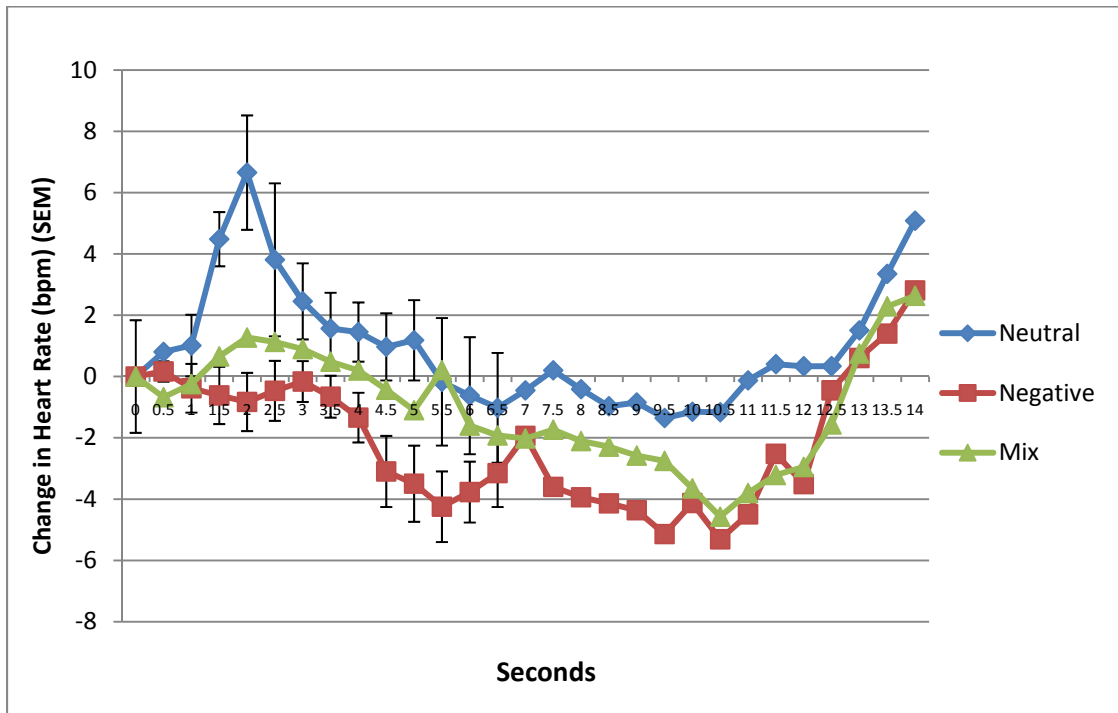


Figure 21. Experiment D: Heart rate change (BPM) as a function of list condition and time (in seconds). Error bars represent the standard error of the mean.

**Physiological results in recognition task.** This section outlines the results for the physiological data in the recognition list phase.

**Heart rate in pure list recognition.** The first six seconds of heart rate after the onset of the image were examined for each participant during the recognition task. A 2 X 2 X 8 (Old and New X Valence X Time Bins (2-9)) repeated measures ANOVA was conducted to examine changes in heart rate across time for the four conditions. Although only small changes in heart rate were observed during recognition, a compressed version

of the standard pattern was observed (Figure 22) (Bradley & Lang, 2007). This included a short deceleration preceding an acceleration probably associated with the task response. The analyses confirmed the significant change across Time (i.e., bin),  $F(7,12) = 5.35$ ,  $p = 0.006$ ,  $\eta^2 = 0.76$ . There were no other significant main effects or interactions. Inspection of Figure 22 suggested that the maximal heart rate effect occurred approximately 4 seconds after image onset. To examine this epoch of the heart rate waveforms further, bins five through nine were analyzed using a 2 X 2 X 5 (Old and New X Valence X Time Bin) repeated measures ANOVA. This revealed only a main effect of Time,  $F(4,15) = 7.35$ ,  $p = 0.002$ ,  $\eta^2 = 0.85$ ; none of the interactions was significant.

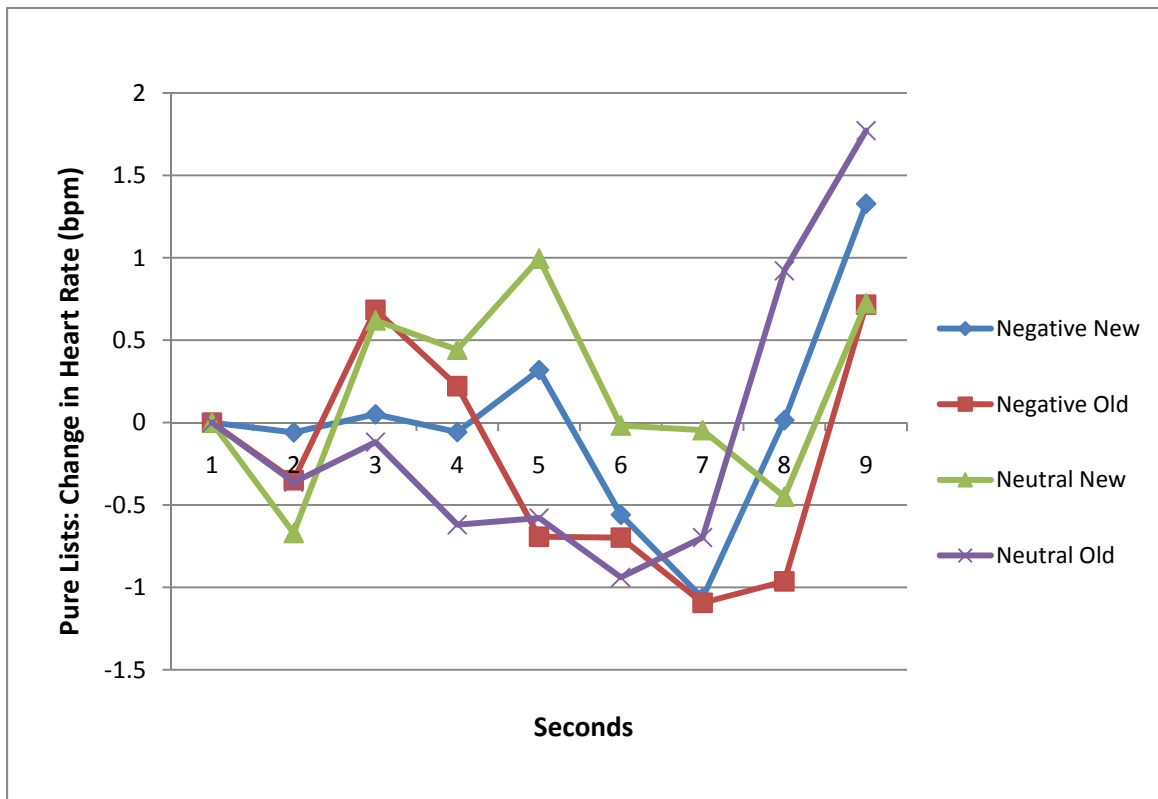


Figure 22. Experiment D: Heart rate change (BPM) in pure lists as a function of old and new, valence, and bin (time in seconds). Changes in heart rate did not vary by old and new or valence. Note the general effect of time (i.e., bin) as demonstrated by the triphasic pattern of responding (i.e., initial acceleration, deceleration, and another acceleration).

***Heart rate in mixed list recognition.*** A 2 (Old and New) X 2 (Valence) X 8 (Time Bin 2-9) repeated measures ANOVA was conducted to examine changes in heart rate across time for the four conditions. As in the analysis for pure list recognition, a short deceleration and subsequent acceleration reflecting the standard pattern was observed (Figure 23). This was confirmed by a main effect of Time,  $F(7,17) = 7.30, p < 0.001, \eta^2 = 0.75$ . Although new images appeared to elicit greater deceleration, there were no other significant main effects or interactions. To examine the epoch of maximal apparent effect in the heart rate waveform, a 2 X 2 X 5 (Old and New X Valence X Time Bin (5-9)) repeated measures ANOVA was conducted. This analysis revealed a Time by Old and New interaction, indicating a greater overall deceleration for new as compared to old images,  $F(1,23) = 5.18, p = 0.03, \eta^2 = 0.18$ , as well as the main effect of Old v New  $F(1,23) = 5.66, p = 0.03, \eta^2 = 0.23$ ; and a main effect of Time  $F(4,20) = 6.88, p = 0.001, \eta^2 = 0.68$ . A quadratic and cubic effect of bin demonstrated the classic triphasic pattern of responding to emotional images,  $F(1,23) = 17.79, p < 0.001, \eta^2 = 0.44$ ;  $F(1,23) = 9.48, p < 0.001, \eta^2 = 0.29$ , respectively; none of the other effects was significant. Taken together, these analyses indicate that subjects showed a greater heart rate deceleration for new as compared to old images irrespective of valence.

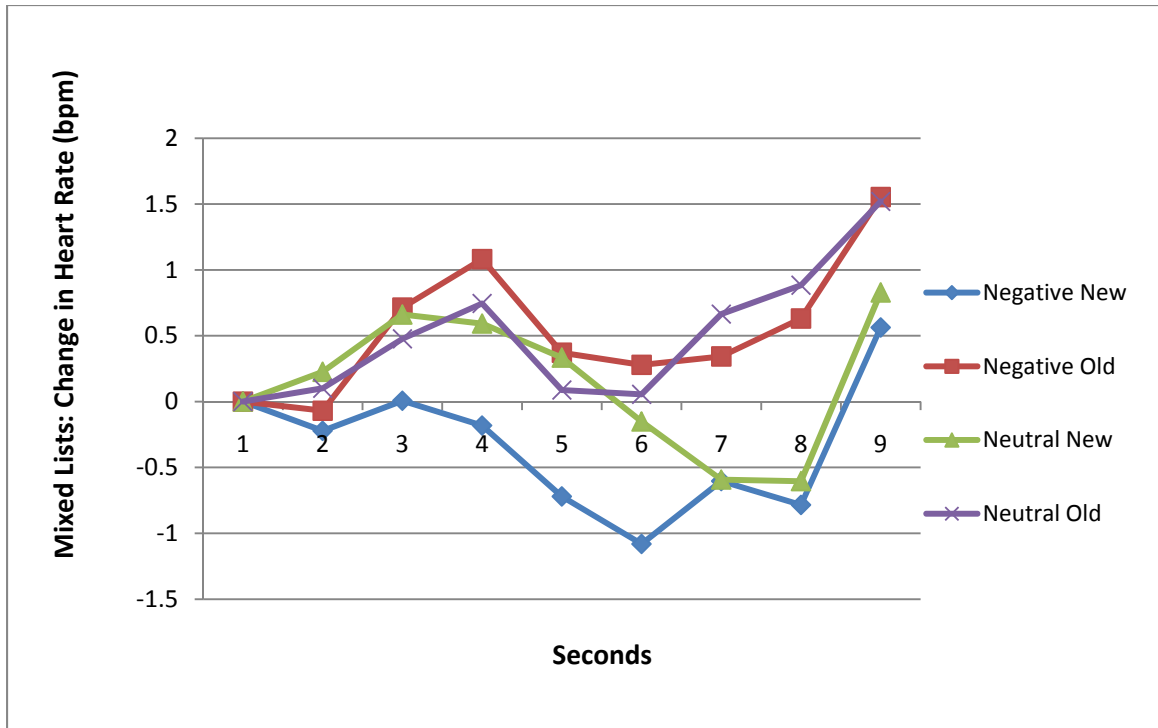


Figure 23. Experiment D: Heart rate change (BPM) in mixed lists as a function of old and new, valence, and bin (time in seconds). Changes in heart rate varied by old and new but not by valence. The classic triphasic pattern of responding to emotional stimuli was captured by the effect of bin.

**Physiology results summary.** Overall, skin conductance amplitude and number of responses did not vary as a function of list condition. Heart rate changes in the study phase demonstrated no effect of list condition, but did show a classic triphasic pattern of response across time. In the pure list recognition phase, heart rate did not vary as a function of valence or old and new, but there was a significant change in heart rate across time (i.e., triphasic pattern). In the mixed list recognition phase, there was an effect of old and new but not valence. New images (negative and neutral) produced a greater overall decrease in heart rate compared to old images, indicating an orienting response to novel stimuli (Öhman, Hamm, & Hugdahl, 2000), as well as an effect across time. Based on the

heart rate data, it is clear that the subjects were indeed perceiving and processing the images.

**Ancillary analyses.** This section outlines post-hoc results to explore areas that were not anticipated by the original hypotheses.

***Order effects in sensitivity and bias.*** Although no significant differences were found in recognition discrimination ( $d'$ ), it is possible that memory performance could differ within blocks; depending on what list type was presented first. In other words, could memory performance have been affected by changes in encoding processes due to a pure or mixed list being presented first? To examine this possibility, an order effects analysis was conducted.

To determine whether or not recognition memory performance differed by the presentation order of the lists, a 2 (Order of presentation) X 2 (List condition) X 2 (Valence) ANOVA was conducted using the dependent variable recognition accuracy. There were no significant main effects although valence,  $F(1,11) = 3.28, p = 0.10, \eta^2 = 0.23$ , and the interaction of Order presentation X List Condition X Valence,  $F(1,11) = 3.85, p = 0.07, \eta^2 = .26$ , approached significance (Figure 24). To explore further, I used paired-sample  $t$ -tests to compare proportions of correctly recognized negative and neutral images within each list condition and order presentation. Although no significant differences were found, a medium size effect (Cohen's  $d = 0.56$ ) for recognition performance of images presented in pure lists when a pure list was presented first and a small effect ( $d = 0.22$ ) for recognition of images in mixed lists when a mixed list was presented first was observed (Table 4). Taken together, these marginally reliable effects revealed that participants had slightly better recognition memory rates in list conditions

that matched the first kind of list presented (e.g., better recognition memory for pure lists when pure lists were presented first).

To account for proportion of hits to false-alarms, the discrimination index  $d'$  was calculated for each list by presentation order, list condition, and valence (Table 4). A 2 (Order presentation) X 2 (List condition) X 2 (Valence) ANOVA was conducted using

Table 4.

