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An abstract of
a thesis submitted to the Faculty of Emory College of Arts and Sciences
of Emory University in partial fulfillment
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Abstract

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Emotional arousal has been shown to enhance memory for emotionally salient events, but its influence on temporally adjacent neutral events remains debated. The retrograde memory enhancement (RME) effect, as termed by Anderson et al. (2006), suggests that emotional arousal can retroactively enhance memory for preceding neutral items. However, subsequent studies have yielded mixed results, with some failing to replicate the effect or even reporting opposite findings. The present study aimed to conceptually replicate the initial findings of Anderson et al. (2006) by investigating the impact of emotional arousal on episodic memory for preceding neutral events. Additionally, the study extended prior research by examining whether the RME effect applies to relational and associative memory, as measured through source memory tests. Participants encoded neutral faces, each followed by either a negative or neutral picture modulator stimulus, and their memory was tested through a surprise recognition test after a 24-hour delay. Contrary to predictions, results indicated no effect of emotional arousal on item or source memory for preceding neutral items. A Bayesian analysis indicated strong evidence in favor of the null hypothesis, suggesting that the RME effect observed by Anderson et al. (2006) may not be robust under conditions similar to those in the present study. Despite this null finding, the expected emotional enhancement of memory (EEM) effect was observed for the emotional stimuli themselves, indicating that the lack of RME was unlikely to be due to ineffective emotional manipulation. We also found that participants with higher susceptibility to arousal exhibited significantly better item memory and picture memory, an intriguing finding that suggests individual differences in arousal predisposition may play a role in modulating memory performance. These findings call into question the generalizability of the RME effect and highlight the need for further research to clarify the conditions under which emotional arousal retroactively influences memory for preceding neutral events.

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Table of Contents

Introduction

From the graphic recollection of a joyous birthday to the haunting memories of a tragic accident, emotional events often leave an indelible mark on our minds, standing out more clearly and enduringly than the mundane details of everyday life. These daily experiences reflect the crucial role that emotions play in shaping how we encode, store, and retrieve memories (Cahill & McGaugh, 1966; Kensinger & Schacter, 2008). Extensive research has established that events with emotional significance are encoded and remembered with higher vividness and accuracy than neutral events. This phenomenon is commonly referred to as the emotional enhancement of memory (EEM) (Hamann, 2001; Tully & Bolshakov, 2010). Emotional arousal, in particular, is thought to act as a modulator of memory processes, influencing both the encoding and consolidation of information (LaBar & Cabeza, 2006; McGaugh, 2004; Phelps, 2006). Interestingly, this modulatory effect of emotional arousal is not confined to the emotional event itself but can extend to neutral events occurring in close temporal proximity (Anderson et al., 2006; Knight & Mather, 2009). Despite the growing understanding of the role of emotional arousal in memory formation, the specific ways in which emotional arousal retroactively influences episodic memory of preceding neutral events remain underexplored. Filling this gap is essential for a comprehensive understanding of how emotional experiences can reshape our memory of prior, non-emotional events, thereby providing insights into the broader implications of emotional dynamics on cognitive performance.

Emotional Enhancement of Memory

There is a growing body of literature supporting the enhancement effect of emotional arousal on memory processes, attributed to its alterations in both biological and psychological mechanisms. Studies on rodents have revealed activation in the locus coeruleus during emotionally provoking situations releases norepinephrine throughout the brain, including amygdala and hippocampus, and thus prioritizing the consolidation of emotional information in long-term memory (Cahill & McGaugh, 1990; Mather et al., 2015; McGaugh 2004; Moreno-Castilla et al., 2017; Tully & Bolshakov 2010). Neurobiological studies on human brains found amygdala activation during encoding and retrieval of emotional stimulus (Ford & Kensinger, 2019; Hamann et al., 1999; Phelps, 2004; Qasim et al., 2023; Richardson et al., 2004). Furthermore, fMRI research indicates that greater amygdala activity during the encoding of emotional stimuli predicts better long-term memory, an effect not observed for neutral content (Canli et al., 2000; Dolcos et al., 2004; Hamann et al., 1999; LaBar & Cabeza, 2006).

In addition to the neurobiological standpoint, emotional arousal has been found to enhance memory by engaging in higher-order cognitive processes, such as enhanced attentional allocation and increased rehearsal. Emotional stimuli elicit preferential processing, which captures and sustains attentional resources, thereby facilitating deeper encoding and improving memory retention (Hamann, 2001; Kim et al., 2013; Sharot & Phelps, 2004; Talmi et al., 2008). Behavioral studies have consistently shown that emotionally salient stimuli evoke heightened attentional engagement, measured through increased reaction times and eye-tracking metrics, and thus predict better memory performance (Christianson et al., 1991; Schmid et al., 2011; Subramanian et al., 2014). Furthermore, emotional arousal has been associated with the formation of more vivid and enduring memory representations, as well as increased confidence in the recall of contextual details (Tulving, 1987; Yonelinas, 2001).

Effects of Emotions on Recollection and Familiarity

One important distinction within the study of episodic memory is between recollection and familiarity. Recollection involves the retrieval of specific contextual details associated with a past event, such as its time, place, or accompanying thoughts (Yonelinas, 2002). Familiarity refers to a more automatic sense of knowing that an event or stimulus has been encountered before, but without recalling specific contextual details (Diana et al., 2007). These distinctions reflect the dual-process nature of recognition memory, which enables both rich, detailed recollection and quick, efficient recognition of familiar stimuli (Yonelinas, 2001).

Recollection and familiarity can be dissociated both from their neurobiological mechanisms and behavioral manifestations. Lesion studies have shown that recollection is primarily dependent on the hippocampus and adjacent medial temporal lobe structures, which support the encoding and retrieval of associative and relational memories (Yonelinas, 2002; Eichenbaum et al., 2007). In contrast, familiarity relies more on the perirhinal cortex, which is involved in processing the strength of item familiarity without linking it to episodic context (Diana et al., 2007). This neurobiological distinction aligns with findings from fMRI studies showing that hippocampal activation is greater during recollection-based memory retrieval, whereas the perirhinal cortex exhibits greater activation when recognizing familiar stimuli without conscious recollection (Ranganath et al., 2004). These neural differences translate into distinct behavioral characteristics, which can be observed through experimental memory tasks. The “remember/know” paradigm is frequently used to distinguish recollection from familiarity, requiring participants to report whether they “remember” (retrieve contextual details) or simply “know” (recognize the stimulus without specific details) a presented item (Tulving, 1985; Yonelinas, 2001). Recollection-based responses are generally slower, more effortful, and associated with higher confidence levels, which reflect the cognitive demands of retrieving detailed episodic information (Yonelinas, 2002). Familiarity-based recognition is faster and less cognitively demanding, as it relies on a general sense of prior exposure rather than detailed retrieval (Jacoby, 1991).

The modulatory effects of emotion on memory processes also differ between recollection and familiarity. Research has shown that emotionally arousing events tend to strengthen recollection, leading to more vivid retrieval of contextual details, whereas familiarity-based recognition is less consistently influenced by emotion (Yonelinas & Ritchey, 2015). The amygdala interacts with the hippocampus to enhance episodic memory consolidation, particularly for recollection-based retrieval (Dolcos et al., 2005). This suggests that emotional memories are more likely to be retrieved with specific details and a sense of reliving the experience, rather than merely producing a feeling of familiarity. Additionally, empirical evidence reveals that emotional valence plays a role in differentiating these effects, with negative emotions often lead to a more detail-oriented encoding style, which enhances recollection, whereas positive emotions tend to promote a gist-based, familiarity-driven retrieval process (Mickley Steinmetz & Kensinger, 2009). Furthermore, mood-congruent memory effects suggest that an individual's emotional state at the time of retrieval can selectively influence recollection by making emotionally consistent memories more accessible, whereas familiarity-based recognition is typically less affected by emotional state (Bower, 1981).

Effects of Emotions on Source Memory

Another distinction within episodic memory is between item memory and source memory. Item memory refers to the memory for a specific stimulus, whereas source memory pertains recall of contextual details surrounding an event. This distinction maps closely onto the dual-process framework of recognition memory with item memory often gives rise to the subjective experience of familiarity, while source memory is typically associated with recollection (Guo et al., 2006). Emerging evidence suggests that item and source memory rely on partially distinct neurobiological mechanisms. Neuroimaging studies have shown that item memory is associated with activation in right prefrontal cortex and parietal cortex (Cabeza et al., 2001; Sakai et al., 2002). In contrast, source memory has been more strongly linked to the left prefrontal cortex (Henson et al., 1999; Nolde et al., 1998). Additional findings have demonstrated a double dissociation in brain activation patterns, with item memory depending more on medial temporal and diencephalic regions, and source memory relying more heavily on frontal lobe functions (Glisky et al., 1995).

Although emotional arousal has been consistently shown to enhance item memory, its effects on source memory have proven more complex. Many studies examining emotional influences on source memory have reported either no effect or lower recognition accuracy for contextual details accompanying emotional compared to neutral stimuli (Kensinger et al., 2007; Meyer et al., 2015). However, emerging studies have found that emotions enhance source memory under certain conditions (Doerksen & Shimamura, 2001; Mather & Nesmith, 2008). These mixed findings suggest that the influence of emotion on source memory may be more sensitive to experimental design, task demands, and individual differences than the relatively robust emotional enhancement of item memory. As such, when investigating the emotional effects on episodic memory, it is crucial to examine how these processes influence the stabilization and integration of source memory as well as item memory.

