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The effect of positively arousing images on Declarative Memory

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Abstract

Declarative memory, that is, the recall of conscious memories from long-term memory, can involve either details of a previous experience (episodic memory) or general knowledge about the world (semantic memory). Research shows that episodic memory is enhanced when the level of emotional arousal elicited by a stimulus is sufficient to engage the amygdala, regardless of the positive/negative nature (valence) of the emotion. However, studies on the effect of emotional arousal on semantic memory are very limited and inconsistent. The present study examined the simultaneous effect of high positive arousal on episodic and semantic recall in 47 young Greek adults. Seven high-arousal positive images and seven low-arousal neutral images were used. Each image was paired with one episodic and one semantic question. Participants were asked to answer these with "true/false/don't know" in a computer program that recorded the precise reaction times of correct responses. The mean response times were analyzed using a 2×2 factorial repeated-measures ANOVA, revealing a significant main effect of Memory ($p<0.001$), but not of Arousal ($p=0.682$) or their interaction ($p=0.554$). The results are interpreted, among other frameworks, through the "modulated-consolidation model" and the "emotional-binding model" for episodic memory, and the "affect-as-information" and "Mood-and-General-Knowledge" hypotheses for semantic recall. This research contributes to understanding how positive arousal interacts with different aspects of memory, which is considered important at both clinical and educational levels.

Keywords

Declarative memory, episodic memory, semantic memory, arousal, emotion, images

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Introduction

Emotional arousal has been shown to enhance the retrieval of conscious memories from long-term memory (declarative memory) (1). Stimuli that elicit high emotional arousal, through neural networks (2), are better memorized and recalled more quickly and accurately, possibly because the brain perceives them as more useful information for survival (3,4). However, extreme emotional arousal is suggested to be detrimental (5).

Specifically, declarative memory consists of interconnected networks/schemas that are activated when we retrieve memories or information. For this to occur, information must first be collected and recorded in the brain (encoding) and subsequently stabilized in long-term memory (consolidation) through two successive phases (cellular/systemic) (6–8). Recent evidence indicates that when long-term memories are retrieved, they are modified or updated and subsequently reconsolidated, suggesting dynamic rather than static processes, as was previously believed (9).

Tulving (10) introduced the distinction within declarative memory between episodic and semantic memory. Episodic memory provides access to the details of a past experience and is temporally encoded, whereas semantic memory refers to general knowledge about the world and is not temporally encoded (11,12). While emotional arousal (positive or negative) is argued to enhance the retrieval of episodic memory (13–26), research on semantic memory is limited and yields conflicting results (27–29).

Regarding episodic memories, studies show that the enhancing effect of positive or negative arousal (hereafter: EEM—emotional enhanced memory) is often greater when memory is tested experimentally after a delay, whereas it is frequently diminished or even reversed when memory is tested immediately after encoding (30–35). In contrast, neutral stimuli, which evoke low arousal, have been shown to be better recalled immediately after encoding but tend to weaken over time (36–37).

The modulated consolidation model (7) constitutes a fundamental explanatory framework for understanding delayed EEM, emphasizing the role of amygdala activity. The model proposes that, upon the occurrence of emotional (positive or negative) stimuli, the adrenal glands secrete stress hormones (epinephrine and cortisol). The action of these hormones is time-dependent (38) and triggers the emotional arousal necessary for the glucocorticoid enhancement of memory (39). Furthermore, the model posits that the amygdala can modulate the early mechanisms of long-term potentiation (LTP) by "tagging," at a molecular level, via projections from the basolateral amygdala to the hippocampus, the synapses that should later be strengthened—thus ensuring that early LTP is prolonged into late LTP, leading to long-term plasticity in the activated synapses (synaptic tagging and capture theory) (40,41). While the model is supported by extensive literature (7,42–46), it has been reported to fall short in explaining the tendency of emotional memories to exhibit selective and/or short-term enhancements, that is, before the completion of consolidation (47).

Recently, an alternative model of emotional binding in human memory (35) was proposed, suggesting that emotional memories "persist" longer than neutral ones because their trace is permanently stored in the amygdala. In contrast, the trace of the neutral/contextual aspects of the episode/stimulus is stored in the hippocampus, where increased neurogenesis and cell death are observed, resulting in instability (35, p. 263).

The EEM observed, to a lesser extent, in immediate memory tests (28,48,49) is thought to be mediated primarily by amygdala effects during encoding (50–54). Research indicates that emotional stimuli involuntarily draw additional attentional resources through distinct mechanisms inaccessible even to the most salient neutral stimuli (55,56), and that arousal amplifies this contrast (Arousal Competition Model) (57). Specifically, the amygdala, during the processing of a stimulus, detects its emotional significance at a very early stage and, through feedback connections, signals the attentional and perceptual systems to prioritize it (58,59). In contrast, neutral stimuli engage fronto-parietal systems at a later stage (60).