*Order Effects: Proportions, standard deviations, correlations, and Cohen's  $d$  as a function of list presentation order, list condition, and valence.*

	Pure List Presented First				Mixed List Presented First			
	Mixed		Pure		Mixed		Pure	
	Neg.	Neu.	Neg.	Neu.	Neg.	Neu.	Neg.	Neu.
<i>M</i>	0.790	0.802	0.802	0.725	0.741	0.707	0.775	0.775
<i>SD</i>	0.122	0.127	0.094	0.197	0.153	0.155	0.143	0.175
Correlation	0.545		0.562		0.520		0.569	
Cohen's $d$	-0.101		0.565		0.225		0.000	

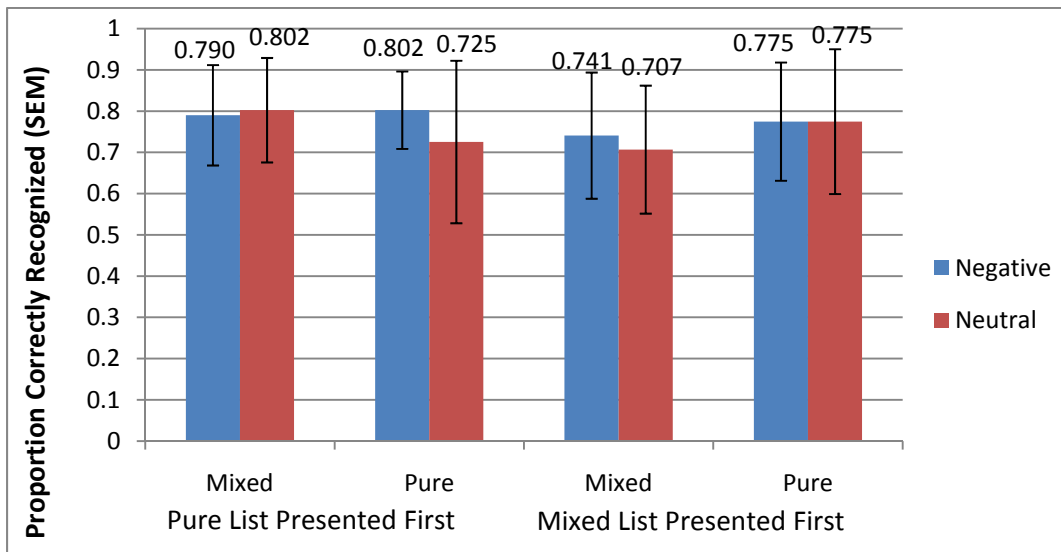


Figure 24. Experiment D: Proportion of correctly recognized images as a function of list presentation order, list condition, and picture valence. Error bars represent standard error of the mean.

the index  $d'$  revealed only a significant 3-way interaction of Presentation order X List condition X Valence was significant,  $F(1,11) = 10.41, p = 0.008, \eta^2 = 0.49$ ; no other main effects or interactions were significant,  $F's(1,11) < 1.10, p's > 0.32, \eta^2's < 0.091$ . To tease apart the interaction, a 2 X 2 (List condition X Valence) ANOVA was conducted for each presentation order pair (i.e., pure list first and mixed list first). Only the List condition X Valence interaction when a pure list was presented first was significant,  $F(11) = 6.14, p = 0.03, \eta^2 = 0.36$ . Follow-up paired-sample T-tests found no significant effect when mixed lists were presented first. However, there was better discrimination of neutral compared with negative images in mixed lists when a pure list was presented first,  $t(11) = -2.95, p = 0.01$  (Figure 25).

Calculation of effect size using Cohen's  $d$  revealed a large effect of valence for images in mixed lists when a pure list was presented first (Cohen's  $d = -0.85$ ), small and medium effects for mixed and pure lists when a mixed list was presented first (Cohen's  $d = 0.22, -0.442$ , respectively), and a negligible effect for pure lists when presented first (Table 5). This result suggested that participants display the most reliable memory, in terms false alarm rates, in pure lists when a pure list was presented first. Similarly, the next most reliable performance occurred in mixed lists when a mixed list was presented first. Thus, it appeared that the order in which a participant viewed a list did affect recognition memory performance.

The order effects analysis provided some evidence that it was the design of the experiment that was affecting recognition discrimination performance ( $d'$ ), similar to the problems encountered in experiment C. In order to explore this finding in more detail I next conducted an order effects analysis of the *remember-know-guess* data.



Table 5.

*Order Effects: Discrimination index  $d'$ , standard deviations, correlations, and Cohen's  $d$  as a function of list presentation order, list condition, and valence.*

	Pure List Presented First				Mixed List Presented First			
	Mixed		Pure		Mixed		Pure	
	Neg.	Neu.	Neg.	Neu.	Neg.	Neu.	Neg.	Neu.
$d'$	1.564	2.028	1.880	1.799	1.823	1.662	1.747	2.032
$SD$	0.380	0.389	0.694	0.737	0.638	0.495	0.469	0.713
Correlation	-0.002		-0.005		0.133		0.326	
Cohen's $d$	-0.853		0.08		0.216		-0.442	

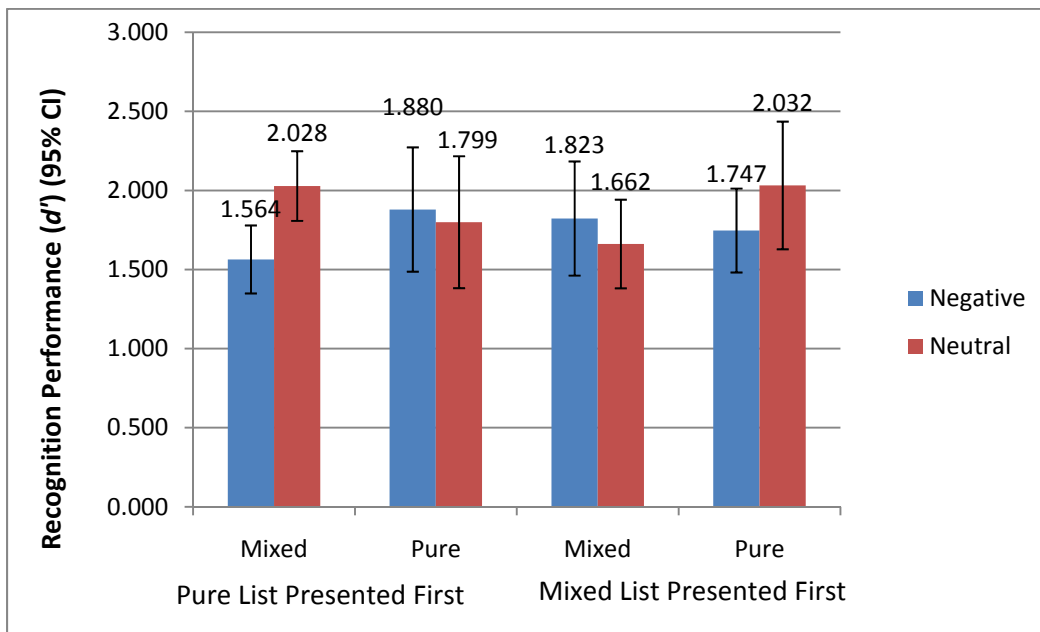


Figure 25. Experiment D: Recognition performance ( $d'$ ) as a function of list presentation order, list condition, and picture valence. Higher numbers indicate greater sensitivity. Error bars represent 95% confidence intervals.

**Order effects in remember-know-guess.** To determine if there were more remember responses as a function of list order presentation, separate 2 X 2 X 2 (Order presentation X List condition X Valence) repeated measures ANOVAs were conducted on hits and false alarms. For hits, the order effect was not significant,  $F(1,11) < 1$ ,  $p = 0.94$ ,  $\eta^2 = 0.001$ , and there were no other significant main effects or interactions. Thus

there was no evidence that the number of hit responses varied as a function of list presentation order. The analysis of false alarms revealed only a main effect of valence,  $F(11) = 8.96, p = 0.01, \eta^2 = 0.45$ . None of the effects involving the Order factor or any other effects or interactions were significant. This suggested that participants did not commit more *remember* false alarms as a function of list order presentation.

**Other analyses.** There was no effect of caffeine, medication, gender, or sleep,  $p$ 's  $> 0.46$ .

### **Experiment D: Results Summary and Discussion**

This experiment built on the lessons learned from experiments A & C. The goal was to replicate experiment A's findings of equivalent memory performance for negative and neutral images in pure lists, as well as generalizing the predictions of the priority-binding hypothesis to mixed lists. Planned comparisons revealed no significant differences in either recognition proportions for old and new images or the recognition discrimination index ( $d'$ ) across list conditions or valence. Recognition memory performance appeared to be equal for both negative and neutral images across both types of lists. The observed results were contrary to the predictions of both priority-binding theory and arousal theory. Several post-hoc analyses were conducted to explain the findings.

First, I explored whether the response bias ( $C$ ) could explain the current findings. Analysis revealed no significant response bias, although there was a slight tendency to commit more false alarms for negative images in both pure and mixed lists. This was a

similar result to experiment C, but this did not fully explain the lack of an observed recognition difference across valence or list conditions.

My next analysis was designed to determine whether or not the emotional manipulation of the images was a success. I explored participants' ratings of the images in two ways: comparing the arousal and valence ratings of images defined as negative to neutral images, and then comparing the valence and arousal ratings with the normative IAPS ratings. Participants in this experiment rated images on the arousal scale as significantly more arousing than the normative IAPS ratings. Images rated on the valence scale were rated in a similarly to the normative IAPS ratings. This result suggested that participants were subjectively perceiving and processing as intended to the arousal and valence dimensions of the images. More importantly, there was no evidence of insufficient arousal throughout the experiment.

Analysis of the physiological data generally supported this finding. Study phase heart rate data revealed an effect of time, where changes in heart rate varied significantly across the study phase as demonstrated by the triphasic pattern of responding. Although participant's heart rates were changing in response to the images, they did not vary significantly by list condition or valence. This differs from experiments A & B, where heart rate varied as a function of image arousal. Recognition heart rate data in the pure and mixed list condition found a similar triphasic pattern of responding; however in the pure list there were no difference in valence or old or new categories. In the recognition heart rate mixed list condition, there was a greater overall deceleration of heart rate for new negative and neutral images, as compared to old negative and neutral images. This change of heart rate however, did not comport with recognition discrimination

performance ( $d'$ ) in the mixed list condition. Skin conductance response data revealed no significant differences across the three list conditions (i.e., mixed, negative pure and neutral pure). As a whole, the physiological and ratings data revealed that subjects were reacting to the images and provided enough evidence to suggest that the emotional manipulation was successful.

Based on this information, I next ran a series of order effects analyses to determine if the presentation of a mixed block or pure block first affected recognition memory for the subsequent block. Recall that the presentation of a mixed or pure block first was pseudo-random and alternated for each subject (i.e., 12 subjects received a mixed block first, and 12 subjects received a pure block first). Generally, subjects tended to commit fewer false alarms in the first block they studied, regardless of whether it consisted of pure or mixed lists. This can be interpreted as a primacy or proactive interference effect. There was not sufficient evidence to suggest that the presentation of a pure or mixed list first significantly changed encoding processes or retrieval performance for the subsequent block.

Analysis of the *remember-know-guess* data for hits revealed more *remember* responses than *know* or *guess*, but this did not vary by list condition or valence. Participants also did not endorse more *remember* responses based on list presentation order. Analysis of the *remember-know-guess* data for false alarms revealed more false alarms for negative images in both list conditions, but there was no effect of list order presentation. These false alarm RKG results, when taken in the context of the primacy/proactive interference effect described in the order effect analysis for  $d'$ , suggest

that although recognition memory discrimination performance ( $d'$ ) differed depending on list presentation order, it did not match false alarm RKG response frequency.

The results of experiment D were similar to experiment C in that neither the predictions of priority-binding theory or arousal theory were supported. The lack of an enhanced memory effect in the mixed list manipulation was especially puzzling. It is unlikely that the lack of differences were due to specific pictures or the picture sets because sets were matched for arousal and valence and studied and new pictures alternated with each subject. This was designed to rule out differences in picture distinctiveness across participants. Neither were the results due to lack of emotional arousal because participants rated the negative images as more arousing and more negative than the neutral images.

It is well-documented that the order in which information is studied and later presented at recall or recognition has an effect on memory performance (Mather, 2007; Mulligan & Peterson, 2008; & McDaniel & Bugg, 2008). If order effects accounted for the current results then it could be said that the presentation of a pure or mixed list affected encoding processes in memory. In experiment D, however, order effects analysis revealed no significant effect of list order presentation.

One possible explanation for the observed results is that visual images are encoded under a different process than taboo words and the priority-binding hypothesis does not generalize to non-lexical stimuli. Results of this type would provide support for arousal theory, although they would run counter to a number of previous experiments (Dewhurst & Parry, 2000; Gruhn, Scheibe, & Baltes, 2005; Gruhn, Scheibe, & Baltes, 2007; Hadley & MacKay, 2006; Mulligan & Peterson, 2008). In this experiment, the lack

of any main effects for memory (notably for the index  $d'$ ) indicated that participants did not recognize negative images better than neutral images in either list condition. This replicates the result to Devore (2008), where equivalent memory performance was found for negative, positive, and neutral images in pure lists. Given that this experiment included both mixed and pure lists and a recognition phase following each, this was an unexpected result because other studies have found enhanced memory performance for negative over neutral stimuli in mixed but not pure lists (MacKay & Ahmetzanov, 2005; Hadley & MacKay, 2006; Gruhn, Smith, & Baltes, 2005), one of which included picture stimuli (Gruhn, Scheibe, & Baltes, 2007).

Another possibility is that the trial presentation rate of 1000 ms (500 ms image duration, 500ms inter-stimulus interval) was too slow and did not produce a sufficient demand on attentional resources for priority-binding to occur (Hadley & MacKay, 2006). The 1000ms presentation rate may have also allowed for a verbal encoding strategy to confound results (Morey & Cowan, 2005). This is unlikely however, given the results of experiment A (Devore, 2008) and Gruhn, Scheibe, & Baltes's (2007) findings using a 1200ms presentation rate (800ms image presentation duration and a 400ms ISI).

Due to the graphic nature of some IAPS stimuli, memory performance may have been impaired due to some repressed memory process. This means that some of the participants may have found the images so disturbing they blocked them out of their minds, preventing later recognition. This explanation is highly unlikely however, as the majority of scientific data suggests that emotion consistently increases memory performance, not decreases it (see Cahill et al., 1994; Cahill & McGaugh, 1998; Christianson & Loftus, 1987). High proportions of correctly recognized images in

experiments A, B, C, & D also run counter to the notion of repression. Suffice to say, it is difficult to explain the lack of an enhanced memory effect in the mixed list condition.

In consideration of the pure list condition, the pure list block consisted of 6 lists: 3 negative and 3 neutral lists consisting of 9 images each. Presentation of these lists was pseudo-random, so that participants would receive no more than 2 negative or 2 neutral lists before the valence of the list would change. It is possible that the pseudo-random alternation of valence in the pure list block caused the information to be encoded in memory as one extended mixed list despite the use of arithmetic tasks to separate the lists. If the lists were encoded as a single extended mixed list, this may have affected memory performance in the recognition memory task. This is similar to the primary conclusion of experiment C, where the pseudo-random alternation of mixed and pure lists apparently caused information to be encoded as one extended mixed list.

Of equal consideration of encoding processes are retrieval factors that may have played a role in the results of experiments C & D, such that the design of the recognition tasks may have played a significant role in the way that encoded information was retrieved and subsequently measured. An explanation of this sort is supported by the findings of McDaniel, Dornburg, & Guynn (2005), whose study is outlined here to put the results of experiments C & D in context.