Selective Impairment Effects of Emotions on Episodic Memory

Emotional arousal has been shown to selectively enhance memory for the central features of emotional events. However, this benefit is frequently accompanied by a decline in memory for peripheral details (Levine & Edelstein, 2010; Schmidt, 2004). This selective impairment of memory has been widely attributed to the "narrowing effect" of emotional arousal, whereby memory is enhanced for central, emotionally salient features at the expense of peripheral information (Christianson & Loftus, 1991; Levine & Edelstein, 2010; Schmidt, 2004). These differential effects may be explained by the Arousal-Biased Competition (ABC) theory, which posits that emotional arousal prioritizes high-salience information at the expense of competing, lower-priority details (Mather & Sutherland, 2011).

This selective impairment induced by emotional arousal extend beyond spatial context to include information that is auditorily or temporally adjacent to the emotional stimulus. For example, emotional arousal has been found to disrupt associative memory for concurrently presented auditory stimuli (Anderson & Shimamura, 2005). Additionally, neutral stimuli presented immediately before or after an emotional event are often remembered less accurately. Prior studies have demonstrated that emotional arousal can impair memory for temporally proximate neutral events, both retroactively and proactively, likely due to a redirection of attentional and encoding resources toward the emotionally salient stimulus (Flaisch et al., 2016, Hurlemann et al., 2005; Strange et al., 2003, Strange et al., 2010).

Retrograde Memory Enhancement Effect of Emotion

Contrary to the findings of memory impairment for the neutral surrounding of emotional materials, Anderson et al. (2006) found an enhancement in episodic memory for neutral events that preceded emotionally salient stimuli, a phenomenon they termed as retrograde memory enhancement (RME) effect. In this study, participants were presented images containing neutral items (faces and houses) followed by modulator pictures varying in emotional valences (neutral, negative, and positive) and arousal level. To investigate the temporal dynamics of the retrograde effect of emotional arousal, the researchers manipulated the time interval between the presentation of the neutral items and the modulator stimuli, setting it at either 4 seconds (short-delay) or 9 seconds (long-delay). Long-term memory retention was assessed through a surprise recognition test after a one-week delay. Their results revealed an enhanced memory for neutral items that preceded emotional stimuli compared to those preceded neutral stimuli. The likelihood of recognition was found to increase with the subjective arousal ratings of the subsequent emotional modulators. Furthermore, the RME effect was observed only within the short-delay condition, suggesting a limited temporal window during which emotional arousal can influence preceding neutral events. Anderson et al. (2006) also found that emotional arousal retroactively enhanced the quality of memory for preceding neutral events. Specifically, recollection of neutral events was significantly associated with the arousal elicited by subsequent emotional stimuli, whereas no such relationship was observed between arousal and familiarity responses.

The Anderson et al. (2006) study has been highly influential in the field of emotional memory. However, its findings have yet to be replicated in subsequent studies. Moreover, other studies have found that emotionally arousing stimuli can have the opposite effect, impairing episodic memory for items preceding arousing stimuli. Hurlemann et al. (2005) investigated the retrograde and anterograde effects of emotion on episodic memory encoding using a free-recall paradigm. Their findings revealed that negative stimuli induced retrograde amnesia, impairing memory for items presented immediately before them. To reconcile the discrepancies in retrograde effects of emotional arousal on episodic memory, Knight and Mather (2009) explored the conditions under which emotional arousal enhances or impairs memory for preceding items. By adopting similar experimental paradigm from Hurlemann et al. (2005), where they controlled for attentional weight by embedding randomly presented “oddball” stimuli (i.e., pictures of distinct content) with either emotional or neutral valence within a list of neutral items. Compared to the experimental design of the Anderson et al. (2006) study, they kept a temporal window of 2 second between the items. Additionally, both an immediate recall test and a one-week delayed recognition test were administered. Their results indicated that enhanced recognition occurred only for neutral items preceding emotional oddballs that were successfully recalled immediately after the encoding session. This enhancement effect was absent in neutral items following emotional oddballs, for neutral items preceding and following neutral oddballs, and for neutral items preceding oddballs that were not successfully recalled. However, the fact that the RME effect was only observed when the items were successfully recalled immediately after encoding suggested that the process of recalling items may have increased their attentional salience and encoding priority. This raises questions about the mechanism underlying the RME observed in their study, as it may not necessarily reflect the same effect proposed by Anderson et al. (2006). Instead, it could be attributed to known memory phenomena such as the testing effect (Roediger & Karpicke, 2006), which enhances later retention through retrieval practice, or the increased attention devoted to recalled stimuli. Given these discrepancies, the failure to replicate the findings of Anderson et al. (2006), and the opposite effects reported by Knight and Mather (2009), it is important to revisit the original paradigm to determine whether the RME is a robust and replicable phenomenon and to determine whether it extends to source memory.

Present Study

The present study aimed to conceptually replicate and boost the RME effect reported by Anderson et al. (2006). This study also explored whether the RME effect extends beyond item memory to relational and associative memory, as assessed through a source memory test. To enhance the likelihood of detecting an RME effect, several methodological refinements were implemented. First, the stimulus set was optimized by selecting stimuli from the high and low extremes of emotional arousal, rather than a continuous distribution of arousal levels. Second, while Anderson et al. (2006) reported recognition performance that was above floor, overall memory accuracy remained relatively low. To address this, the exposure duration for neutral encoding stimuli was increased, thereby enhancing overall recognition rates and thus improving the ability to detect an RME effect. Third, the long-delay condition (i.e., 9-second interval between neutral items and emotional stimuli) used by Anderson et al. (2006), which did not reliably yield an RME effect, was excluded. Instead, the present study employed a fixed, short interval of 2 seconds, intended to strengthen the temporal proximity and therefore the potential impact of emotional arousal on memory for preceding neutral events. Additionally, the study used only neutral face stimuli, as prior findings indicated no differential effects between face and house stimuli, and the original analyses collapsed across the two stimulus types. This refinement enabled a more streamlined experimental design and helped reduce total task duration, thus minimizing participant fatigue. Memory performance was also assessed after a 24-hour retention interval, rather than the one-week delay used by Anderson et al. (2006). Pilot testing revealed that a one-week delay led to floor-level performance, particularly for source memory. Moreover, evidence from the literature suggests that 24 hours is sufficient for the consolidation of long-term memory (Diekelmann et al., 2009; McGaugh, 2004; Takashima et al., 2009).

A variety of individual differences may potentially influence the RME effects. One such factor is arousal predisposition, which refers to an individual's baseline tendency to experience and react to arousing stimuli (Coren, 1990). A brief self-report questionnaire designed to measure an individual's habitual arousability has been validated and shown to predict meaningful individual differences in physiological and psychological responses to emotional stimuli (Coren & Mah, 1993). Participants are asked to rate how accurately various statements describe them (e.g., "I am restless and fidgety"), which together index their general susceptibility to arousal. This measure provides insight into individual variability in emotional reactivity and has been used to explore the role of trait-level arousability in domains such as sleep disturbance (Coren, 1988), stress reactivity (Coren & Aks, 1991), and antisocial behavior (Coren, 1999). Given that individuals with heightened arousal predisposition tend to exhibit stronger physiological responses to arousing stimuli, which have been strongly implicated in memory modulation mechanisms (McGaugh, 1990), this trait may potentially modulate the RME. In particular, individuals higher in this trait may be more aroused by emotionally arousing pictures and as a result may exhibit larger RMEs. As such, considering the role of arousal predisposition may provide deeper insight into the factors that contribute to individual variability in the retrograde effects of emotions on memory for preceding neutral events.

The goal of the present study is to attempt to conceptually replicate the findings of Anderson et al. (2006) by investigating the RME effect of emotional stimuli on preceding neutral events and also examining its potential influence on source memory. Based on the findings of prior research, the current study had the following hypotheses: (1) emotional arousal elicited by emotional picture stimuli will significantly retroactively enhance item memory (i.e., recognition memory) for preceding neutral face stimuli, consistent with the findings of Anderson et al. (2006), (2) picture stimuli rated higher in arousal will be associated with larger RME effects and will also be associated with higher levels of item recognition for pictures, consistent with the well-established EEM effect in episodic memory, (3) emotional arousal will retroactively increase the level source memory for preceding neutral face events, demonstrating retrograde effects of emotion on relational memory, (4) emotionally arousing picture stimuli will selectively enhance recollection-based memory for preceding neutral events, while familiarity-based recognition will not be affected, and (5) individuals higher in arousal susceptibility will show increased RME and EEM effects, relative to individuals lower in arousal susceptibility.

Method

Participants

A total of sixty-eight students from Emory University were recruited for this study from an undergraduate psychology participant pool. This study was reviewed and approved by the Emory University Institutional Review Board in accordance with ethical guidelines for the protection of human subjects. Of the recruited participants, one participant withdrew from the study, eleven participants failed to return for the second session, thirteen participants failed to respond on more than 10% of the experimental trials, resulting in a final sample of 43 participants (79.07% female), with age range of 18 to 22 (M = 18.74, SD = 1.14). Among the participants, 30.23% were identified as White/Caucasian, 13.95% as Black/African American, 11.63% as Hispanic/Latino, 27.91% as Asian, 2.33% as Middle Eastern/North African, 4.65% as other. All participants were required to be over the age of 18 and in good physical and mental health. Participants were compensated with course credit.