McDaniel and colleagues proposed a new experimental paradigm to decouple the retrieval set from the study list type and used this paradigm to investigate encoding and retrieval accounts of the bizarreness effect. In that experiment, participants were presented with two pure lists of either bizarre or common sentences (counterbalanced for order) separated by a 5-min distractor task. During the test phase, half of the participants

were given a recall test for List 1 and then given a recall test for List 2 (or vice versa). The other half were given a combined recall test in which they were asked to recall any of the sentences from either list. The test manipulation was designed to vary the retrieval set. In the separate recall condition, each test should induce a pure retrieval set, with items of only one type. In the combined condition, the retrieval set was mixed, consisting of items from both lists (and both sentence types). Because encoding conditions were held constant, the encoding accounts argue that the effect of bizarreness should be constant across test conditions. Furthermore, because pure lists were used, the encoding accounts predict little effect of bizarreness in either recall condition. In contrast, the retrieval accounts argue that the combined test condition should induce a mixed retrieval set, rendering the bizarre items relatively distinct (producing a bizarreness effect), whereas the separate test condition should induce pure retrieval sets, no relative distinctiveness, and no bizarreness effect. McDaniel et al.'s (2005) results corresponded to the retrieval account: A significant bizarreness effect was found in the combined condition, but not in the separate condition.

It is important to note that Hadley and MacKay (2006) kept encoding demands consistent across their experiment and they used a separate recall test following presentation of each list condition (i.e., pure and mixed lists). Because a combined retrieval task provides poor discrimination between list conditions, separate recall tests for each list were likely a significant factor in their results. In contrast, experiments C & D both used a combined retrieval task (i.e., negative and neutral images in the recognition task). Although encoding processes and retrieval set demands are important factors to consider when interpreting the current results, they do not fully explain why negative



images in experiment D were not better remembered in the mixed list condition.

Furthermore, the design manipulations from experiment C to experiment D confounded interpretation of encoding versus retrieval demands because both encoding processes and retrieval demands changed (i.e., image presentation and recognition task design changed from experiment C to D).

It is unlikely the results can be explained by a ceiling effect. Participants correctly recognized 76.5% of all images and the proportion of correctly recognized images in experiment D was similar to other recognition memory studies. In a larger study consisting of 600 pictures, researchers found human recognition memory rates of 90%, 92%, and 98% between old and new pictures (Shepard, 1967). D'Argembeau and Van der Linden (2005) found recognition memory performance rates of 89%, 84%, and 77% for negative, positive, and neutral images, respectively. Gruhn, Scheibe, & Baltes (2007) found recognition memory rates of 78%, 73%, and 74% for negative, neutral, and positive images, respectively. This suggests the current results are consistent with human recognition memory performance and not supportive of a ceiling effect.

In sum, the design of experiment D was likely not precise enough to properly test the predictions of priority-binding and arousal theory. Moving forward, the design of experiment E was crafted from the lessons of all the previous experiments to closely approximate the test conditions of Gruhn, Scheibe, & Baltes (2007).

## Experiment E

### Major Hypotheses, Aims, and Significance

The path to experiment E has been an evolution of experimental design. Recall that experiments A & B examined the priority-binding hypothesis using a pure list design. Experiments C & D attempted to integrate the pure and mixed list design, with the intent of replicating experiment A's equivalent recognition memory results for pure lists with the additional goal of finding enhanced memory performance for negative over neutral images in mixed lists. Ultimately, the results of experiments C & D were inconclusive and not supportive of either priority-binding theory or arousal theory. I proposed the notion that the previous designs could not discriminate enough to provide a fair test of the priority-binding hypothesis because the retrieval demands used a combined set type (i.e., the recognition task had items from mixed and pure list conditions).

Building on the lessons of all the previous experiments, experiment E was designed to test the priority-binding hypothesis using a design similar to Gruhn, Scheibe, & Baltes (2007). In their study they used a between-subjects design of young adults and elderly adults and compared recognition memory performance between groups. Their results supported the predictions of the priority-binding hypothesis in young, but not old adults. Because the population used in experiment E consisted of undergraduate students ages 18-45 ( $M = 25$ ), I report the young adult results here only. Using a separate retrieval list design, they found an enhanced memory effect for negative over neutral and positive images in mixed lists. Recognition performance in pure lists found enhanced memory for

negative over positive, but not neutral images. Overall, young adults recognized pictures much better in pure lists than mixed lists (i.e., higher value for index  $d'$ ).

Experiment E used a four block design consisting of two pure blocks and two mixed blocks. Each block consisted of a 27-image study list. The mathematical distracter task from experiments C & D was omitted and a recognition memory task followed each block. This design was chosen to eliminate the combined retrieval set confound related to the pseudo-random alternation of negative and neutral pure lists, which were hypothesized to be encoded as one large mixed list in experiment D's pure block condition. This design differs from Gruhn, Scheibe, & Baltes (2007) in that their study used negative, neutral, and positive images, and had 6 blocks consisting of three pure blocks and three mixed blocks. Each block consisted of 42 images.

The goal of experiment E was to replicate the cognitive results of Gruhn, Scheibe, & Baltes (2007) and to understand the physiological correlates of emotion processing using heart rate and skin conductance. From a broader perspective, conducting this research elucidates the fundamental mechanisms of how emotion affects memory and how the physiological correlates of emotion processing are related to memory performance. Knowledge of this type informs theories of human information processing and provides a better understanding of how emotion affects attention-mediated processes.

**Hypotheses.** The hypotheses are identical to experiment D but are reiterated here for continuity.

**Recognition measures.** This design was chosen to test the priority-binding hypothesis for pure and mixed RSVP lists. It is expected that for pure lists there will be equivalent recognition memory performance between negative and neutral images.

Within mixed lists it is expected that there will be significantly enhanced memory performance for negative over neutral images. Using the logic of the priority-binding theory, there should be greater sensitivity ( $d'$ ) for negative over neutral images in mixed lists, but not pure lists. Similarly, there should be more *remember* than *know* or *guess* responses for hits in mixed lists, but not in pure lists. This result would comport with the predictions of priority-binding theory and the findings of Dewhurst & Parry (2000). If participants indicate more *remember* and *know* responses in both pure and mixed lists for negative stimuli, this result would be in support of arousal theory.

***Physiological data.*** It is predicted that heart rate data during the study and recognition phase will comport with the triphasic deceleration, acceleration, deceleration response seen in similar picture studies (Lang, Bradley, & Cuthbert, 1999; Bradley & Lang, 2007). The greatest change in mean beats per minute is expected to occur during negative-valence images. For skin conductance in the study phase it is expected that mean amplitude and number of SCR responses will be greater for negative over neutral images as a function of arousal. SCR for recognition memory will not be included due to practical considerations of the study design (i.e., speed of participant responses tends to be faster than the length of time necessary for SCR responses to be measured accurately). These expected physiological results are well supported by the literature in emotion and motivation research (Bradley et al., 2001).

Recognition memory performance should not correlate with heart rate changes in pure lists, but should in mixed lists. A result of this type would suggest that recognition memory performance is independent of measures of physiological arousal (Devore et al., 2008).

***Arousal and valence ratings.*** It is predicted that participants will rate the selected IAPS images similarly to the standardized IAPS ratings. Arousal ratings should be higher and valence ratings lower for negative than for neutral images. A result to the contrary would suggest that participants were not affected in the same way as the population in the standardized IAPS ratings, and consideration of this would be important in interpreting all relevant data. To explain a contrary result, it is possible that increased media exposure to violence, gore, and sexually explicit material in the participant population has desensitized their subjective experience of the material, rendering negative stimuli not as arousing.

## **Research Design and Methods**

**Participants.** Participants ( $N = 24$ ) were recruited from undergraduate subject pools at California State University, San Bernardino (22 women, aged = 18-45,  $M = 25$ ,  $SD = 7$ ). Participants spoke fluent English, were right-handed, reported normal-or-corrected vision, and received credit which could be applied toward their course in exchange for their participation in the study. All participants in the experiment gave informed consent; to comply with ethical guidelines, the consent form explicitly mentioned that they would be seeing potentially disturbing and graphic pictures and were told they were free to withdraw from the experiment with no penalty at any time. No participant in this experiment reported having a history of neurological or mental illness.

**Power analysis.** The power analysis, identical to experiment C, determined that 18 participants would be necessary to achieve a power of .9 with alpha set at .05 to detect significant results for a medium effect size of .5..

**Physiological measures.** Heart rate and skin conductance measures were identical to experiment C.

**Materials.** Materials were identical to experiment C (i.e., 108 studied images and 108 new images).

**Procedure and design.** The procedure changed from experiment D to match a design similar to Gruhn, Scheibe, & Baltes (2007). The experiment consisted of four blocks with two pure and two mixed blocks consisting of 27 images each. The pure blocks consisted of either 27 negative or neutral images. The two mixed blocks consisted of 13 negative and 14 neutral images and 14 negative and 13 neutral images. Blocks were pseudo-random in presentation, such that participants would receive at least one mixed and one pure block in each half of the experiment (Figure 26). Image presentation rate and inter-stimulus-interval was identical to experiments A, B, C, and D (Figure 2). A recognition memory task followed presentation of each block (Figure 27). Each recognition memory task consisted of the 27 studied images presented in the block and 27 new, unstudied images to be used as foils. In the mixed blocks, the number of new images by valence matched the number of studied images (i.e., 14 negative and 13 neutral *studied* images was followed by 14 negative and 13 neutral *new* images in addition to the studied images). Image presentation in the recognition memory task was random. Image selection was randomized for each participant, so that each participant received a unique selection of images in each studied block and recognition phase. Following the recognition phase, participants were asked to rate all of the images they viewed on valence and arousal using the Self-Assessment-Manikin-derived scale (Lang et al, 1999). These ratings were then compared to the IAPS normative ratings.

# Experiment E

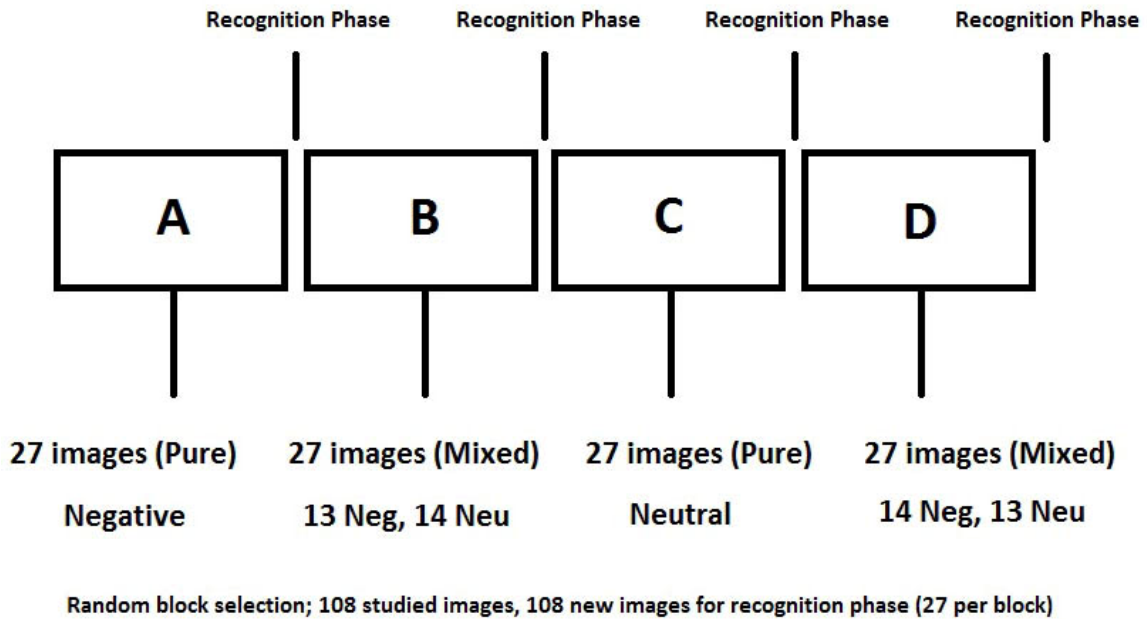


Figure 26. Experiment E design. There were a total of four blocks; two pure and two mixed. Pure blocks consisted of either 27 negative or neutral images. The order of the blocks varied across participants. Mixed blocks had 27 total images, with one block consisting of 13 negative and 14 neutral images, and the other block consisting of 14 negative and 13 neutral images. A recognition memory task was presented at the end of each block consisting of 27 old and 27 new images.

*Step 1*  
Have you seen this image?



Press 1 for Yes, 9 for No

*Step 2*  
*Memory Judgment*  
Enter "R" for Remember  
Enter "K" for Know  
Enter "G" for Guess

Figure 27. Experiment E recognition phase. Participants were shown 27 images from the studied phase and 27 new images in random order. Following a "Yes/No" response, participants entered a memory judgment for the *remember-know-guess* query.

## Results

**Recognition memory task.** For each valence category and list condition, Table 6 provides percentages of hits and false alarms, the discrimination index  $d'$ , and the response bias  $C$ .

Table 6

*Recognition Performance in the Pure and Mixed List Conditions*

Index X Valence	<i>M</i>		<i>SD</i>	
	Pure	Mixed	Pure	Mixed
Hit Rates				
Negative	0.844	0.874	0.102	0.084
Neutral	0.867	0.847	0.102	0.109
False Alarms				
Negative	0.174	0.147	0.128	0.119
Neutral	0.119	0.111	0.134	0.122
$d'$				
Negative	2.154	2.419	0.586	0.659
Neutral	2.583	2.526	0.637	0.746
$C$				
Negative	-0.040	-0.031	0.379	0.334
Neutral	0.055	0.118	0.402	0.349

*Note.* Hit rates and false-alarm rates are in percentages.

**Recognition memory proportion correct.** The proportion of correctly recognized “old” images was not affected by image valence or list condition,  $F$ 's(1,23) < 0.34,  $p$ 's > 0.57 and the interaction was not significant,  $F(1,23) = 2.19$ ,  $p = 0.15$  (Figure 28). The proportion of correctly recognized “new” images was affected by image valence,  $F(1,23) = 21.56$ ,  $p < 0.001$ ,  $\eta^2 = 0.48$ , but not list condition,  $F(1,23) = 0.73$ ,  $p = 0.40$ ; the interaction was not significant,  $F(1,23) = 0.01$ ,  $p = 0.92$  (Figure 29). These results



suggested that “old” negative images were not better remembered in either pure or mixed lists; however, “new” neutral images were better recognized in both list conditions.

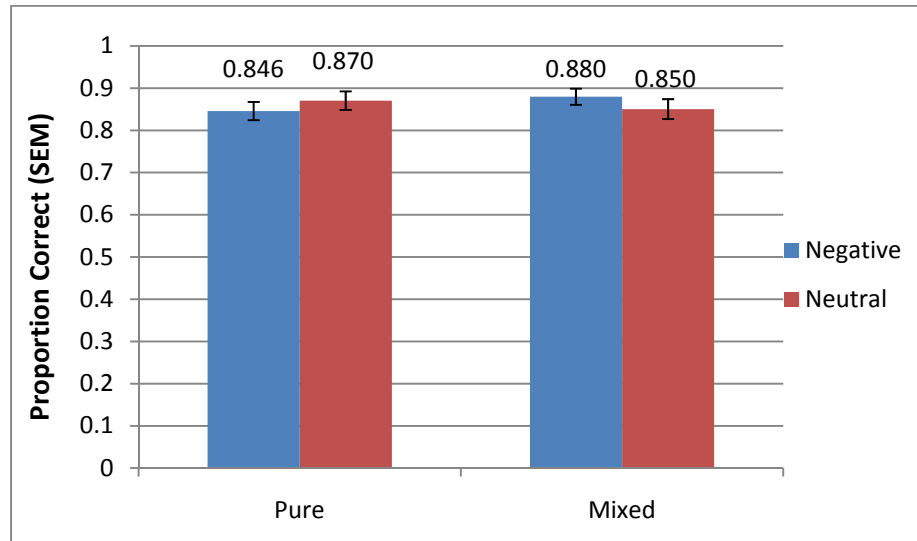


Figure 28. Experiment E: Mean proportions of recognition memory performance for old images as a function of list condition and picture valence. Error bars represent standard error of the mean.

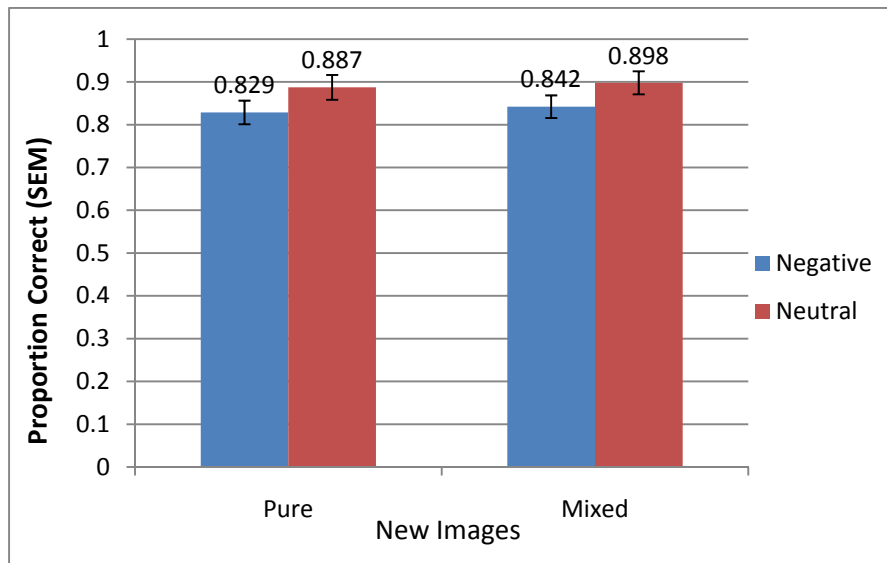


Figure 29. Experiment E: Mean proportions of recognition memory performance for new images as a function of list condition and picture valence. Error bars represent standard error of the mean.

**Signal detection measures.** The recognition discrimination index  $d'$  was analyzed with a 2 x 2 (List condition X Valence) ANOVA. Participants recognized neutral images better than negative images,  $F(1,23) = 7.10, p = 0.014, \eta^2 = 0.24$ ; there was no main effect of list condition,  $F(1,23) = 1.24, p = 0.28, \eta^2 = 0.05$ ; moreover, the interaction of List condition X Valence was not significant,  $F(1,23) = 2.07, p = 0.16, \eta^2 = 0.08$  (see Figure 30).

Even though the interaction was not significant, follow-up paired-sample  $t$ -tests were conducted which confirmed the better recognition memory performance for neutral over negative images in pure lists,  $t(23) = -3.376, p = 0.003$  but not mixed,  $t(23) = -0.628, p = 0.536$ .

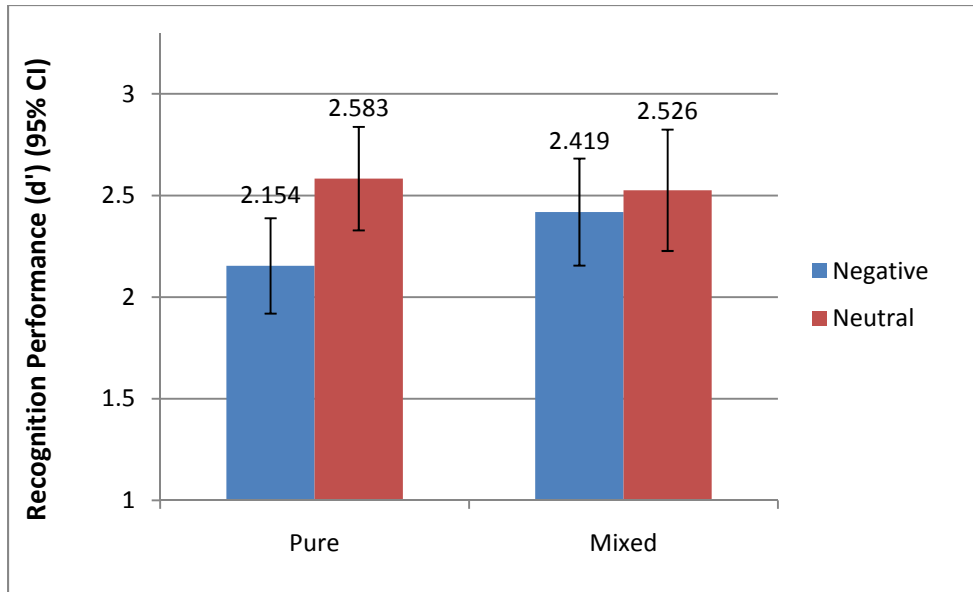
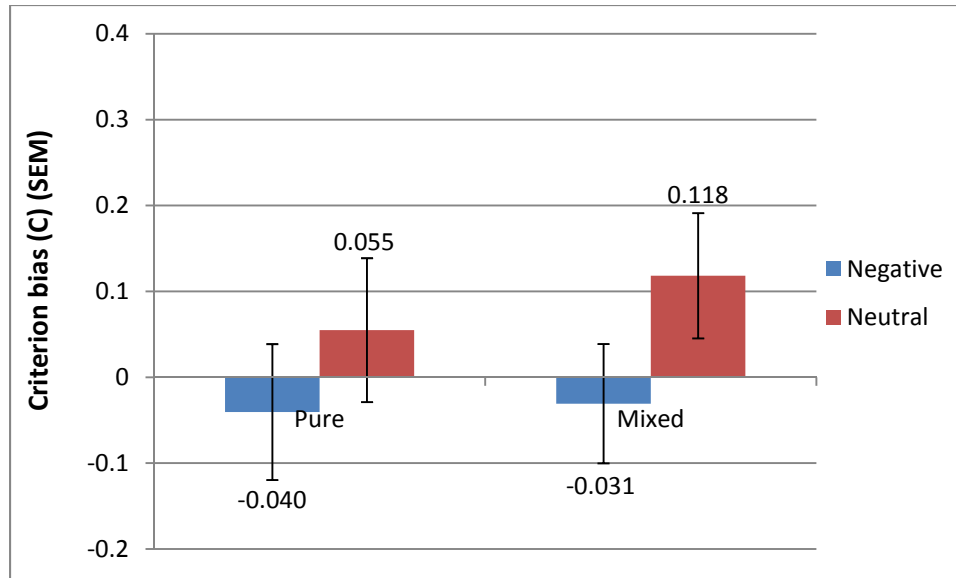


Figure 30. Experiment E: Recognition performance ( $d'$ ) as a function of list condition and picture valence. Higher numbers indicate greater sensitivity. Error bars represent 95% confidence intervals.

The recognition discrimination index ( $d'$ ) results were contrary to the predictions of priority-binding theory because negative images should have a higher  $d'$  value than neutral images in the mixed, but not pure list condition. To understand these results, I ran an analysis on the response bias index ( $C$ ) to disentangle discrimination from response bias.

Participants displayed a more liberal response bias for negative than neutral images tending to make more negative than neutral image false alarms,  $F(1,23) = 4.29$ ,  $p = 0.05$ ,  $\eta^2 = .16$ . This bias pattern for more negative over neutral false alarms was similar in pure and mixed lists,  $F(1,23) = 0.63$ ,  $p = 0.44$ ,  $\eta^2 = .027$ ; the interaction was not significant,  $F(1,23) = 0.25$ ,  $p = 0.60$ ,  $\eta^2 = .01$  (see Figure 31).



*Figure 31.* Experiment E: Criterion bias (C) as a function of List condition and picture valence. Lower numbers (i.e.,  $C < 0$ ) indicate a liberal bias, indicating more false alarms and higher numbers (i.e.,  $C > 0$ ) indicate a conservative bias.

***Arousal and valence ratings.*** As expected, negative pictures (as compared to neutral) were rated as significantly more negative,  $t(18) = -16.75, p < .001$ ; and more arousing,  $t(18) = 12.12, p < .001$ . Compared to the normative IAPS ratings, participants rated the negative images as more negative,  $t(18) = -4.79, p < 0.001$ , and more arousing although the difference only approached significance,  $t(18) = 2.04, p = 0.06$ . There were no significant differences between the normative IAPS ratings and participant ratings for neutral images on the arousal or valence scales ( $p$ 's  $> 0.46$ ) (see Table 7). According to the ratings data, participants subjectively reacted to the images as intended. Physiological data, including heart rate and skin conductance responses, should corroborate the ratings data. Additionally, analyses with gender-based (females only) IAPS norms were conducted and did not alter the results or interpretations.

Table 7

*Mean Ratings of IAPS Images displaying Means, Standard Deviations, Confidence Intervals, and Standard Errors*

	Mean	Mean Diff.	Std. Dev.	CI 95%	Std. Error
<i>Valence</i>					
Negative	1.803	-0.635*	0.528	0.238	0.125
Neutral	5.394	0.15	0.952	0.428	0.224
<i>Arousal</i>					
Negative	6.690	0.941*	1.155	0.519	0.296
Neutral	3.026	0.182	1.256	0.565	0.296

Note: Valence ratings are rated unpleasant to pleasant (1-9); Arousal ratings are rated calm to excited (1-9). Mean Difference is difference of selected images from the normative IAPS ratings. \* $p < 0.057$ .

***Remember-know-guess.*** Planned comparisons expected more *remember* than *know* or *guess* responses. Pure lists were expected to have an equivalent number of *remember* responses across valence while mixed lists were expected to have more *remember* responses for negative than neutral images. Figure's 32 and 33 present the mean proportions for *remember-know-guess* responses for hits and false alarms (respectively) as a function of list condition and picture valence. A 3 X 2 X 2 (Response type x List condition x Valence) Omnibus ANOVA was conducted. Mauchly's test indicated that the assumption of sphericity had been violated  $\chi^2(2) = 16.58, p < 0.001$ , therefore, degrees of freedom were corrected using Greenhouse-Geisser estimates of sphericity ( $\epsilon = 0.64$ ). The results show an effect of response type,  $F(2,20) = 4.05, p = 0.045, \eta^2 = 0.16$ . This means that participants reported more of a particular response type so post-hoc pairwise comparisons using the Bonferroni correction of *remember-know-*

guess responses was conducted. The analysis revealed more *remember* than *know* or *guess* responses,  $p = 0.038$ , but this did not differ significantly across list condition or valence.

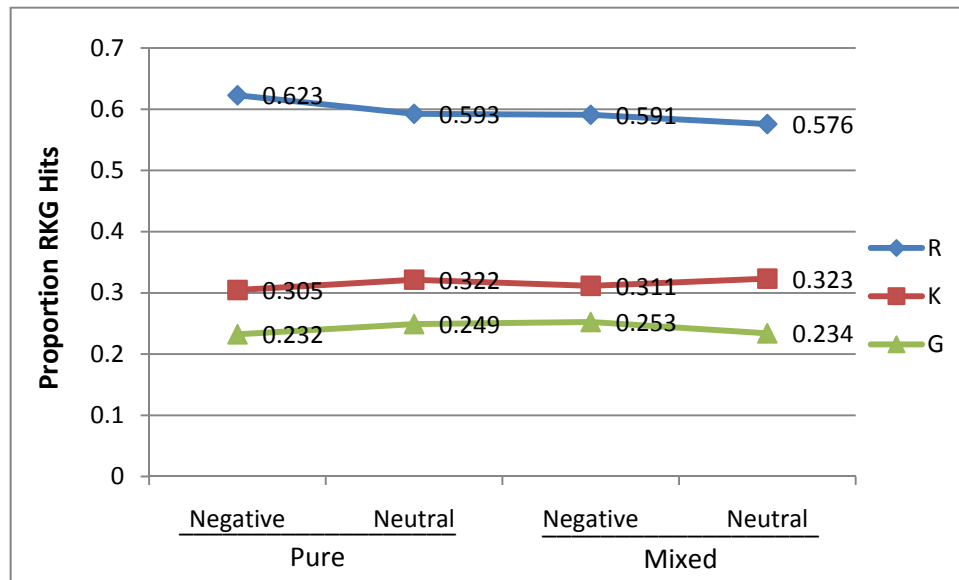


Figure 32. Experiment E: Proportion of *Remember-know-guess* hit responses as a function of list condition and picture valence.

Analysis of *remember-know-guess* data for false alarms began using a 3 X 2 X 2 (Response type X List condition X Valence) Omnibus ANOVA. In addition to the main effect of response type,  $F(2,22) = 13.25$ ,  $p < 0.001$ ,  $\eta^2 = 0.55$ , there was also an effect of valence,  $F(1,23) = 21.86$ ,  $p < 0.001$ ,  $\eta^2 = 0.49$ . There was a significant interaction effect for Response type X Valence,  $F(2,22) = 11.67$ ,  $p < 0.001$ ,  $\eta^2 = 0.52$ . No other effects or interactions reached significance.

To disentangle the interaction, a 2 X 2 (List condition X Valence) ANOVA was conducted for *remember* responses (which varied the most across valence). There was a

main effect of valence,  $F(1,23) = 39.73, p < 0.001, \eta^2 = 0.63$ , with more negative than neutral false alarm *remember* responses (Figure 33). The *remember-know-guess* false alarm data demonstrated that participants made more *remember* false alarm judgments for negative over neutral images. This comports with the liberal criterion bias for negative over neutral images seen in the signal detection analysis.