Materials and Measures

Stimuli Selection. Two types of stimuli were presented during each encoding trial: neutral face encoding stimuli and emotional and neutral picture modulator stimuli. The face encoding stimuli included 120 emotionally neutral faces selected from the Chicago Face Database (CFD), consisting of 60 male and 60 female faces, all full-face photographs of Caucasian individuals. Each face was presented against a colored frame, with one of four colors (red, blue, green, yellow) randomly assigned to each image. The picture modulator stimuli featured scenes varying in emotional valence and arousal. For use as modulator pictures, we selected 120 pictures from the International Affective Picture System, a standard set of pictures that vary in emotional arousal and valence (IAPS; Lang et al., 1988). The picture modulator stimuli were comprised 60 negative and 60 neutral pictures. Based on the normative ratings provided for the IAPS (Lang et al., 1997), the images of negative stimuli had a mean valence of 2.48 (*SD* = 0.61) and mean arousal of 6.40 (*SD* = 0.40). The images of neutral stimuli had a mean valence of 5.14 (*SD* = 0.29) and mean arousal of 2.70 (*SD* = 0.51). The negative and neutral pictures were selected so as to maximize the difference in emotional arousal between the two sets of pictures, with the aim of increasing the magnitude of the RME, which increased with increasing differences in arousal in the Anderson et al. (2006) study.

The pairing of face encoding stimuli and picture modulator stimuli was counterbalanced using a Latin square design to ensure that each face and picture stimulus appeared equally as both target and distractor across sessions and participants. In addition, each of the four colored frames used to assess source memory was paired equally often with the neutral faces and the negative vs. neutral picture modulators. Each materials counterbalancing set comprised 120 pairs of face encoding stimuli and picture modulator stimuli. Of these, the face stimuli and picture stimuli associated with 80 pairs served as targets (faces: 40 males, 40 females; pictures: 40 negative, 40 neutral), presented during both the encoding and retrieval sessions, while the face and picture stimuli associated with the remaining 40 pairs were reserved for use as distractors (faces: 20 males, 20 females; pictures: 20 negative, 20 neutral), presented only during the recognition memory test in the retrieval session.

Individual Differences Measures. The Arousal Predisposition Scale (APS) is a standardized 12-item self-report measure designed to assess an individual's susceptibility to arousal. It is rated on a 5-point scale ranging from never (1) to always (5). The APS has demonstrated good internal consistency (α = .84; Coren, 1990) and has been widely used to examine individual differences in physiological and cognitive responses to emotional stimuli. Prior research has linked APS scores to stress under cognitive load, and individual differences in autonomic arousal (Coren & Mah, 1993).

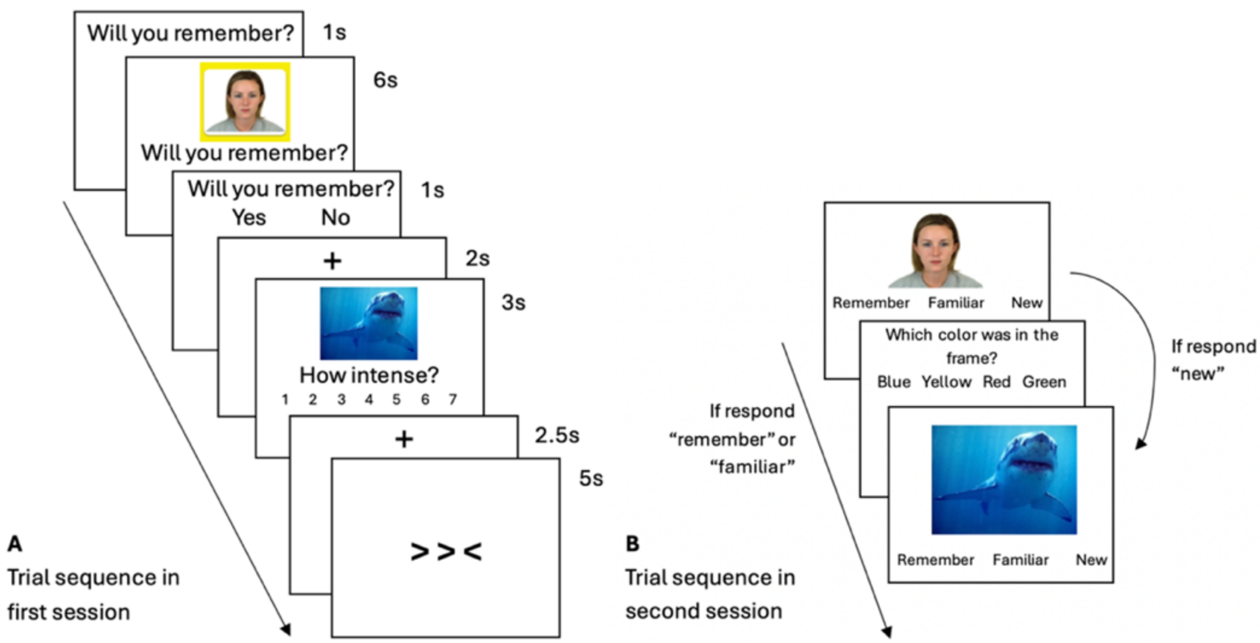
Procedure

Upon arrival, informed consent was obtained from the participants. The experimental procedures were conducted using the PsychoPy (version 2023.2.0) program on a Macintosh desktop computer. The experimenter remained in the testing room with the participant during the entire study to answer any potential questions and to monitor performance. During the first session, participants were given a brief orientation to the experimental setup and instructions to the behavioral tasks. To familiarize them with the task procedure, all participants completed a 5-trial practice session using the same trial sequence as in the encoding session. Each trial started with a 1-second fixation point. One second before the face encoding stimulus appeared, participants were presented with the question, “Will you remember?” on the screen. This question served as a cover task designed to engage participants with the facial features by prompting them to decide if they found the face image presented on the screen memorable to them by responding with either “Yes” or “No” to the question. The face encoding stimulus was displayed for 6 seconds. After the face encoding stimulus disappeared, the question remained on the screen, and participants were instructed to make their response within the 1-second interval, indicating whether they found the face memorable. After participants made their response for the face encoding stimulus, a central fixation point was displayed for 1 second, followed by an interstimulus interval (ISI) of 2 seconds. During the presentation of the picture modulator stimulus, which lasted for 3 seconds, participants were asked, “How intense do you feel?” They were instructed to rate their subjective level of emotional arousal when the picture modulator stimulus appeared on the screen using a 7-point Likert scale (1 = lowest intensity, 7 = highest intensity) by pressing the corresponding key on the keyboard. To minimize the carryover effects of emotional responses between trials and provide sufficient time for the arousal response from each picture modulator stimulus to dissipate before the next trial, participants completed a rapid response flanker task, commonly used for cognitive testing, for 5 seconds after a 2.5-second fixation interval. In the flanker task, they were presented with three arrows while the directions of the arrows were randomized in each trial. The flanker task required them to identify the direction of the middle of three arrows by pressing the corresponding key for each of the five consecutive 1-second trials. Each trial lasted 20.5 seconds, with a total of five 20-second breaks every 16 trials to prevent fatigue and help participants sustain consistent attention and performance throughout the session. The encoding session comprised 80 trials, totaling approximately 30 minutes (see Figure 1A).

At the end of the first session, participants were scheduled for a second session approximately 24 hours later. They were not informed in advance that this session would involve a memory test. During the second session, they were shown the face encoding stimuli followed by the picture modulator stimuli, one at a time, and were asked to indicate whether they recognized any images from the first session. In the recognition task, participants selected one of three options: “remember” for recollection, “familiar” for a sense of familiarity, and “new” for a lack of recognition. This approach enabled us to assess qualitative differences in memory performance. For faces identified as “remember” or “familiar,” participants proceeded to a source memory discrimination task, where they were asked to recall and choose the color of the frame from the original presentation (see Figure 1B). Participants were self-paced while completing the second session to ensure they had adequate time to make recognition judgement.

Following the memory test in the second session, participants completed a series of questionnaires administered through Qualtrics. These questionnaires collected demographic information, including age, gender, race, and ethnicity. Participants were also asked whether they had anticipated a memory task and, if so, whether they made any specific efforts to remember the stimuli. The post-experiment survey also included individual differences measure including the APS and allowed participants to report general comments regarding the experiment.

Figure 1. *Sequence of trial events in the encoding and retrieval phases*



Statistical Analysis

Two indexing approaches were employed to categorize the picture modulator stimuli for analysis. First, picture modulator stimuli were sorted based on their normative ratings as provided by IAPS into two emotion categories (negative and neutral). Second, each participant's self-reported arousal ratings for the picture modulator stimuli were used to divide the stimuli into two arousal level categories (high- and low-arousal). Stimuli were rank ordered within each participant, and the top and bottom halves were assigned to the high- and low-arousal categories, respectively. In cases where ties in arousal ratings prevented an even division, the mean arousal ratings calculated across all participants for the tied modulator stimuli were used as a secondary reference to assign items, ensuring equal-sized high- and low-arousal categories.