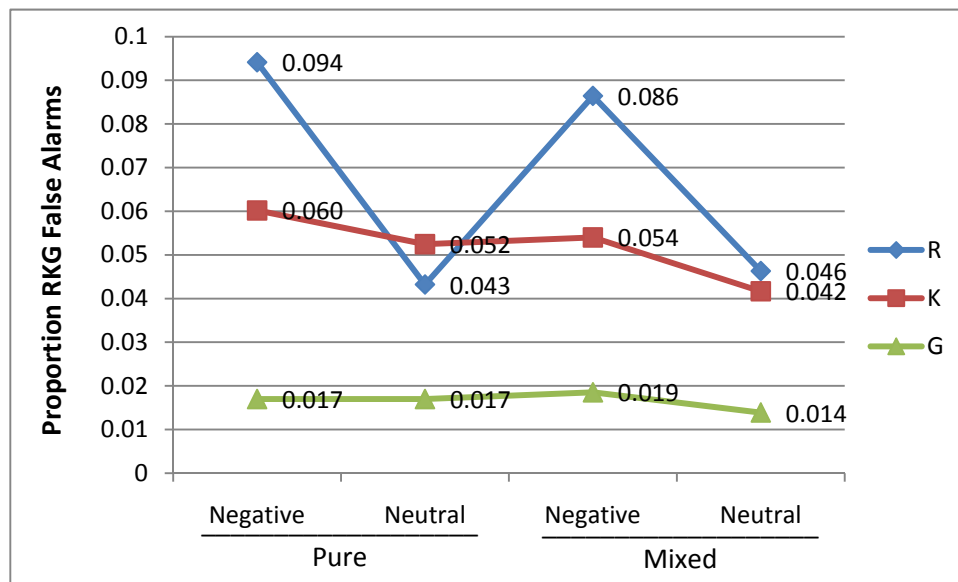


Figure 33. Experiment E: Proportion of *Remember-know-guess* false alarm responses as a function of list condition and picture valence.

**Physiological results in studied lists.** This section outlines the results for the physiological data in the studied list phase.

**Skin conductance.** A repeated measures ANOVA was conducted to determine if the mean amplitude of responses varied by list condition. It was expected that participants would demonstrate increased amplitude to negative images in both pure and mixed lists; however, they demonstrated the greatest amplitude to images in the mixed condition (but

not significantly so). Nevertheless, statistical analyses revealed no significant differences in electrodermal responding across list conditions,  $F(2,20) = 0.89, p = 0.43, \eta^2 = 0.08$  (Figure 34). Similarly, there was no effect of list condition on the number of responses produced,  $F(2,20) = 0.31, p = 0.74, \eta^2 = 0.03$  (Figure 35).

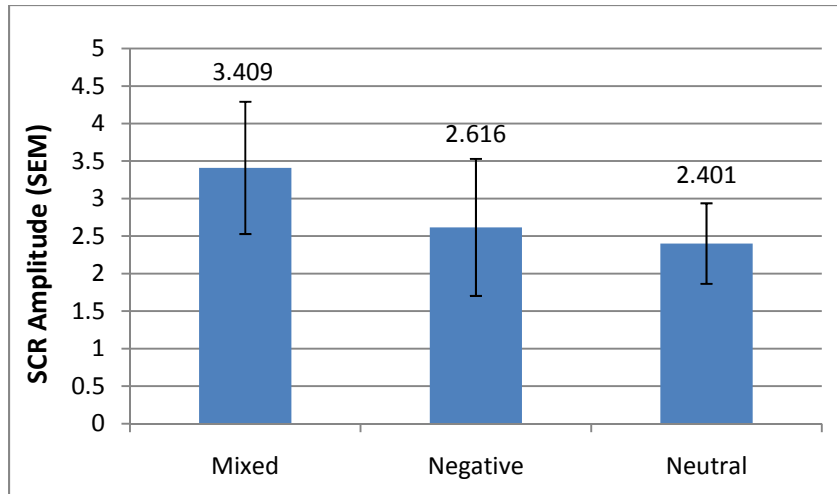


Figure 34. Experiment E: Mean skin conductance amplitude as a function of list condition. Error bars represent standard error of the mean.

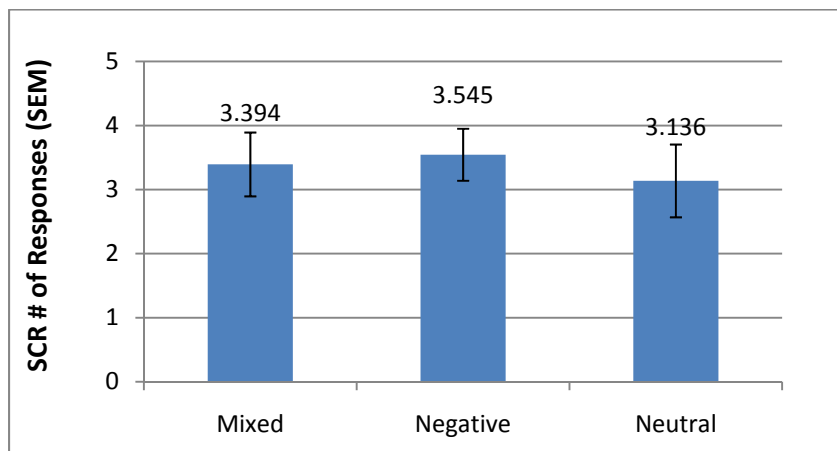


Figure 35. Experiment E: Number of skin conductance responses as a function of list condition. Error bars represent standard error of the mean.



Similar to experiment D, the lack of difference across list conditions for amplitude and number of responses conflicts with the well-established literature of increased skin conductance reactivity to negative stimuli (Bradley & Lang, 2007). Although participant's subjective ratings of the images indicated that they experienced negative images as negative and arousing as intended, they demonstrated no greater skin conductance response. It was expected that participants would demonstrate increased amplitude and number of responses to negative images in the pure and mixed list conditions. Examination of Figures 34 and 35 indicates that although the results were not significantly, the directionality of both amplitude and number of responses was as expected (i.e., higher amplitude and more responses for pure negative and mixed conditions) and comports with the ratings data.

***Heart rate in studied lists.*** As may be observed in Figure 36, following onset of the first image in the list, heart rate decelerated at the onset of image list presentation and remained below baseline throughout the list. These data were analyzed with a 3 X 28 (List condition X ½ - second Time Bins, beginning with bin 4) repeated measures ANOVA. Heart rate response to stimuli revealed no differences among the list conditions,  $F(2,19) = 0.37, p = 0.69, \eta^2 = 0.04$ . Not surprisingly, heart rate varied significantly over Time,  $F(27) = 6.08, p < 0.001, \eta^2 = 0.23$ ; the interaction was not significant,  $F(54) = 0.62, p = 0.99, \eta^2 = 0.03$ .

Contrary to expectation, this result suggested that, although heart rate decelerated significantly during the study phase, it did not vary by valence (Figure 36). Similarly to the skin conductance results and well established literature on heart rate variability during exposure to emotional images (Bradley & Lang, 2007), it was expected that changes in

heart rate would decelerate more in negative pure or mixed list conditions than in the neutral pure list condition. Nevertheless, although not significant, examination of Figure 36 shows a trend for greater heart-rate deceleration for the negative and mixed lists than for neutral.

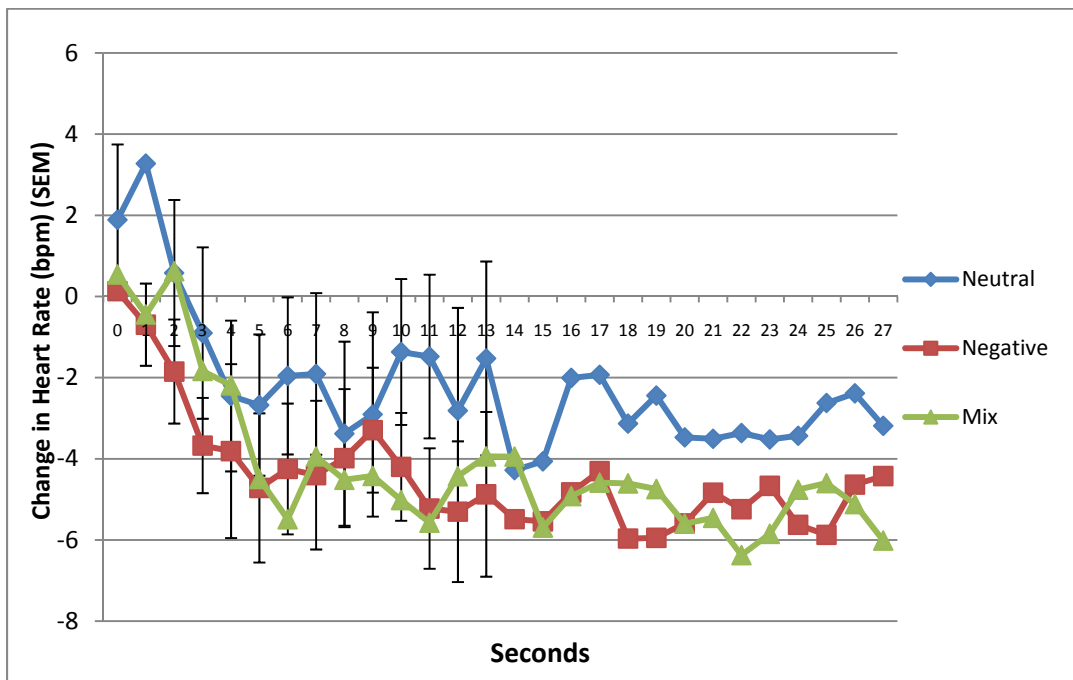


Figure 36. Experiment E heart rate change (BPM) as a function of list condition and time (seconds). Error bars represent the standard error of the mean.

**Physiological results in recognition task.** This section outlines the results for the physiological data in the recognition list phase.

**Heart rate in pure list recognition.** The first 6 seconds of heart rate after the onset of the image were examined for each participant during the recognition task. A 2 X 2 X 8 (Old and New X Valence X Time Bins (2-9)) repeated measures ANOVA was conducted to determine changes in heart rate across time for the four conditions. Although only

small changes in heart rate were observed during recognition, a compressed version of the standard pattern was observed (Figure 37) (Bradley & Lang, 2007). This included a short deceleration preceding an acceleration, probably associated with the task response. The analyses confirmed a significant change across Time (i.e., bin),  $F(7,14) = 5.798$ ,  $p = 0.003$ ,  $\eta^2 = 0.744$ , and heart rate decelerated greater for new as compared to old images,  $F(1,20) = 9.83$ ,  $p = 0.005$ ,  $\eta^2 = 0.33$ . The interaction of old and new X bin was significant,  $F(7,14) = 3.94$ ,  $p = 0.01$ ,  $\eta^2 = 0.66$ . This indicated that in pure list recognition tasks, “new” negative and neutral images had a greater decrease in heart rate over time (Figure 37). Inspection of Figure 37 suggested that the maximal heart rate effect occurred approximately four seconds after image onset. To examine this epoch of the heart rate waveforms further, seconds five through nine were analyzed using a 2 X 2 X 5 (Old and New X Valence X Time Bin (5-9)) repeated measures ANOVA. This revealed that the main effects of old and new,  $F(1,20) = 11.42$ ,  $p = 0.003$ ,  $\eta^2 = 0.36$ ; and Time,  $F(4,17) = 4.88$ ,  $p = 0.008$ ,  $\eta^2 = 0.53$  remained significant; however, the old and new x bin interaction was no longer significant,  $F(4,17) = 2.14$ ,  $p = 0.12$ ,  $\eta^2 = 0.34$ .

The effect of Time demonstrated the classic triphasic pattern of responding to emotional stimuli (i.e., initial acceleration, then a deceleration, followed by another acceleration) (Bradley & Lang, 2007). This was supported by a within-subjects contrast which revealed a significant quadratic,  $F(1,20) = 7.662$ ,  $p = 0.012$ ,  $\eta^2 = 0.277$ ; and cubic effect,  $F(1,20) = 7.515$ ,  $p = 0.013$ ,  $\eta^2 = 0.273$ . The fact that participants’ heart rate changed in response to the images also supported the subjective arousal and valence ratings to negative and arousing images in the ratings analysis.

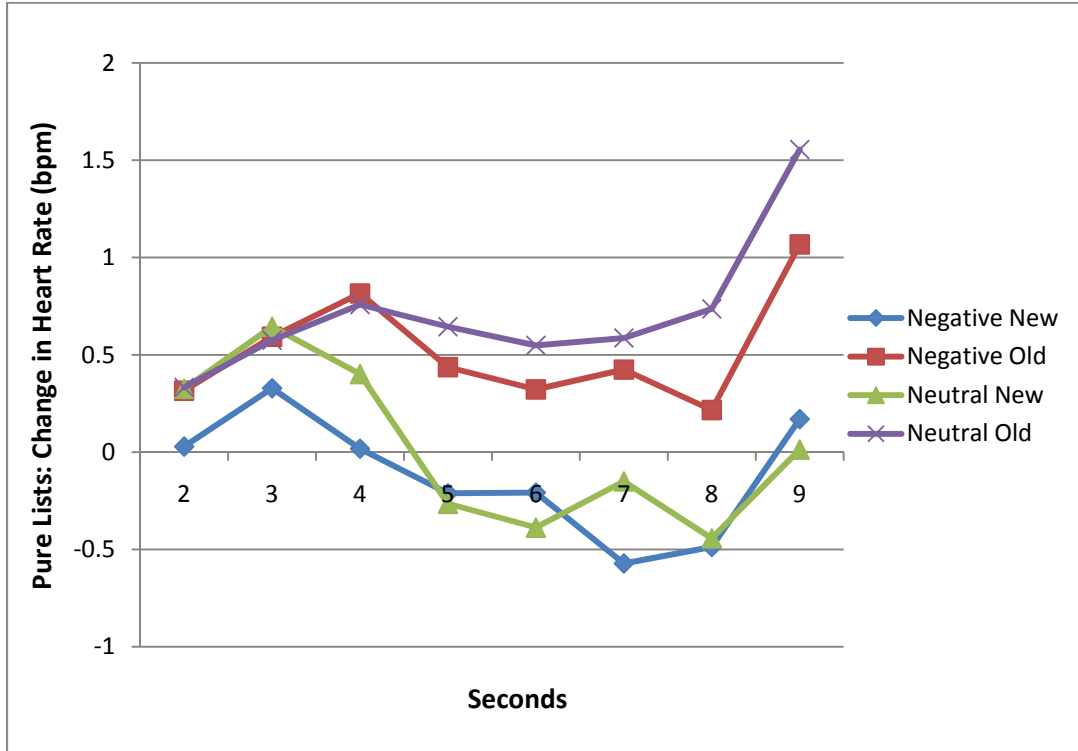


Figure 37. Experiment E: Heart rate change (BPM) in pure lists as a function of old and new, valence, and bin (time in seconds). Changes in heart rate varied by old and new, with new images showing a greater overall decrease in heart rate. Note the general effect of time (i.e., bin) as demonstrated by the triphasic pattern of responding (i.e., initial acceleration, deceleration, and another acceleration).

**Heart rate in mixed list recognition.** A 2 X 2 X 8 (Old and New X Valence X Time Bin (2-9)) repeated measures ANOVA was conducted to determine changes in heart rate across time for the four conditions. As in the analysis for pure list recognition, a short deceleration and subsequent acceleration reflecting the standard pattern was observed (Figure 38). Heart rate decelerated more for negative new images,  $F(1,20) = 4.68, p = 0.04, \eta^2 = 0.19$ ; and varied significantly across time,  $F(7,14) = 14.76, p < 0.001, \eta^2 = 0.88$ ; there were no other significant main effects or interactions. To examine the epoch of maximal apparent effect in the heart rate waveform, a 2 X 2 X 5 (Old and

New X Valence X Time Bin (5-9)) repeated measures ANOVA was conducted. This analysis revealed a near significant main effect of old and new,  $F(1,20) = 3.85, p = 0.06, \eta^2 = 0.16$ ; and valence,  $F(1,20) = 3.92, p = 0.06, \eta^2 = 0.16$ . There was a significant effect of bin,  $F(4,17) = 8.94, p < 0.001, \eta^2 = 0.68$ . None of the interactions were significant. Taken together, these data indicate that subjects tended to show a greater deceleration in heart rate for “new” images, and to new negative images in particular (Figure 38).