We employed these two approaches to examine whether the findings would be robust to different picture modulator selection methods. In the first method, we used the normative arousal-based approach as a standardized basis for assessing emotional content. This approach also aimed to account for a potential confound in the Anderson et al. (2006) study, where the participants were asked to rate the memorability of each face stimulus (i.e., respond to the question "Will you remember?"). The participants' response might indirectly influence emotional arousal ratings for the picture modulator stimuli that followed the face encoding stimuli. For example, if a participant rated a face encoding stimulus as highly memorable, this judgment might bias their arousal rating of the following picture due to a general tendency to give elevated ratings across consecutive items. Using normative arousal ratings that were acquired from a different group of participants would remove this possible confound. In the second method, we used the individual arousal rating based method to capture individualized emotional responses and examine the effects of emotional arousal in a similar way to that used by Anderson et al. (2006). In the original study, the stimuli were categorized into 4 arousal-based quartiles using participants' subjective ratings due to the continuous distribution of arousal in their stimulus set. As the present study intentionally selected stimuli that were clustered near the high and low extremes of the arousal scale in order to enhance the likelihood of observing an RME effect, it was more appropriate to categorize stimuli into two distinct arousal level categories (i.e., high- and low-arousal) rather than applying the quartile-based method used in the original study.

The primary memory measures included corrected recognition rates and *d'* statistics for both the face encoding stimuli and the picture modulator stimuli, as well as source memory accuracy rates. Corrected recognition rates were computed separately for face encoding stimuli and picture modulator stimuli by calculating hit rates (collapsed across "remember" and "familiar" responses) and subtracting false alarm rates. To further assess recognition sensitivity, *d'* statistics were derived by subtracting the z-transformed false alarm rate from the z-transformed hit rate (Stanislaw & Todorov, 1999). In the present study, *d'* was prioritized in the interpretation of results due to its ability to assess the participants' ability to discriminate between target and distractor. Source memory performance was assessed by calculating the proportion of correct source judgments (i.e., correctly identifying the colored frame associated with the face encoding stimuli) for only the trials where participants correctly recognized the face image. Recollection and familiarity estimates were derived using the dual-process signal detection model based on participants' remember and familiar responses during the recognition test (Yonelinas, 2001). Specifically, the recollection estimate was calculated by subtracting the false alarm rate from the hit rate for remember responses:

$$\text{Recollection estimate} = H_R - F_R.$$

The familiarity estimate was calculated using the ratio of familiarity-based responses for old versus new items, each corrected for the probability of recollection:

$$\text{Familiarity estimate} = \frac{\frac{H_F}{1-H_R}}{\frac{F_F}{1-F_R}},$$

where H_R and F_R represent the hit and false alarm rates for remember responses, respectively, and H_F and F_F represent the hit and false alarm rates for familiar responses.

Means and standard errors for corrected recognition rates were calculated and reported separately for each indexing approach (i.e., emotion categories based on normative ratings, and arousal level categories based on self-reported arousal ratings). To evaluate the presence of an RME effect, one-way ANOVAs were conducted separately for each indexing approach to examine the effects of emotion categories (negative and neutral) and arousal level categories (high- and low-arousal) on recognition performance for the face encoding stimuli. For analyses of source memory accuracy, one-sample t-tests were employed to determine whether performance significantly exceeded the chance level of 25%. Subsequently, one-way ANOVAs were conducted separately using both indexing approaches to assess the influence of emotion categories (negative and neutral) and arousal level categories (high- and low-arousal) on source memory accuracy. Finally, one-way ANOVAs were conducted separately for each indexing approach to examine the effects of emotion categories (negative and neutral) and arousal level categories (high- and low-arousal) on recognition performance for the picture modulator stimuli.

In a separate analysis to assess possible effects of differences in arousability, the median APS scores (median = 38, range = 22 – 50) were used to split the participants into high ($N = 22$) and low ($N = 21$) APS groups. Two-way ANOVAs were conducted with memory performance as dependent variable, arousal level categories (high- vs. low-arousal) and APS groups (high vs. low) as within-subject factors. Interaction effects between arousal level categories and APS group were examined to assess whether arousability moderated memory performance.

To evaluate the strength of evidence for or against the null effects, Bayesian ANOVAs were conducted separately using memory performance as the dependent variable, emotion categories and arousal level categories as independent variables.

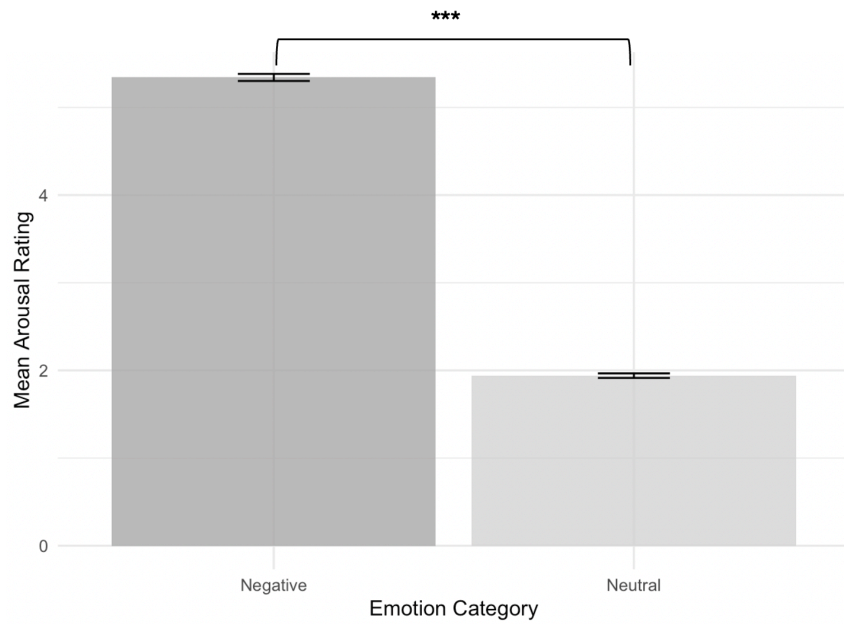
The criterion for statistical significance was set at $\alpha = .05$ for all frequentist analyses. Effect sizes were also calculated for each statistical test to quantify the strength of observed effects. All analyses were conducted using R Statistical Software (v4.3.2; R Core Team, 2023).

Results

Picture Modulator Ratings

In order to determine if the picture modulator stimuli were effective at inducing a state of arousal after the exposure of face encoding stimuli, emotional intensity ratings were analyzed using an independent t-test between different emotion categories (negative and neutral). Results indicated that emotional intensity ratings significantly differed by emotion categories, $t(42) = 70.86$, $p < .001$, $d = 2.41$. Specifically, negative picture modulator stimuli ($M = 5.34$, $SE = .04$) were rated as significantly more arousing compared to neutral picture modulator stimuli ($M = 1.94$, $SE = .03$). See Figure 2.

Figure 2. *Average emotional arousal ratings*



Note. Error bars display standard error of the mean. *** $p < .001$.