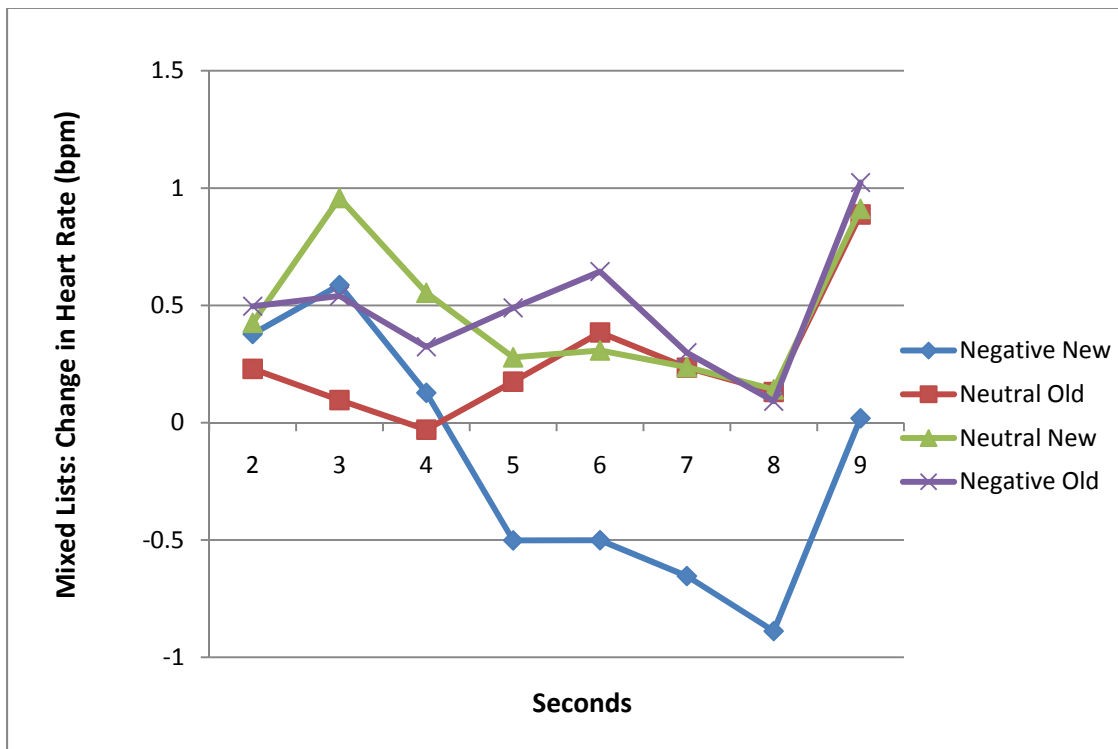


Figure 38. Experiment E: Heart rate change (BPM) in mixed lists as a function of old and new, valence, and bin (time in seconds). Changes in heart rate varied by new negative images. The classic triphasic pattern of responding to emotional stimuli was captured by the effect of bin.

**Physiology results summary.** Overall, skin conductance amplitude and number of responses did not vary as a function of list condition although the direction of the

amplitude and responses was as expected (i.e., greater amplitude and more responses in the negative pure and mixed conditions). Heart rate changes in the study phase demonstrated no effect of list condition, but did show a classic triphasic pattern of response across time. Again, negative pure and mixed conditions were in the expected direction but were not significant (i.e., greater deceleration than in the neutral pure condition).

In the pure list recognition phase, heart rate varied as a function of old and new and there was a significant change in heart rate across time (i.e., triphasic pattern). In the mixed list recognition phase, there was an effect of valence and change across time (i.e., bin). These results are interesting because they appear to corroborate with priority-binding theory. In the pure list condition, affective arousal was assumed to be equivalent in each list, and the greatest deceleration occurred for new images and did not vary by valence. This is akin to a general orienting response to novel stimuli. In the mixed list condition, however, only negative new images showed the greatest deceleration. It appears that in the mixed condition the contrast of negative and neutral new images created differential affective engagement of the cardiac system, which resulted in a greater deceleration for negative new images. This comports with the predictions of priority-binding theory (i.e., greater deceleration for negative new images in mixed but not pure lists). Also, based on the heart rate data, it was clear that the subjects were indeed reacting to the images.

**Ancillary analyses.** This section outlines post-hoc analyses that the original hypotheses did not anticipate.

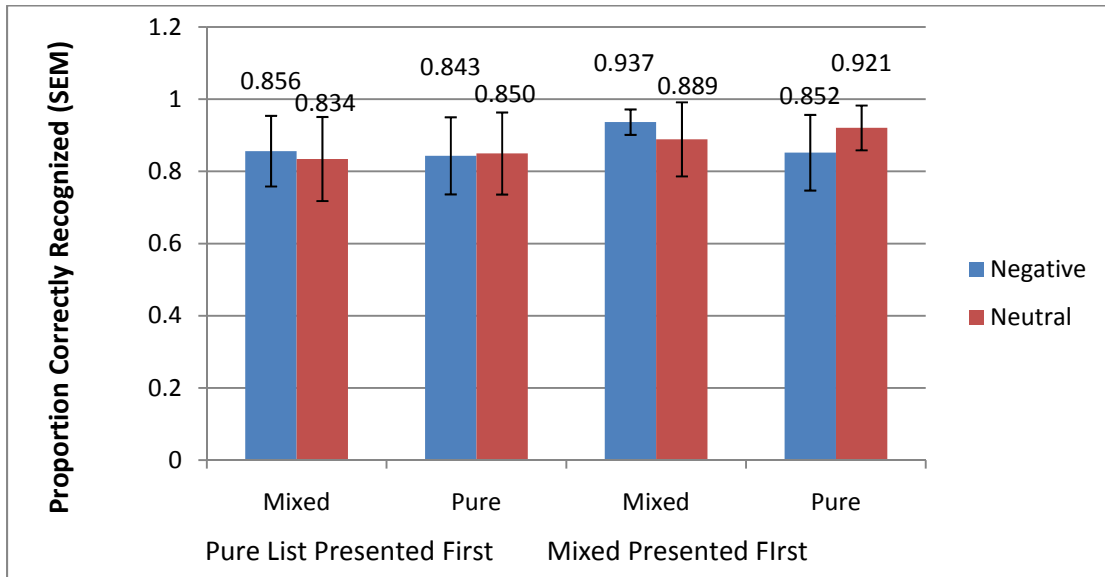
**Order Effects.** List order presentation was pseudo-random across participants, such that each participant would receive a pure and mixed list in the first and second half of the experiment (for a total of four viewed lists). This prevented two pure or two mixed lists being presented in each half of the experiment. Of the 24 participants, 7 received a mixed list first, and 17 received a pure list first.

A 2 X 2 X 2 (List order presentation X List type X Valence) revealed that presentation order did not affect recognition memory performance,  $F(1,6) = 0.12, p = 0.74, \eta^2 = 0.02$ , did not vary by list condition,  $F(1,6) = 0.84, p = 0.39, \eta^2 = 0.12$ , and was not affected by image valence,  $F(1,6) = 0.24, p = 0.64, \eta^2 = 0.04$ . The List order presentation X Valence interaction was near significance,  $F(1,6) = 5.59, p = 0.056, \eta^2 = 0.48$ , and the List condition X Valence interaction was significant,  $F(1,6) = 23.71, p = 0.003, \eta^2 = 0.79$  (Figure 39). Follow-up paired sample *t*-tests revealed no significant differences between each list pair (i.e., mixed list presented first, negative and neutral images in pure list condition),  $p's > 0.073$ . A large effect size was found however, for both list conditions when a mixed list was presented (Cohen's  $d = -0.918, 0.886$ ; pure and mixed lists, respectively), suggesting that recognition memory performance differed when a mixed list was presented first. Statistical analysis did not support this, however.

Table 8

*Order Effects: Proportions, standard deviations, correlations, and Cohen's d as a function of list presentation order, list condition, and valence.*

	Pure List Presented First				Mixed List Presented First			
	Mixed		Pure		Mixed		Pure	
	Neg.	Neu.	Neg.	Neu.	Neg.	Neu.	Neg.	Neu.
<i>M</i>	0.843	0.849	0.856	0.834	0.852	0.921	0.936	0.889
<i>SD</i>	0.107	0.114	0.098	0.117	0.105	0.062	0.035	0.103
Correlation	0.189		-0.008		0.598		0.696	
Cohen's <i>d</i>	-0.046		0.143		-0.918		0.886	



*Figure 39.* Experiment E: Proportion of correctly recognized images as a function of list presentation order, list condition, and picture valence. Error bars represent standard error of the mean.

To account for proportion of hits to false-alarms, the discrimination index  $d'$  was calculated for each list by presentation order, list condition, and valence (Table 9). A 2 X 2 X 2 (Order presentation X List condition X Valence) ANOVA revealed presentation order did not affect subsequent recognition memory,  $F(1,6) = 0.01, p = 0.91, \eta^2 = 0.002$ .



There was also no effect of list condition,  $F(1,6) = 1.93, p = 0.21, \eta^2 = 0.24$ , or valence,  $F(1,6) = 0.71, p = 0.43, \eta^2 = 0.11$ .

The order effects analysis provided no evidence that list presentation order had any significant effect on recognition memory performance. Note however, that the sample size for the order analysis using mixed lists presented first was limited by the number of participants ( $n = 7$ ).

Table 9

*Order Effects: Discrimination index  $d'$ , standard deviations, correlations, and Cohen's  $d$  as a function of list presentation order, list condition, and valence.*

	Pure List Presented First				Mixed List Presented First			
	Mixed		Pure		Mixed		Pure	
	Neg.	Neu.	Neg.	Neu.	Neg.	Neu.	Neg.	Neu.
$d'$	2.217	2.522	2.265	2.597	2.001	2.733	2.792	2.354
$SD$	0.588	0.591	0.573	0.693	0.598	0.766	0.745	0.897
Correlation	0.424		0.418		0.735		0.327	
Cohen's $d$	-0.482		-0.486		-1.473		0.459	

**Other analyses.** There was no effect of caffeine, medication, gender, or sleep,  $p$ 's  $> 0.337$ .

### **Experiment E: Results Summary and Discussion**

Experiment E was developed from the lessons learned from the previous four experiments in order to create enough experimental precision to adequately test the predictions of priority-binding theory. Using a design similar to Gruhn, Scheibe, and Baltes (2007), experiment E was unable to replicate their results using an undergraduate population, namely equivalent recognition memory performance and discrimination ( $d'$ )

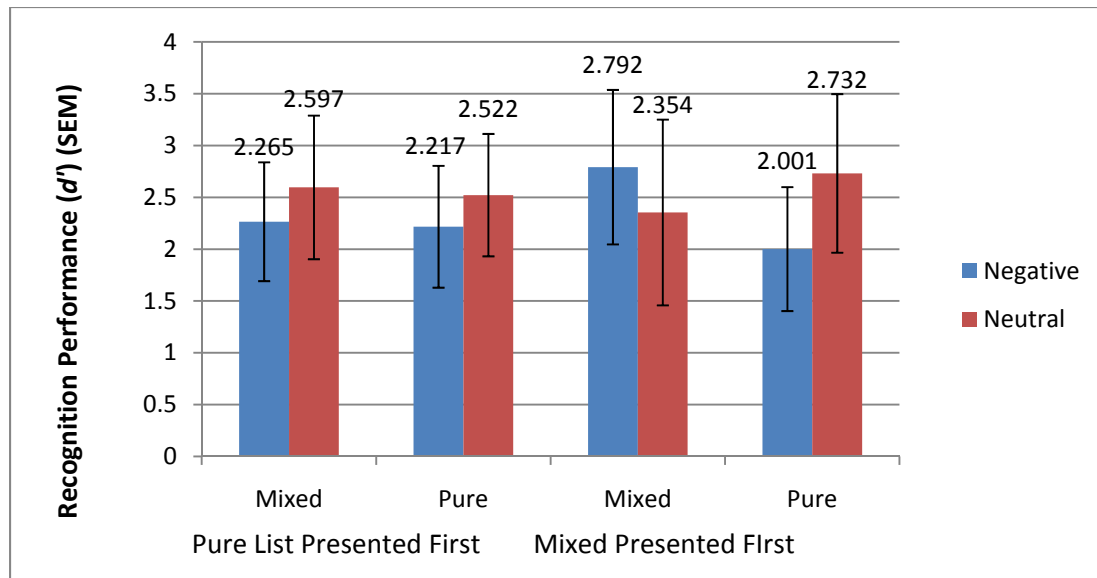


Figure 40. Experiment E: Recognition performance ( $d'$ ) as a function of list presentation order, list condition, and picture valence. Higher numbers indicate greater sensitivity. Error bars represent 95% confidence intervals.

in pure lists for neutral and negative images and enhanced recognition memory performance and discrimination ( $d'$ ) for negative over neutral images in mixed lists. Experiment E found no significant differences in proportions of “old” images correctly recognized, however proportions of neutral “new” images were better discriminated than negative images in both list conditions.

There was significantly enhanced recognition discrimination ( $d'$ ) for neutral over negative images in pure lists, but not mixed lists. Analysis of the criterion bias (C) revealed a liberal response bias for negative images in both list conditions (i.e., more false alarms). The direction of the recognition discrimination ( $d'$ ) did not support priority-binding theory. Participants *remember-know-guess* judgments did not indicate more *remember* responses for negative or neutral images across list conditions. There were more *remember* judgments false alarms for negative images across both list

conditions, however, suggesting that participants believed they had remembered more negative images when they in fact had not.

Ratings of the images revealed that participants rated negative images as less pleasant and more arousing than neutral images and that the pattern of ratings in this study mirrored the IAPS normative ratings. This suggested that the images were inducing the emotional manipulation as expected.

Skin conductance responses did not significantly distinguish negative study lists from neutral study lists, although with a larger sample size or a longer inter-stimulus interval the expected directionality of these measures might have approached significance. Similarly, heart rate in the study phases varied significantly across time but did not distinguish mixed and pure list conditions. There was a non-significant trend for greater heart-rate deceleration for the negative and mixed list condition, but more importantly, the change across time represented the triphasic pattern of responding. Heart rate in the recognition phases revealed greater deceleration for negative and neutral images in the pure condition. In the mixed condition there was greater deceleration for negative new images. Although priority-binding theory does not make predictions for physiological reactivity, the results of experiment E comport with priority-binding theory in that there was equivalent heart rate performance for negative and neutral new images in pure lists, and enhanced heart rate performance for negative new images in mixed lists. Both pure and mixed list heart rate recognition phase results revealed triphasic patterns of responding.

Ancillary analyses revealed no significant effect of list order presentation, although there was some evidence that when a mixed list was presented first, there was

better recognition discrimination ( $d'$ ) for neutral images. Note however, that the sample size for the order analysis using mixed lists presented first was limited by the number of participants ( $n = 7$ ). There was also no effect of gender,  $p's > 0.337$ .

Overall, the predictions of priority-binding theory were not statistically supported in experiment E. The emotional manipulation of the images was determined to be successful based on participant ratings, heart rate, and skin conductance data. The liberal criterion bias represented a general tendency for participants to respond “yes” to any negative image in the recognition phase, especially in pure lists. This tendency certainly affected recognition discrimination performance ( $d'$ ), but does not fully explain the equivalent recognition memory proportion performance. A detailed discussion of the possibilities behind the results for experiment C, D, and E follows.

## General Discussion

With three experiments I tested the priority-binding hypothesis to determine if binding theory generalized beyond taboo words, specifically to complex visual stimuli using a rapid serial visual presentation list paradigm. The priority-binding hypothesis predicted that memory for emotional stimuli will be enhanced in mixed but not in pure lists due to emotional stimuli creating an interference effect when presented quickly and when mixed with neutral stimuli. Hadley & MacKay (2006) stated that this interference effect in turn facilitates the binding of emotional over neutral stimuli in memory, resulting in enhanced memory performance for emotional stimuli. This study found no enhanced recognition memory performance for negative over neutral stimuli, except for experiment C, in which accuracy was greater for negative over neutral images in both mixed and pure lists (rather in mixed lists only). Sensitivity (mean  $d'$ ) was consistently greater for neutral images (significantly so in experiments C and E, and nearly so in D). A liberal criterion bias for negative images in both mixed and pure lists was consistent across all experiments. Subjects reported significantly more *remember* than *know* responses for correctly identified negative images, however, they also reported significantly more *remember* than *know* responses for false alarms. Physiological data indicated that subjects were reacting to the images and the results were generally correlated with the cognitive data. Overall, these results were not supportive of either the priority-binding hypothesis or arousal theory.

The divergence of my results from the predictions of binding theory can be viewed in a number of different ways. The description of which factors may account for

my findings will first be discussed in terms of the differences in memory retrieval paradigms (i.e., recognition versus recall memory) and the effect of response bias for negative over neutral images. Then I will discuss the differences in encoding processes for words and pictures and the psychophysiological correlates to the cognitive data. Finally, I will conclude with a discussion of design methodology and the limitations of this study.

### **Enhanced Memory Effects in Recall and Recognition Memory Paradigms**

Explanatory accounts for enhanced memory for emotional stimuli has been attributed to the activation of the amygdala (Windmann & Kutas, 2001), the capture of attention (Cahill & McGaugh, 1998), the binding of emotional stimuli to context (MacKay et al., 2004) and stimulus distinctiveness (Ochsner, 2000). Regardless of whether or not these explanations are mutually exclusive, all of them predict that memory should be better for emotional stimuli that elicit heightened states of arousal. Support for enhanced memory for emotional stimuli has come largely from free recall experiments (e.g., Danion, Kauffmann-Muller, Grange, Zimmermann, & Greth, 1995; Doerksen & Shimamura, 2001; Guy & Cahill, 1999; Hertel & Parks, 2002; Kensinger, Brierley, Medford, Growdon, & Corkin, 2002; Kensinger & Corkin, 2003). Review of the episodic recognition literature revealed findings that are much less consistent in support of an enhanced memory effect for negative over neutral stimuli. Some studies have shown that negative words are recognized better than neutral words (Comblain, D'Argembeau, Van der Linden, & Aldenhoff, 2004; Gruhn, Smith, & Baltes, 2005; Hamann, 2001; Kensinger & Corkin, 2003; Pesta, Murphy, & Sanders, 2001), negative images are better

recognized than neutral images (Gruhn, Scheibe, & Baltes, 2007; Ochsner, 2000), whereas others have shown no difference in accuracy for neutral versus negative words (Doerksen & Shimamura, 2001). Still others have found decreased accuracy for negative stimuli (Danion et al., 1995; Dougal & Rotello, 2007; Maratos, Allan, & Rugg, 2000). Thus, in the episodic literature there is no consensus about whether emotional stimuli are better recognized than neutral stimuli. Until this series of studies, testing the predictions of binding theory in an RSVP paradigm using complex visual images had not been adequately explored, and it was unclear whether or not the interference effect seen in the priority-binding hypothesis would affect subsequent recognition memory performance. The experiments in this study support the literature where no difference or decreases in accuracy were found for negative over neutral stimuli. The reason for why this occurred can best be explained by the liberal response bias for negative images that was seen across experiments.

### **Response Bias and Recognition Memory**

A significant and consistent liberal response bias for negative images was observed across my experiments. This is counter to the priority-binding hypothesis because it predicted that memory would be enhanced for negative over neutral images in mixed lists, and the higher incidence of false alarms demonstrated that memory for negative images was actually poorer. Despite the lack of concordance with the priority-binding hypothesis, my results were consistent with several other studies.

In two experiments, Dougal and Rotello (2007) used lists of positive, negative, and neutral words that were presented randomly at three seconds each. They assessed

whether emotional words resulted in increased memory sensitivity, whether response bias changed as a function of emotion, and whether emotion increased the use of a recollective process in recognition. Their recognition task presented one word at a time and included a *remember-know* procedure. Their results found that negative-arousing words consistently elicited more “old” judgments on a recognition test than neutral or positive-arousing words. The “old” judgments to negative stimuli were associated with a greater probability of the subjective experience of “remembering” than were neutral or positive words. Grider and Malmberg (2008) used a similar study and recognition task design and found a similar response bias effect. Thapar and Rouders (2009) investigated age-related differences of the emotional enhancement effect in recognition memory using emotional words in a heterogeneous list. Using a forced-choice recognition task, they found an emotional enhancement effect in both young and old adults that was due to a liberal response bias for emotional words. However, the pattern of bias differed in that younger adults were more willing to classify negative words as “old”. The younger adults were also more likely to report a higher subjective experience of remembering, which was actually a misattribution of familiarity. Maratos, Allan, and Rugg (2000) found a liberal response bias for negative over neutral words in an ERP study where words were presented in RSVP lists at a rate of 300ms. Each of the aforementioned studies used college-age populations supporting the generalizability of my findings.

The findings of these studies were convergent with the results of my experiments for recognition accuracy, sensitivity ( $d'$ ), and the finding that participants had more *remember* than *know* or *guess* responses for negative false alarms. On the basis of these findings, it can be concluded that emotion uniformly changes response bias in recognition



paradigms and that *remember* judgments to emotional stimuli tend to be made on the basis of item familiarity, not recollection. Thus, the notion that a high-threshold recollective process contributes to the recognition of emotional stimuli when using a *remember-know* procedure is inconsistent with data supporting the phenomenon of a liberal response bias. Moreover, the evidence from my experiments suggests that this dynamic also applies to complex visual images.

In contrast, divergent findings include the results of Ochsner (2000) and Kensinger and Corkin (2003). In three experiments Ochsner studied the effects of emotion on recollection and familiarity using complex visual images. Pictures were presented for either one or two seconds (depending on the experiment) and the recognition test was presented two weeks after the study phase. Ochsner found better recognition accuracy and discrimination ( $d'$ ) for negative over neutral images and stronger subjective memory (i.e., more *remember* responses) for negative over neutral images. Interestingly, Ochsner reported a liberal criterion bias for negative over neutral images, but not strong enough to significantly affect the sensitivity index  $d'$ . This finding was consistent with the pattern found in my results. In a series of six experiments Kensinger and Corkin used taboo, emotional, or neutral words (2-second inter-stimulus interval) presented in mixed lists. Following the study phase they used an “old” or “new” recognition task or recall task depending on the experiment. Overall, they found better recognition memory for taboo and emotional words. Participants also indicated better subjective memory for negative over neutral words, with the magnitude of the effect being greatest for words that elicited the greatest arousal. Signal detection analyses were

not used in this study and comparison of response bias measures to my experiments was unavailable.

As a whole, it appears that a liberal response bias affects recognition of both words and complex visual images more than recall memory paradigms. In my experiments the extent to which response bias affected sensitivity discrimination index  $d'$  varied slightly across experiment design, but the consistency of the pattern was a significant factor in being unable to generalize the predictions of binding theory from taboo words to complex visual images in a recognition memory paradigm. Because response bias is a significant factor that affects recognition memory paradigms, the priority-binding hypothesis may best be suited as an explanatory mechanism for RSVP designs which utilize recall tasks to measure memory performance.

### **Encoding and Retrieval Processes: Words versus Pictures**

Another finding was the failure to observe greater recognition memory accuracy for negative over neutral images in mixed but not pure lists. This finding differs from the predictions of the priority-binding hypothesis which were based primarily on taboo words and not complex visual images to support its conclusions. Understanding how encoding and retrieval processes differ for words and images may provide insight into the results of my experiments.

Fundamentally, the encoding of all emotional stimuli is relatively similar. An emotional experience causes emotional arousal, which in turn affects interactions among the amygdala, prefrontal cortex, medial temporal lobe memory system, and hormonal systems which in turn influence the retention of information in memory storage (see

Cahill & McGaugh, 1998, for review). The details of this process are beyond the scope of discussion here; however, there is evidence to suggest differences between how word and picture stimuli are encoded and retrieved in memory can explain the differences in results between my experiments and the predictions of binding theory.

Kohler, et al. (2000) found that right medial temporal-lobe (MTL) structures were differentially involved in picture processing during encoding and recognition. A posterior MTL region showed higher activation in response to presentation of pictures than to words across all conditions. An anterior right MTL region showed greater activation for recognition of objects that had been encoded as pictures, irrespective of whether the retrieval cue was pictorial or verbal. These findings were supported by Papanicolaou et al., (2002) in which the left MTL was more active than the right during word recognition, whereas the right MTL was relatively more active during picture recognition. In a positron emission tomography study, Menard et al. (1996) found that during silent reading the left angular gyrus, supramarginal gyrus, and Broca's area were active while the bilateral middle temporal, inferior parietal, striate, and extrastriate were active when subjects viewed pictures. In an fMRI study, researchers revealed that a subset of the brain regions involved specifically in encoding of pictures were also engaged during recognition memory for the encoded pictures. Encoding of pictures relative to words engaged bilateral extrastriate visual cortex, namely fusiform, lingual, middle occipital, and inferior temporal gyri. Recognition memory judgments about words that were encoded as pictures relative to those that were encoded as words activated fusiform and inferior temporal gyri primarily in the left hemisphere. The authors conclude that their

findings suggest a neural basis for encoding specificity and transfer appropriate processing in human memory (Vaidya et al., 2002).

In the context of binding theory, Hadley and MacKay (2006) used an immediate recall task following presentation of taboo words in RSVP lists. They posit that when participants view a word in a RSVP list the location of that word's lexical (or semantic) node is activated in the cortex and is primed or readied for activation to a binding node (located, say, in the hippocampus). Given that words and pictures are encoded and retrieved using slightly different anatomical processes, perhaps the semantic nodes associated with pictures and words are processed differently too? The work of Van Doren et al., (2010) suggests otherwise. Their fMRI study revealed considerable neuroanatomical overlap between processing the meaning of words and pictures, specifically the occipitotemporal sulcus (OTS), intraparietal sulcus, inferior frontal junction, and the middle third of the inferior frontal sulcus (IFS). Activation of the IFS and OTS predicted subsequent memory retrieval success.

Few studies outside of neuroimaging have examined differential processing of the semantic content of verbal and picture stimuli. Some authors claim that meaning is represented in a functional unitary system that is directly accessed by both visual objects and words (Caramazza, 1996). However, an alternative theoretical perspective (Glaser, 1992) postulates a distinction between a semantic system involved in the perception of images, which contains only semantic knowledge, and a lexicon that is responsible for language perception, which includes only linguistic knowledge. In this view, pictures have a privileged access to all nodes of the semantic system, because language perception comprises additional processes before accessing the semantic system. A study using a

word-picture affective Stroop task found that emotional pictures, but not words, produced interference effects. Also, naming times were reduced for negative pictures, but not for negative words. These authors concluded that pictures have enhanced access to emotional information (De Houwer & Hermans, 1994). In an fMRI study, emotional words and pictures were presented to subjects and found that the processing of both emotional words and pictures enhanced the activity of the amygdala and several regions of the prefrontal and anterior temporal cortex. These effects were more pronounced in the case of pictures (Kensinger & Schacter, 2006). In an ERP study designed to understand differential processing of pictures and words, researchers found that emotional information operated in a different way for words and pictures even under equivalent experimental circumstances in which no explicit semantic processing was required. Differences were evident at both behavioral and electrophysiological levels and indicated that affective information modulated the processing of pictures and had little influence in word processing (Hinojosa et al., 2009).

The neuroimaging literature seems to agree that there are neuroanatomical differences in how pictures and words are processed, where pictures tend to be processed bilaterally while words are processed primarily in the left hemisphere. Conversely, the semantic context of words and pictures appears to activate similar neuroanatomical regions. Cognitive studies of words and pictures suggest differential processing for words and pictures, with pictures evoking greater affective modulation. The lack of convergence between the neuroimaging and cognitive science studies reviewed here suggests that the dynamic that appears to best explain my results is likely related to differences between

recall and recognition task demands and the effect of response bias for negative over neutral images.

### **Encoding and Retrieval Demands**

Experiments C, D, and E all varied encoding and retrieval demands in order to create an increasingly specific set of conditions in which to test the predictions of binding theory. Although changing the experimental design did not significantly affect recognition memory performance or response bias across experiments, a number of memory effects have been demonstrated to be modulated by manipulating encoding and retrieval demands including the bizarreness, generation, and perceptual interference effects (Mulligan & Peterson, 2008). Understanding how encoding and retrieval demands affect recall and recognition memory is important to understand the applicability of binding theory to RSVP paradigms using images and visual recognition memory.

Encoding and retrieval demands play an important role in theoretical accounts, both in general, unifying accounts and in specific accounts of individual manipulations of memory phenomena (Mulligan & Peterson, 2008). In a series of experiments, they studied the effects of list composition and presentation on recall and recognition memory for the bizarreness, generation, and perceptual interference effects. Using mixed and pure list designs, they discovered that varying encoding and retrieval contexts resulted in different patterns of memory performance for each effect. In general, the effects of bizarreness were demonstrated more consistently in recall than in recognition memory, whereas the effects of perceptual interference and generation are demonstrated more readily in recognition than recall memory.

In experiment C an alternating list design produced enhanced recognition memory performance for negative over neutral images. When encoding and retrieval demands were changed in experiments D and E the enhanced memory effect disappeared. Response bias, however, was consistent across experiments and reflects the consistency of this effect for picture and word stimuli in recognition memory paradigms. Roediger (2008) commented that design effects have been taken as part of the evidence for the relativity of memory.