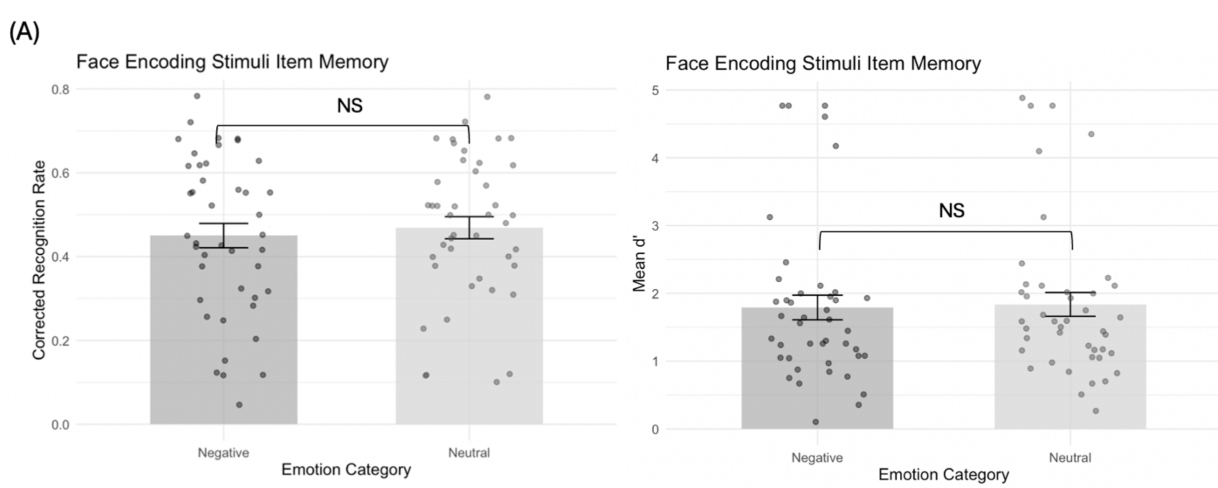
Emotion Category and Memory Performance

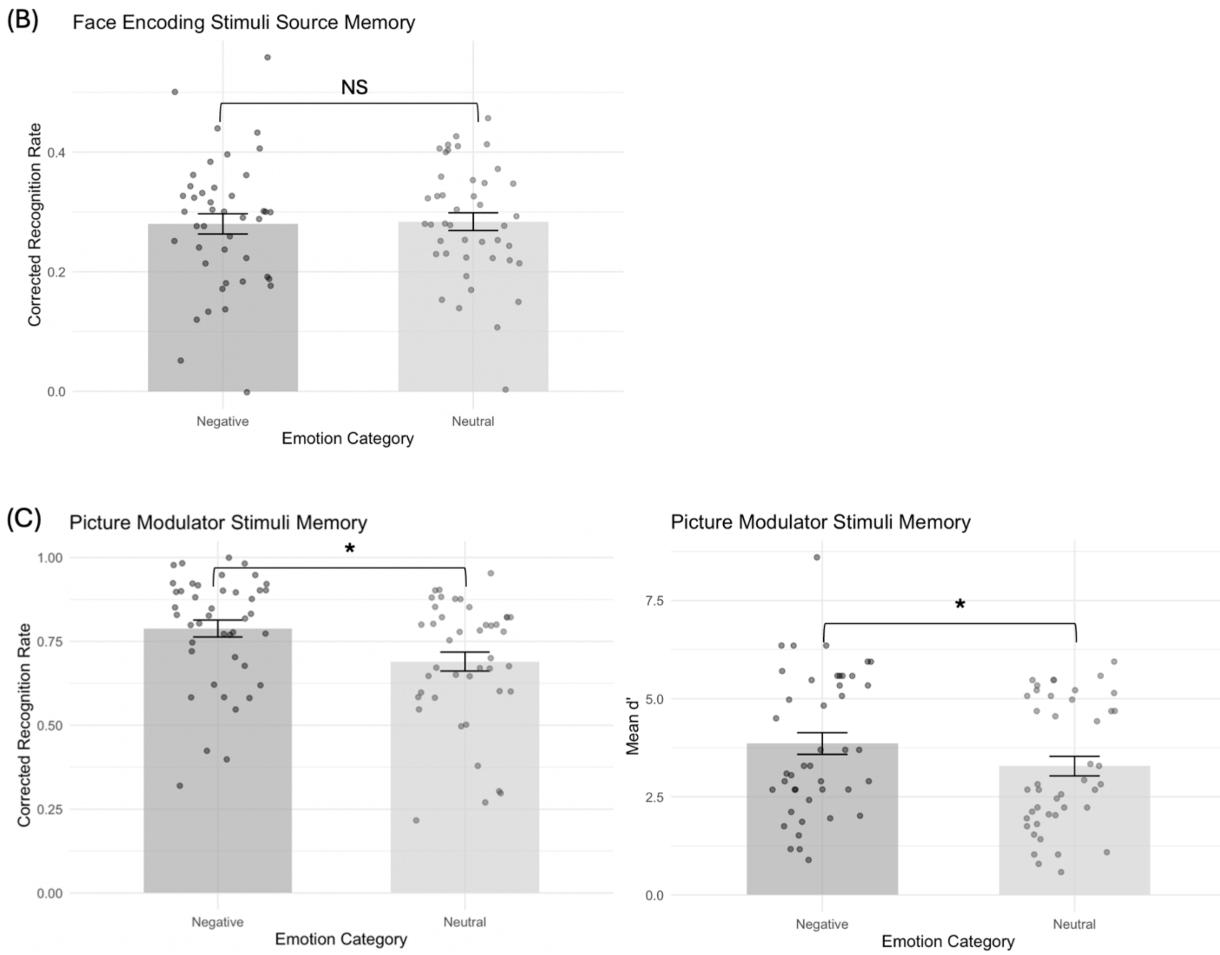
Face (item) memory. A one-way ANOVA was conducted to examine the effect of emotion categories (negative and neutral) on memory performance for preceding face encoding stimuli. Results revealed no statistically significant difference in item memory performance between face encoding stimuli followed by negative modulator stimuli ($M = .45$, $SE = .03$) and those followed by neutral modulator stimuli ($M = .47$, $SE = .03$), $F(1, 42) = .23$, $p = .63$, $d = -.10$, 95% CI [-.19, .07]. A Bayesian ANOVA indicated strong evidence in favor of the absence of effect of emotion categories on item memory performance ($BF_{10} = .25$). See Figure 3A.

Source memory. A one-sample t-test was used to compare source memory performance against chance level (25%), to determine whether overall source memory performance (not subdivided by the type of subsequently presented modulator picture) was above floor. Source memory performance was significantly above chance, $t(42) = 2.84$, $p < .01$. A one-way ANOVA was conducted to examine the effect of emotion categories (negative and neutral) on source memory performance. Results revealed no statistically significant difference in source memory performance between face encoding stimuli followed by negative modulator stimuli ($M = .28$, $SE = .02$) and those followed by neutral modulator stimuli ($M = .28$, $SE = .01$), $F(1, 42) = .03$, $p = .87$, $d = -.04$, 95% CI [-.07, .14]. A Bayesian ANOVA indicated strong evidence in favor of the absence of effect of emotion categories on source memory performance ($BF_{10} = .23$). See Figure 3B.

Picture modulator stimuli memory. To investigate the effect of emotion categories (negative and neutral) on picture modulator stimuli memory performance, a one-way ANOVA was conducted. The results revealed a statistically significant difference in memory performance, $F(1, 42) = 6.73$, $p = .01$, $d = .56$, 95% CI [.03, .17]. Participants performed significantly better on memory tasks for negative modulator stimuli ($M = .79$, $SE = .03$) compared to neutral modulator stimuli ($M = .69$, $SE = .03$). See Figure 3C.

Figure 3. *Memory performance as a function of emotion categories*





Note. Error bars display standard error of the mean. * $p < .05$. NS = not significant.

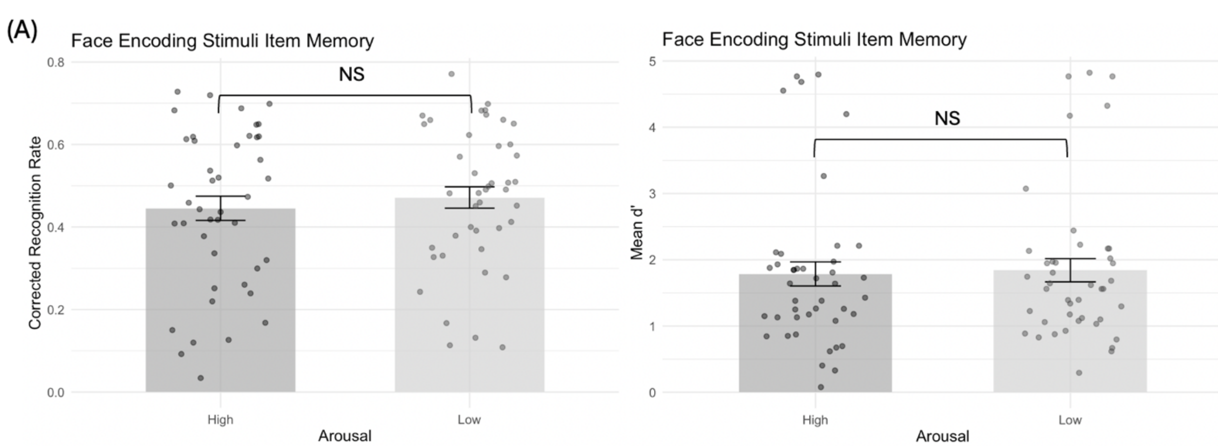
Emotional Arousal and Memory Performance

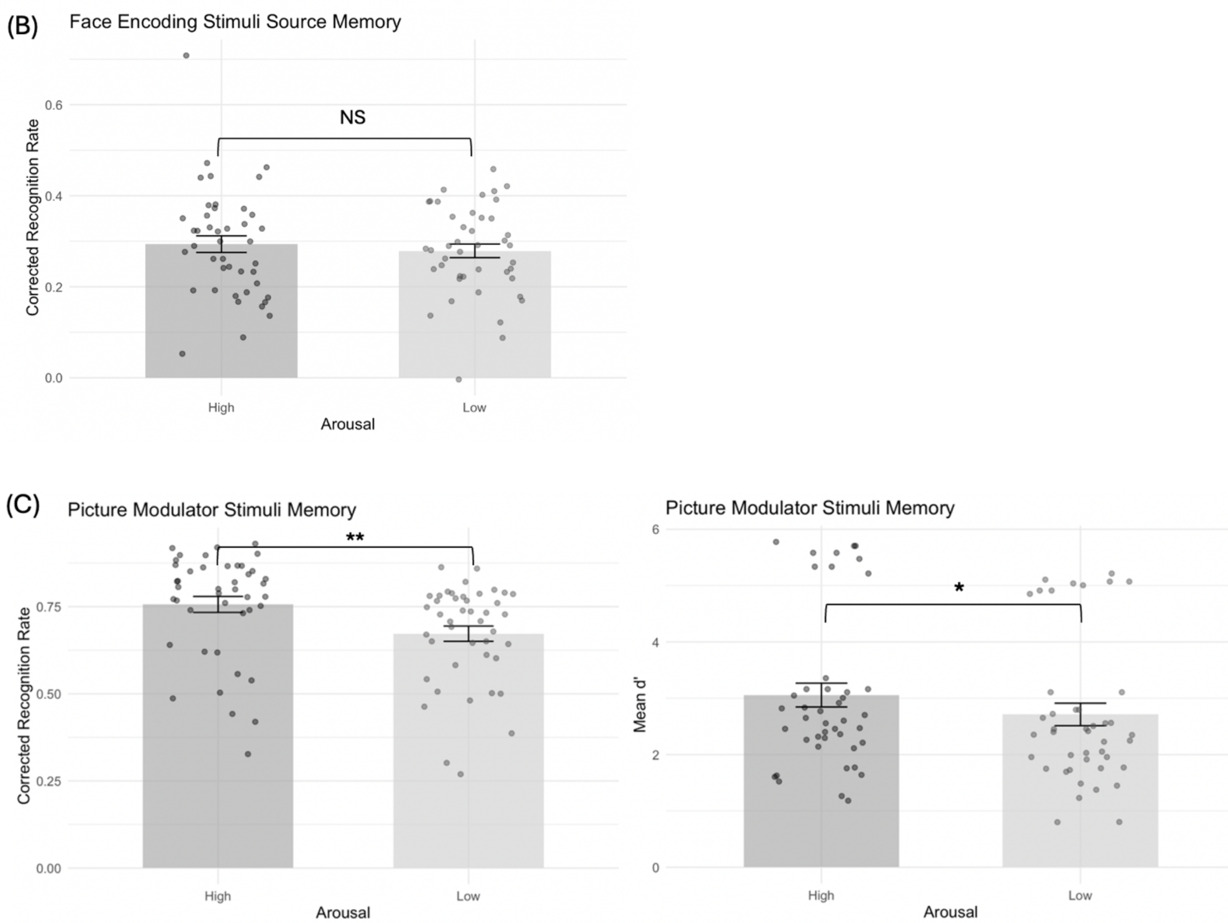
Face (item) memory. A one-way ANOVA was conducted to examine the effect of arousal level categories (high- and low- arousal) on item memory performance for preceding face encoding stimuli. Results revealed no statistically significant difference in item memory performance between face encoding stimuli followed by high-arousal modulator stimuli (M = .45, SE = .03) and those followed by low-arousal modulator stimuli (M = .47, SE = .03), F(1, 42) = .45, p = .50, d = -.14, 95% CI [-.10, .05]. A Bayesian ANOVA indicated strong evidence in favor of the absence of effect of arousal level on item memory response ($BF_{10} = .27$). See Figure 4A.