At this time, the generalizability of binding theory to RSVP lists using visual recognition memory paradigms has mixed results. Enhanced recognition memory performance for negative over neutral images was observed in Gruhn, Scheibe, and Baltes' (2007) study; however, the results of my studies did not corroborate their findings. Additional research is needed to test the generalizability of binding theory to RSVP lists using visual images and recall memory.

### **Psychophysiological Correlates in Episodic Processing**

One of the goals of this study was to understand the relationship between perceptual inputs (varying in arousal and valence) and outputs (measured in a variety of different response systems such as electrodermal response, heart rate, and memory performance). In the context of binding theory, previous research revealed that in RSVP pure list presentation, representations generated by motivational processes (i.e., approach or avoidance systems) are not preferentially bound to attention-based information in memory (Devore et al., 2008). In other words, change in physiological measures (i.e., skin conductance and heart rate performance) was independent of memory performance

in pure RSVP picture lists. In experiments D and E this study's predictions held that skin conductance and heart rate would vary as a function of image arousal rating (i.e., increasing levels of arousal would increase the magnitude and number of skin conductance responses), that heart rate would display the classic triphasic pattern of responding varying as a function of image valence rating, and that in the spirit of the predictions of binding theory, heart rate and skin conductance measures would correlate with memory performance in mixed lists, but not in pure lists.

Skin conductance data across experiments revealed that mean amplitude and number of SCR responses did not significantly vary as a function of image valence or list condition in the study phase. SCR results in experiment E, although non-significant, were in the expected direction (i.e., higher mean magnitude and more responses for negative images in pure and mixed lists). My SCR results are contrary to established psychophysiological literature where SCR significantly varies as a function of rated image arousal (Bradley & Lang, 2007). Thus, the current skin conductance findings are anomalous and potential explanations for the current data are explored here.

Verbally labeling pictures has been shown to decrease emotional responding (McRae, Taitano, & Lane, 2010); however, it is unlikely that subjects were able to verbally label the images given the rapid presentation rate (and no notable verbalizations were noted during data collection). Subjective ratings and heart rate data indicated that subjects were reacting to the images, so it is surprising not to see similar results in the SCR data.

A study of repetitive picture presentation (6-s duration) and found that affective valence continued to elicit emotional reactions and never led to a decrease (i.e.,



habituation) in affective discrimination (Bradley, Cuthbert, & Lang, 1996). A follow-up study of affective reactions to briefly presented pictures (500 ms) revealed that SCR mean magnitude and number of responses were significantly larger for emotionally arousing (pleasant and unpleasant) as compared to neutral pictures (Codispoti, Bradley, & Lang, 2001). In both studies they used a 6-second inter-stimulus interval to measure SCR responses and they found no decrease in SCR responding despite repeated presentation of the selected images. Presentation of images in my experiments was rapid at a rate of one per second (500 ms viewing, 500 ms ISI) for 9 or 27 seconds (experiment D and E, respectively). Historically, accurate measurement of SCR responses occurs for a few seconds following presentation of a stimulus (Dawson, Schell, & Fillion, 2007). Thus, the rapid presentation rate of images and rapid switching of attentional mechanisms likely inhibited the capacity to measure a full SCR response and is the most likely explanation for a lack of significant difference across list conditions.

Heart rate data across experiments in the study phase did not vary as a function of image valence or list condition, but did display the triphasic pattern of responding across time. The lack of difference for image valence is consistent with the literature on heart rate variability in response to briefly presented IAPS images (Codispoti, Bradley, & Lang, 2001). An initial heart rate deceleration was observed, supporting previous literature associated with sensory detection (Graham, 1992). Although not significant, visual inspection of the graphs (see Figures 19 and 34) showed the expected direction of decreased heart rate for images in negative and mixed lists. Heart rate responding in the study phase was not supportive of binding theory or arousal theory.

Heart rate data during the recognition phase differed between experiments in the pure list condition. Experiment E results demonstrated heart rate deceleration for new stimuli, supportive of novel stimulus detection (Graham, 1992); however, experiment D did not. There was a significant triphasic pattern of responding across both experiments and in all conditions. In the mixed list condition of experiment D there was greater heart rate deceleration for negative and neutral new images; however, in experiment E only new negative images were found to have greater overall deceleration. Across both experiments, changes in heart rate were not predictive of memory performance and this supported the findings of experiment A and B. This is divergent from heart rate studies using pictures and emotional words (Abercrombie, Chambers, Greischar, & Monticelli, 2008; Buchanan, Etzel, Adolphs, & Tranel, 2006), and is likely related to the significant response bias observed in sensitivity ( $d'$ ) data. Furthermore, the deceleration of negative new images in the experiment E recognition mixed list condition was supportive of differential affective engagement of the cardiac system. This result supported my cardiac performance predictions in relation to priority-binding theory (i.e., greater deceleration for negative new images in mixed but not pure lists); however, it did not correlate with recognition memory performance. In the reviewed literature, experiments D and E are the first of its kind to observe changes in heart rate in RSVP lists of mixed and pure images.

### **The Feeling of What Happened**

The current results are likely due to a number of inter-related factors. As discussed, a significant response bias was observed across experiments and response bias is a common phenomenon in recognition memory paradigms. It is possible that response

bias was exacerbated by potential sex-related differences in how women (a significant majority of my participants) process and remember negative information as compared to men. Pictures are also processed differently than words, and the use of complex images instead of taboo words affected the generalizability of priority-binding theory. I suspect that this was due in part to certain salient features of negative images (i.e., blood or a weapon) attracting more attentional resources than other aspects of that image, thus reducing the level of processing for the image as a whole. So when a target item was later tested in the recognition phase, overall recognition memory performance was reduced because only the salient features were effectively encoded and the entire context of what those features were a part of (i.e., the whole image) were lost. I believe that this helps explain the liberal response bias. I suspect that the presentation rate of 1000 ms (500 ms presentation rate and 500 ms ISI) was sufficient to engage an interference effect. The use of a recall or two-alternative forced choice recognition test could parse this out further.

The rapid presentation rate of images in this study likely reduced my capacity to effectively measure SCR responses. This is because SCR responses are typically measured over several seconds after presentation of a stimulus and rapid switching of attentional resources mitigated my ability to measure differences across conditions. Thus, measurement of SCR may have been inappropriate for this RSVP paradigm. The heart rate data generally behaved as expected with respect to the triphasic pattern of responding, however differential cardiac performance was not predictive of recognition memory performance. This is likely due to the liberal response bias.

## **Methodological Limitations**

This dissertation has explored the predictions of binding theory across five experiments and found little support for its generalizability to RSVP picture lists and visual recognition memory. Now I present several caveats that are important factors to consider regarding the conclusions rendered in this discussion.

I did not vary the presentation rate of 500 ms per image (500 ms ISI) in any of my experiments. Perhaps increasing the presentation rate may have facilitated the interference effect described in binding theory that facilitated enhanced memory for taboo over neutral words at 200 ms presentation rates. Interestingly, however, the enhanced memory effect disappeared at a presentation rates of 1000 ms. In fact, memory for neutral items was *better* at the 1000 ms presentation rate (Hadley & MacKay, 2006). For all of my experiments the image presentation rate of 500 ms (500 ms ISI) was chosen based on the design and results of Akyurek & Hommel (2005), who demonstrated that presenting images too fast can result in the attentional blink (AB) phenomenon. There was no evidence of a floor effect as each study demonstrated high proportions of correctly recognized images averaging 87%, 73%, 76%, and 86% (experiments A, C, D, and E, respectively). Comparing my results to Gruhn, Scheibe, and Baltes (2007), they used an 800 ms presentation rate and found enhanced recognition memory performance for negative over neutral words. This suggests that my presentation duration of 500 ms would have been rapid enough to facilitate an interference effect, especially in experiment E, which used a similar design to Gruhn, Scheibe, and Baltes (2007). Additional experiments should consider varying the presentation rate to determine if 500

ms was actually too slow or too fast to cause the interference effect needed for priority binding of arousing information.

It is important to consider gender differences that may account for my results because the majority of participants across experiments self-identified as female (72%, 96%, 92%; experiments C, D, and E, respectively). Threat-related stimuli such as the negative IAPS images presented in my studies have been demonstrated to be processed differently in women than in men. There is evidence to support sex differences in the hemispheric distribution of encoding-related amygdala activity, with men showing right-lateralized effects and women showing left-lateralized effects (LaBar & Cabeza, 2006). In an fMRI study looking at whether amygdala responses to emotional pictures would predict performance on an immediate recognition memory test, sex differences were found in amygdala activation that was related to false-positive error rates in recognizing unpleasant pictures. Specifically, increased right amygdala activation during unpleasant picture viewing was related to lower false-positive rates for men and higher false-positive rates for women. This study indicated that increased amygdala activation while viewing unpleasant pictures preferentially facilitated immediate recognition memory in men relative to women (Aikins, Anticevic, Kiehl, & Krystal, 2010). I speculate that the higher false-positive rate (i.e., response bias) observed across my experiments was because I had a significant majority of female participants. It should be noted, however, that recognition memory performance (i.e., recognition accuracy and  $d'$ ) comparing negative and neutral images remained statistically insignificant across experiments even when male participants were removed.

Of note is also the type of stimuli used in these studies. Image content varied across pictures of animals, abstract designs, humans, common objects, and landscapes. Wolfe et al. (2007) reported that visual attention modulates memory performance and it is likely that attention varied with arousal during list presentation. Without eye tracking data it is unknown if the individual content of each image may have had any effects on memory as a function of increased visual attention for any salient features. Although one could compare memory performance across image type (humans, landscape, animals, etc) and whether or not any difference was related to the observed response bias, the small number of images in each category taken together with the diversity of the images selected, made this sort of comparison impossible.

Some may argue that the graphic nature of some of the IAPS images may be repression prone and that some participants may have found the images so disturbing that they may have blocked them out of their minds, preventing accurate memory retrieval. Jacobs, Nadel, and colleagues argue that because high levels of stress disrupt hippocampal and prefrontal function, memory binding should be impaired for arousing events (Jacobs & Nadel, 1998; Payne, Nadel, Britton, & Jacobs, 2004). They also argue that because stress simultaneously facilitates amygdalar function, memory for item information from the arousing event should be enhanced, potentially leading to vividly remembered fragments of emotional events. This suggests that recognition memory for arousing images (or salient features thereof) should be enhanced, while contextual details of the experience of the event may be lost (i.e., experimenter instructions, details of the lab setting, etc). Given the liberal response bias across experiments, it is more likely that subjects just ‘remembered it was negative,’ as opposed to specific images, giving some

plausibility to the repression hypothesis. This is further supported by the increased false-positive rate for negative stimuli observed in females as compared to males (Aikins, Anticevic, Kiehl, & Krystal, 2010). Another explanation is the “weapon focus effect” seen in eyewitness testimony (Loftus, Loftus, & Messo, 1987). The weapon focus effect describes how when a weapon is involved in a crime eyewitness memory is impaired for other details of a scene (e.g., perpetrator description) due to attention being diverted and focused on the weapon. Salient features of an image, such as a bloody knife or mutilated finger, may have attracted greater attention resources leaving reduced attentional resources to process other details of the image. It is possible that a mechanism similar to the weapon focus effect reduced overall recognition memory while salient features of a particular image may have been better remembered. In contrast, the majority of scientific data suggests that emotion consistently increases memory performance, not decreases it (see Cahill et al., 1994; Cahill & McGaugh, 1998; Christianson & Loftus, 1987), although this interpretation does specifically take into context recognition memory and complex visual images.

Observed power for the criterion bias analysis was lower than expected, although significant differences were found for experiments C and E and a near significant difference in experiment D (power statistics were 0.96, 0.39, 0.51; experiments C, D, and E, respectively). Effect sizes ranged from small to medium ( $d = 0.48, 0.12, 0.16$ ; experiments C, D, and E, respectively). Nonetheless, the consistency of the response bias effect for negative images suggests that something noteworthy is going on.

A better designed replication study with a larger sample size, larger list length, and an even balance of male and female participants might be justified. Additional

consideration is the use of a two-alternative force choice procedure (2AFC) instead of the old-new recognition paradigm used in my studies. Under standard testing conditions the 2AFC uses one target and one foil during the recognition test phase. The 2AFC procedure can be used to assess response bias by using null-choice comparisons. For null-choice trials, either two targets or two foils are presented that vary with respect to the factor that is manipulated experimentally. These trials are intermixed with the standard trials, and hence, the subject must simply choose which of the two alternatives was studied. Of course, there is no single correct answer for the null comparisons, and bias is revealed if there is a greater-than-chance tendency to choose a negative over a neutral item for both the null-target and null-foil comparisons. For instance, a null-target comparison might include a negative target and a neutral target, and a null foil comparison might include a negative foil and a neutral foil. If there is a greater bias to indicate negative items as old, subjects should select the negative alternatives as a greater-than-chance rate (Zeelenberg, Wagenmakers, & Rotteveel, 2006). Thus, the advantage of using the 2AFC procedure instead of the old-new procedure is that in the old-new procedure subjects can give a correct answer even if they don't know, whereas in the 2AFC forcing them to choose allows the experimenter to decide when they don't know instead of them deciding for themselves.

## **Summary**

The general aim of this dissertation was to better understand the mechanisms of recognition memory consolidation for negative and neutral visual images and its psychophysiological correlates. Hypotheses were developed based on the predictions of



priority-binding theory, which stated that enhanced memory performance would occur for negative over neutral images in mixed, but not pure RSVP lists. The present results found no enhanced memory effect, but instead found a consistent liberal response bias for negative over neutral images, which was consistent with the literature on emotion and recognition memory (see Dougal and Rotello, 2007; Grider and Malmberg, 2008). My experiments revealed limitations in the predictions of priority-binding theory such that it does not account for why memory performance in my experiments was worse for arousing items than for neutral items. The finding that arousal does not always have the same effect on memory for items may help explain why, for emotional events, people's subjective sense of memory vividness often has little relation to their memory accuracy (Christianson & Engelberg, 1999). This was observed experimentally where participants had significantly more *remember* than *know* or *guess* responses for false-alarms. This has implications for forensic issues such as eyewitness testimony and police lineups, as well as clinical implications for treatment of trauma (e.g., PTSD) and exploring the etiology of maladaptive beliefs and the memories that underlie them.

Additionally, this series of studies provided the first known observation of heart rate and skin conductance data identifying psychophysiological reactions to arousing and neutral stimuli in RSVP picture lists. The data revealed that RSVP picture lists with limited inter-stimuli intervals (i.e., < 500 ms) engaged approach and avoidance mechanisms so rapidly that typical response patterns to arousing and neutral stimuli were not observed. Implications for additional psychophysiological research using heart rate and skin conductance measures in RSVP lists should take into consideration the time it takes for biological systems to sufficiently react to stimuli.

This research supports a model of memory that assumes that arousal can actually impair, rather than facilitate, the encoding of item memory (Jacobs & Nadel, 1998; Payne, Nadel, Britton, & Jacobs, 2004). In a broader perspective, understanding the interaction between emotion and memory is central to understanding our motivations, our behavior, and ultimately our well-being.

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