Source Memory. A one-way ANOVA was conducted to examine the effect of arousal level categories (high- and low- arousal) on source memory performance for preceding face encoding stimuli. There was no significant difference in source memory performance between face encoding stimuli followed by high-arousal modulator stimuli ($M = .29$, $SE = .02$) and those followed by low-arousal modulator stimuli ($M = .28$, $SE = .01$), $F(1, 42) = .39$, $p = .54$, $d = .13$, 95% CI [-.03, .06]. A Bayesian ANOVA indicated strong evidence in favor of the absence of effect of arousal level on source memory response ($BF_{10} = .27$). See Figure 4B.

Picture modulator stimuli memory. A one-way ANOVA was conducted to examine the effect of arousal level categories (high- and low- arousal) on picture modulator memory performance. The results revealed a statistically significant difference in memory performance, $F(1, 42) = 7.03$, $p < .01$, $d = .57$, 95% CI [.02, .14]. Participants performed significantly better on memory tasks for negative modulator stimuli ($M = .76$, $SE = .03$) compared to neutral modulator stimuli ($M = .67$, $SE = .02$). See Figure 4C.

Figure 4. *Memory performance as a function of arousal level categories*





Note. Error bars display standard error of the mean. ** $p < .01$. * $p < .05$. NS = not significant.

Emotions and Recollective Experience

A series of one-way ANOVAs were conducted separately for each indexing approach to examine the effects of emotion categories (negative and neutral) and arousal level categories (high- and low- arousal) on recollection and familiarity estimates, analyzed separately.

Face (item) memory. No significant effect of emotion categories was found on recollection estimates for item memory, with similar recollection for face encoding stimuli followed by negative modulator stimuli ($M = .24$, $SE = .02$) and neutral modulator stimuli ($M = .23$, $SE = .02$), $F(1, 42) = .09$, $p = .76$, $d = .07$, 95% CI [-.10, .07]. A Bayesian ANOVA indicated strong evidence in favor of the absence of effect of emotion categories on recollection memory response (BF_{10} = .23). No significant effect of emotion categories was found on familiarity estimates, with comparable familiarity for face encoding stimuli followed by negative modulator stimuli (*M* = .34, *SE* = .03) and neutral modulator stimuli (*M* = .36, *SE* = .03), $F(1, 42) = .48$, $p = .49$, $d = -.15$, 95% CI [-.20, .10]. A Bayesian ANOVA indicated strong evidence in favor of the absence of effect of emotion categories on familiarity memory response (BF_{10} = .28). See Figure 5A.

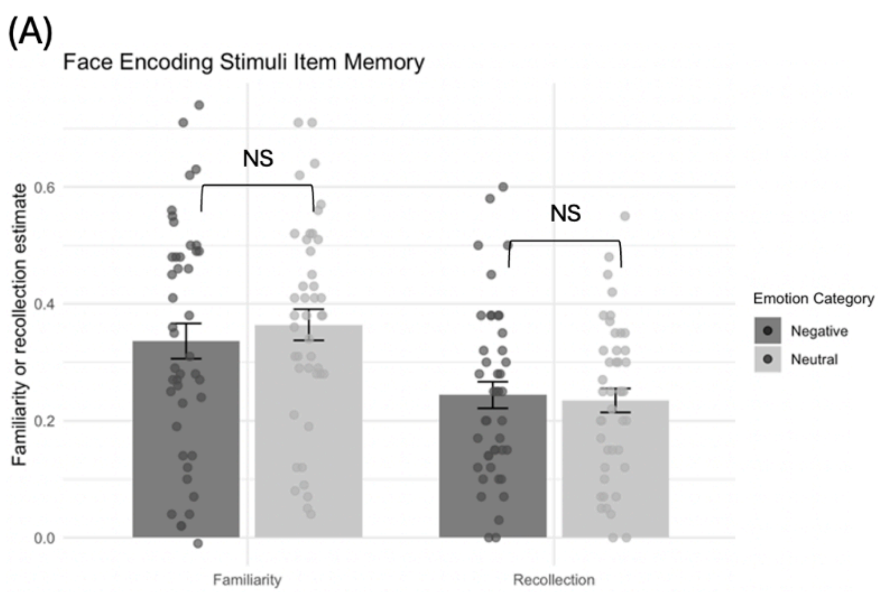
For arousal effects, recollection estimates did not significantly differ between face encoding stimuli followed by high-arousal modulator stimuli (*M* = .22, *SE* = .02) and low-arousal modulator stimuli (*M* = .21, *SE* = .02), $F(1, 42) = .23$, $p = .63$, $d = .10$, 95% CI [-.04, .07]. A Bayesian ANOVA indicated strong evidence in favor of the absence of effect of emotional arousal level on familiarity response (BF_{10} = .25). No significant effect of arousal was found on familiarity estimates, with face encoding stimuli followed by high-arousal modulator stimuli (*M* = .37, *SE* = .02) and low-arousal modulator stimuli (*M* = .40, *SE* = .02) showing comparable familiarity, $F(1, 42) = .85$, $p = .36$, $d = -.20$, 95% CI [-.10, .04]. A Bayesian ANOVA indicated strong evidence in favor of the absence of effect of arousal level categories on familiarity memory response (BF_{10} = .33). See Figure 6A.

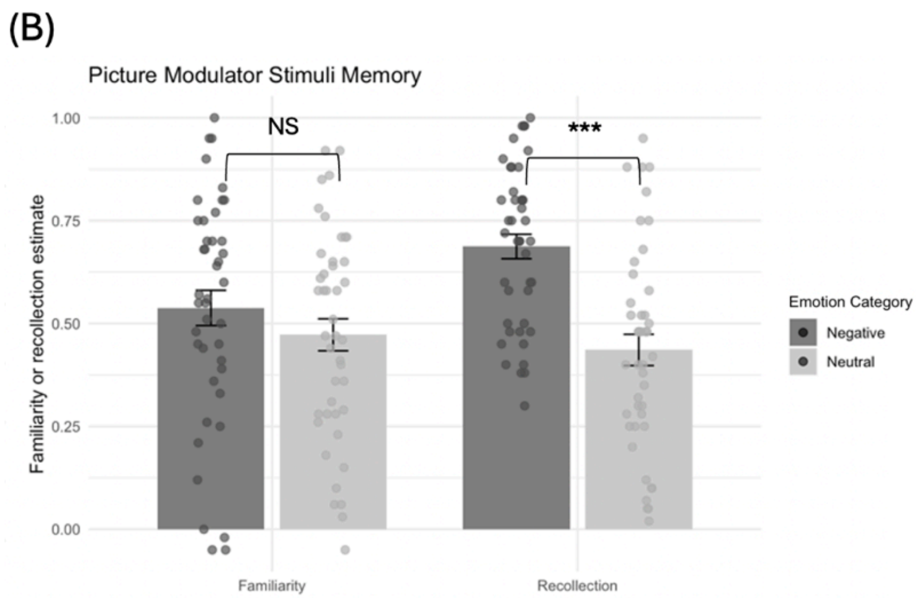
Picture modulator stimuli memory. A significant effect of emotion categories was found on recollection estimates for picture modulator stimuli, with higher recollection for negative modulator stimuli (*M* = .68, *SE* = .03) compared to neutral modulator stimuli (*M* = .44, *SE* = .04), $F(1, 42) = 27.1$, $p < .001$, $d = 1.12$, 95% CI [.16, .34]. For familiarity estimates, no significant difference was observed between negative modulator stimuli (*M* = .54, *SE* = .04) and neutral modulator stimuli (*M* = .47, *SE* = .04), $F(1, 42) = 1.28$, $p = .26$, $d = .25$, 95% CI

[-.05, .18]. This indicates that emotion categories do not influence familiarity-based recognition. A Bayesian ANOVA indicated strong evidence in favor of the absence of effect of emotion categories on familiarity memory response ($BF_{10} = .40$). See Figure 5B.

A significant effect of arousal was found on recollection estimates, with higher recollection for high-arousal modulator stimuli ($M = .70$, $SE = .03$) compared to low-arousal modulator stimuli ($M = .45$, $SE = .04$), $F(1, 42) = 30.49$, $p < .001$, $d = 1.19$, 95% CI [.16, .34]. For familiarity estimates, no significant difference was found between memory for high-arousal modulator stimuli ($M = .61$, $SE = .04$) and low-arousal modulator stimuli ($M = .54$, $SE = .04$), $F(1, 42) = 1.60$, $p = .21$, $d = .27$, 95% CI [-.04, .18]. A Bayesian ANOVA indicated strong evidence in favor of the absence of effect of arousal level categories on familiarity memory response ($BF_{10} = .46$). See Figure 6B.

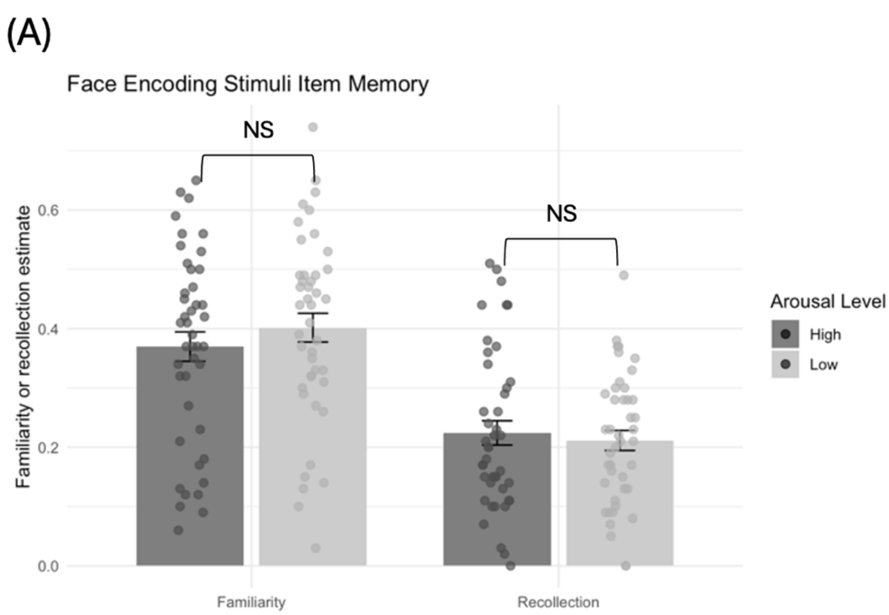
Figure 5. *Familiarity and recollection estimates based on emotion categories*

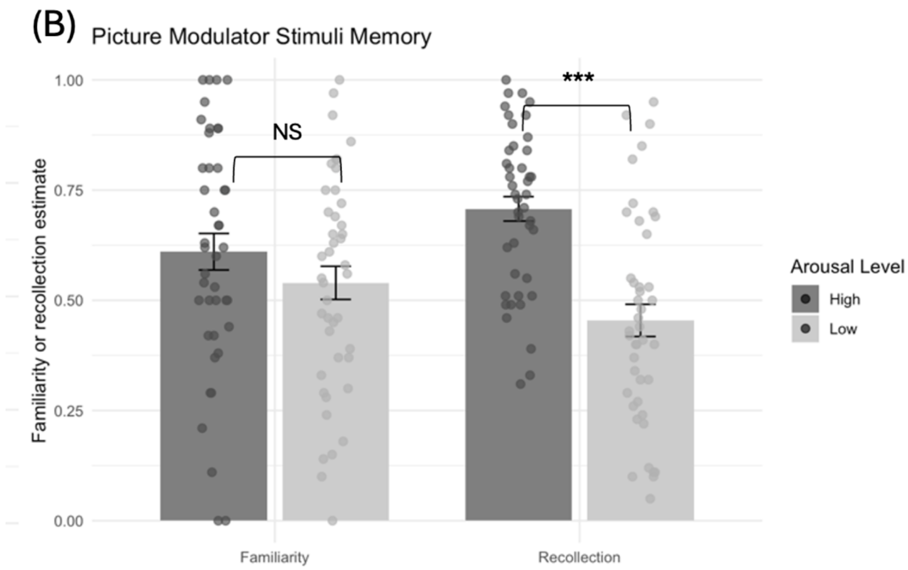




Note. Error bars display standard error of the mean. *** $p < .001$. NS = not significant.

Figure 6. *Familiarity and recollection estimates based on arousal level categories*





Note. Error bars display standard error of the mean. *** $p < .001$. NS = not significant.

Individual Differences

To assess the potential influence of individual differences in arousability, a Pearson correlation was first conducted between participants' APS scores and their average self-reported arousal ratings toward emotional modulator stimuli. A statistically significant positive correlation was revealed, $r(42) = .24$, $p < .05$, indicating that individuals with higher arousal susceptibility tended to report greater levels of emotional arousal in response to emotional stimuli (see Figure 7A). We then examined the relationship between APS scores and the RME effect, which was operationalized as the difference in *d'* statistics for face encoding stimuli associated with high- versus low-arousal picture modulator stimuli. This correlation was not statistically significant, $r(42) = .04$, $p = .82$.

To further explore whether arousal susceptibility modulates the effect of stimulus arousal on memory performance, a series of two-way factorial ANOVAs were conducted with arousal level categories (high- and low-arousal) and APS level (high and low) as within-subjects factors.

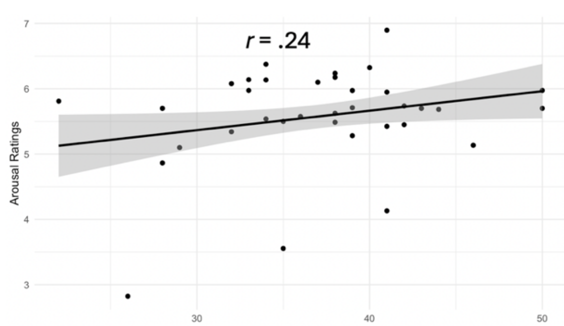
Face (item) memory. When considering arousal level and APS level without their interaction, the results revealed a significant main effect of APS level ($p < .01$) on item memory, with individuals with high arousal predisposition ($M = .67$, $SE = .01$) exhibited significantly better item memory performance compared to those with low arousal predisposition ($M = .56$, $SE = .01$). When the interaction term (arousal level × APS level) was added, the interaction effect was not significant ($p = .53$). See Figure 7B.

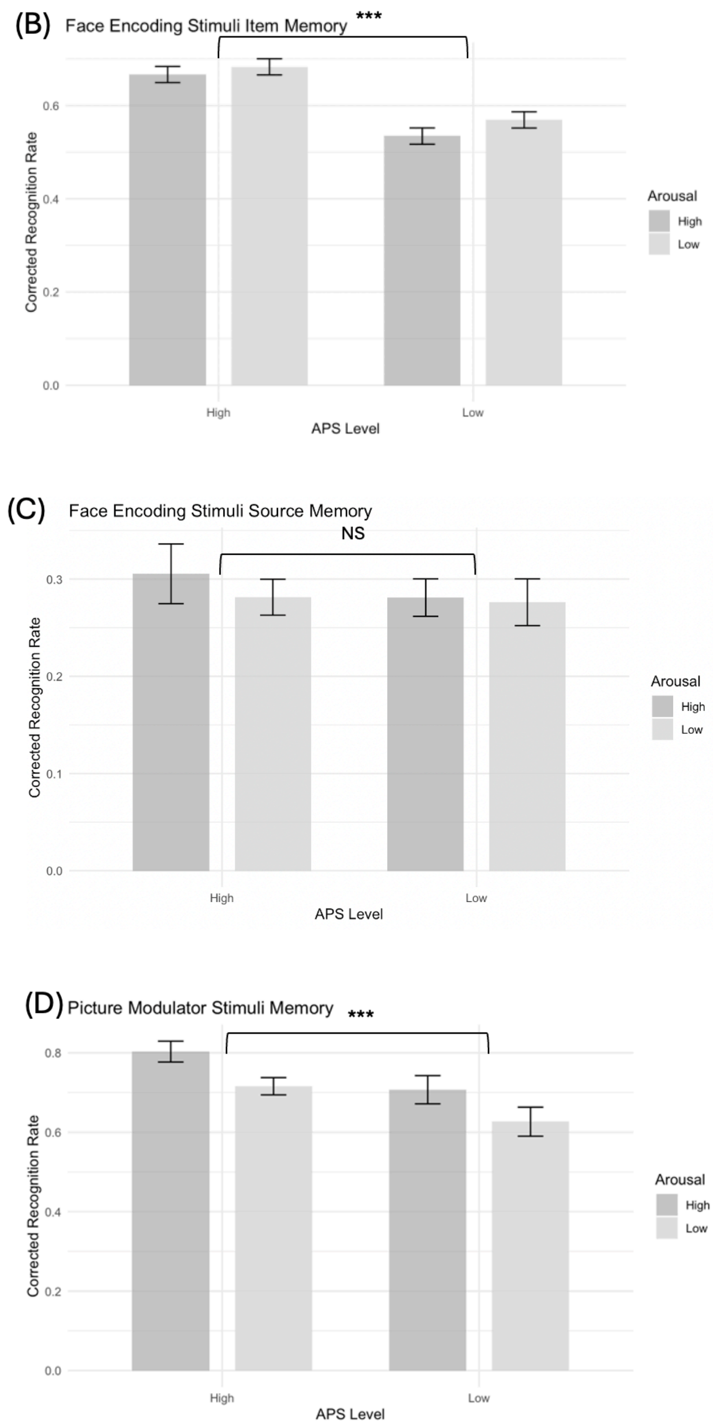
Source memory. The model including arousal level and APS level revealed that APS level ($p = .18$) did not significantly predict source memory performance. No significant difference was found between source memory performance for individuals with high ($M = .19$, $SE = .01$) and low arousal predisposition ($M = .16$. $SE = .01$). Furthermore, the interaction term (arousal level × APS level) was not significant ($p = .85$). See Figure 7C.

Picture modulator stimuli memory. A significant main effect of APS level ($p < .01$) was observed, with individuals with high arousal predisposition ($M = .83$, $SE = .01$) exhibited significantly better memory performance for picture modulator stimuli compared to those with low arousal predisposition ($M = .76$, $SE = .01$). However, interaction term (arousal level × APS level) was not significant ($p = .49$). See Figure 7D.

Figure 7. *Relationship between APS score, arousal ratings, and memory performance*

(A)





Note. Error bars display standard error of the mean. *** $p < .001$. NS = not significant.

Discussion

The present study investigated the retrograde effects of emotional arousal on memory for preceding neutral events, with a focus on item memory, source memory, and the dissociable processes of recollection and familiarity. All interpretations regarding memory performance in the present study are based on *d'* statistics, given their greater sensitivity and ability to account for response bias relative to raw correct recognition rates. It was hypothesized that emotional picture stimuli would retroactively enhance memory for neutral face stimuli presented immediately beforehand, with higher levels of arousal predicting greater RME effects, and selectively enhancing recollection rather than familiarity-based responses. Contrary to expectations, the findings did not support the presence of an RME effect. Emotional arousal did not significantly influence item memory performance for neutral items that preceded either negative versus neutral or high- versus low-arousal stimuli, as measured by corrected recognition rates, *d'*, recollection, or familiarity responses. Prior literature has emphasized the critical role of arousal in enhancing memory, with higher-arousal stimuli generally associated with more pronounced memory enhancements (LaBar & Cabeza, 2006). As such, one potential explanation for the null effect observed in the present study is that the selected emotional stimuli may not have evoked sufficiently high arousal to drive the memory enhancement processes. However, manipulation checks based on participants' subjective arousal ratings revealed a statistically significant difference between negative and neutral picture modulator stimuli, with a large effect size, indicating successful emotional induction. Furthermore, memory performance was significantly higher for negative modulator stimuli compared to neutral ones, consistent with the well-established EEM effect. These results suggest that the absence of an RME effect cannot be attributed to ineffective stimulus selection. To further evaluate the robustness of the null findings, Bayesian analyses were conducted, which provided strong evidence in favor of the null hypotheses. This leads to the conclusion that emotional arousal does not retroactively influence episodic memory for preceding neutral events. Consequently, these findings raise questions regarding the robustness and replicability of the RME effect reported by Anderson et al. (2006), at least under conditions similar to those employed in the present study.

With regard to source memory, we predicted that emotional arousal will retroactively enhance source memory for preceding neutral events. However, analyses revealed no significant differences in source memory across emotion categories or arousal level categories. These findings suggest that the ability to remember associative information related to neutral items was not differentially influenced by the emotional arousal elicited by the subsequent stimuli. Notably, while source memory accuracy was significantly above chance level (25%), the mean source memory performance (28%) was only marginally higher than chance. Such outcome could potentially suggest the presence of a floor effect, which occurs when performance on a given measure is so low that it limits the ability to detect meaningful effects and could thus affect the robustness of findings (Šimkovic & Träuble, 2019). Given this possibility, the current findings should be interpreted with caution. Future modification of the experimental design is necessary to draw a more conclusive assessment of the retrograde emotional effect on source memory for preceding neutral events.

A secondary aim of the study was to explore whether individual differences in arousal susceptibility modulate emotional memory effects. It was hypothesized that individuals higher in arousal susceptibility would exhibit greater RME and EEM effects compared to those lower in arousal susceptibility. Supporting the theoretical validity of the construct, APS scores were positively correlated with participants' average self-reported arousal ratings to emotional stimuli, indicating that individuals with higher arousal predisposition perceived emotional content as more arousing. However, the prediction that higher arousal susceptibility would be associated with greater RME effects was not supported. One possible explanation for this null finding is the overall absence of a robust RME effect observed in the present study. Interestingly, although neither a significant correlation between APS scores and RME effects nor a significant interaction between APS level and stimulus arousal category was observed, individuals with higher arousal susceptibility demonstrated significantly better item memory performance overall. Moreover, the hypothesis concerning EEM effects was supported, as individuals with greater arousability exhibited significantly better memory for emotional modulator stimuli relative to neutral ones. These findings were unexpected but align with prior research suggesting that heightened arousability may facilitate attentional engagement during encoding and promote long-term memory consolidation (Nielson & Lorber, 2009). Notably, this effect was not observed for source memory, suggesting that arousal susceptibility may preferentially influence item-based rather than associative or contextual memory processes. While the mechanisms underlying arousal predisposition remain unclear, the current findings underscore its relevance as a potential individual difference factor influencing memory outcomes in emotionally salient contexts.

There are several implications of the results of the current study. The original study by Anderson et al. (2006) reported an RME effect of emotional arousal and served as influential evidence supporting that the memory-enhancing properties of emotional events could extend to temporally adjacent, preceding neutral events. The present study sought to conceptually replicate this effect by using a highly similar experimental paradigm, in terms of stimulus selection, timing, and trial structure. Despite these efforts, as well as additional modifications designed to increase likelihood to detect the effect, we observed no evidence of an RME effect. This pattern of null effects, even under favorable conditions, may suggest that the associative link between emotionally arousing events and immediately preceding neutral stimuli is more fragile or context-dependent than previously assumed. The failure to replicate the RME effect raises questions about the boundary conditions under which such retrograde enhancements occur. For instance, findings from Knight and Mather (2009) indicate that the RME effect was observed only when participants had previously recalled the neutral items in an immediate free recall test. This suggests that RME may rely on the degree of attentional engagement or elaborative rehearsal directed toward the neutral items. From a neurobiological standpoint, this supports the idea that emotional enhancement of memory consolidation depends not only on arousal-induced neuromodulatory mechanisms but also on the allocation of attention and cognitive resources to the to-be-remembered material (Mather, 2007; Mather & Sutherland, 2011).

Several limitations of the current study should be considered when interpreting these findings. First, the categorization of arousal into high and low levels based on individual ratings may have limited the sensitivity of the analysis. A continuous modeling approach, such as mixed-effects regression using arousal ratings as a predictor, may better capture the associations between arousal and memory performance. Second, the potential floor effect in source memory performance suggests that the experimental design may have lacked sufficient sensitivity to detect differences in associative memory. The use of colored frames as contextual cues, though methodologically standard, may not have elicited strong face-frame associations. Future studies might benefit from more distinctive or task-relevant contextual features. Third, arousal was measured exclusively via self-report. While this was in line with the methodology used in Anderson et al. (2006), incorporating objective psychophysiological measures (e.g., skin conductance, heart rate variability) could provide a more comprehensive and reliable assessment of arousal. Fourth, by using a 24-hour delay interval between encoding and retrieval rather than the one-week delay used in the original Anderson et al. (2006) study serve as another potential limitation. This modification was made based on pilot testing, which revealed that a one-week delay led to floor-level performance for source memory. Although prior research indicates that a 24-hour period is sufficient for substantial memory consolidation to occur, it remains possible that a longer delay is necessary for the RME effect to emerge.

Future studies should explore new avenues based on the present findings. One direction would be to implement an immediate recall task, as in Knight and Mather (2009), to increase the attentional salience of the to-be-remembered stimuli and facilitate their consolidation. Although such a design is challenging with unfamiliar face stimuli, it may be feasible to used famous faces or verbal materials as encoding stimuli. Furthermore, the observed individual differences in arousal predisposition warrant deeper investigation. Replication with larger samples could help clarify the mechanisms linking arousability and memory. Finally, a direct, preregistered replication of the Anderson et al. (2006) study using their exact procedures would be valuable in determining whether the original findings are robust or alternately, were dependent on specific contextual or sample characteristics. If such a replication fails to demonstrate an RME effect, this would suggest that emotional arousal does not reliably enhance memory for preceding neutral events. However, if the replication is successful, it would underscore the importance of identifying boundary conditions under which the RME effect can be observed.

In conclusion, the present study did not find an RME effect of emotional arousal for preceding neutral events as reported by Anderson et al. (2006). These null findings suggest that the retroactive influence of emotional arousal on episodic memory may be more context-dependent than previously assumed. The successful induction of emotional arousal and the robust EEM for the emotional stimuli themselves suggested that the absence of an RME effect cannot be attributed to ineffective manipulation. Instead, the findings highlight the importance of attentional and cognitive factors, such as immediate rehearsal or elaborative encoding, in enabling retroactive memory benefits, as suggested by prior work (Knight & Mather, 2009). Additionally, the unexpected finding that individuals with higher arousal predisposition exhibited better memory performance points to the relevance of individual differences in susceptibility to arousal, warranting further investigation. Together, these findings refine our understanding of the boundary conditions under which emotional arousal influences memory consolidation and call for future research to probe the interplay between arousal, attention, and individual traits. Ultimately, this study contributes to a growing body of literature questioning the generalizability of the RME effect and emphasizes the need for well-powered replications to delineate when and for whom emotion retroactively modulate episodic memory.

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