However, although it has been shown that, for the enhancement of episodic declarative memory, it is sufficient for a stimulus to evoke a level of arousal adequate to engage the amygdala (61)—regardless of the positive or negative nature (valence) of the emotion (62–65)—it is argued that negative information is remembered with greater visual detail than positive or neutral information, as evidenced by reduced activity in the intraparietal cortex, a region that facilitates the shifting of attention in visual space (66). Furthermore, successful encoding of negative stimuli appears to depend on increased activity in the visual cortex and fusiform gyrus (regions associated with sensory processing), whereas positive stimuli rely on increased activity in lateral prefrontal and temporal regions (associated with conceptual-semantic processing) (67,68). These findings reinforce evidence that negative stimuli tend to narrow attention to central details, whereas positive stimuli favor the extraction of the overall meaning (37,69–71). Notably, data indicate that these valence-dependent networks are also present during retrieval (48).

With regard to the effect of arousal on semantic memory, there is a notable lack of research (28). However, the "affect-as-information" hypothesis (72–78), which explains the impact of mood on memory and other cognitive processes, provides useful insights. According to this view, emotional stimuli convey information about the appropriateness of using available general knowledge to interpret the current situation (79). Thus, individuals in positive emotional states perceive the current situation as non-threatening and therefore consider it safe to rely on available general knowledge structures, heuristic methods, or stereotypes to interpret it (80–83). Similarly, the "Mood-and-General-Knowledge" (MAGK) hypothesis (84–86) suggests that positive affect is likely to increase one's confidence in relying on available information, since such reliance has been effective in the past.

In light of the scarcity of studies examining the effect of emotional arousal on semantic memory—and particularly in comparison to episodic memory, with which it forms part of a highly interactive common LTM network (87,88)—Constantinou et al. (28) investigated, to our knowledge for the first time, the simultaneous effect of high-arousal negative emotion, induced through photographs from the OASIS database (89), on episodic and semantic retrieval in 47 young adults, compared to neutral low-arousal images. The results showed that participants were faster and more accurate in episodic retrieval compared to semantic retrieval, especially following exposure to high-arousal negative images.

The present study examined whether the above findings are also confirmed in the case of high-arousal positive emotion. Understanding how arousal interacts with the content of memories (episodic vs. semantic) was deemed important, given the deficits in declarative memory observed in various psychiatric disorders (schizophrenia, post-traumatic stress disorder, major depressive disorder) (90–93), as well as the need to design effective educational curricula where information retrieval plays a crucial role (94). It was hypothesized that there would be a significant effect of arousal and memory type, but not of their interaction, on the retrieval times of correct episodic and semantic responses—consistent with the findings of Constantinou et al. (28). Specifically, it was expected that participants would be faster in episodic retrieval compared to semantic retrieval, particularly after viewing high-arousal positive images.

Methodology

Design:
A factorial repeated-measures ANOVA 2×2 design was used, meeting the parametric assumptions, with IV1: Declarative Memory (Episodic/Semantic), IV2: Arousal (high—positive valence / low—neutral valence), DV: reaction time for correct responses, and N = 47 (28).

Participants:
The study involved 47 healthy young adults, of whom 31 were male (M = 22.62, range = 18–30, SD = 3). All participants met the inclusion criteria: normal vision, possession of a secondary education diploma to ensure homogeneity in semantic knowledge, and absence of neuropsychiatric disorders or alcohol/substance use. A convenience sample was used.

Materials/Tools:
The experiment was conducted using the Psychopy Runner program (v2023.2.3; Peirce et al., 2019, 2022), running on a Dell G15 Ryzen Edition computer with a 15.6´´ Full HD display. Fourteen color images were used as visual stimuli for the memory retrieval conditions. Stimuli were selected from the OASIS database (89) based on their elicited arousal ratings. Specifically, seven high-arousal positive images (faces) with sensual content (topless women/couples embracing) were chosen , and seven low-arousal neutral images (objects) were chosen, ensuring a deviation of two standard deviations from the mean arousal rating in each direction (28). Each image was paired with one episodic and one semantic question concerning its central theme. For analysis of mean response times, IBM SPSS Statistics (v.28.0.1.0) was used. Additional materials included: an information sheet, a consent form, and a debriefing document.

Procedure:
Participants were randomly recruited from the Mediterranean College premises. They were given an information sheet summarizing the procedure, data protection and anonymity measures, their right to withdraw, and the researchers' contact details. Once eligibility criteria were met, they signed the informed consent form and proceeded to run the program on the computer. For each experimental trial, participants first saw a brief instruction screen informing them they would be answering questions about an image they had just seen, using key 1 for "True," key 2 for "False," and key 3 for "Don't know," and were prompted to press the 1 key to begin the experiment. The first three images/questions were trial runs to familiarize participants with the task.

Each experimental trial began with the presentation of a high- or low-arousal image for 4 seconds, followed by a blank grey screen for 1 second. A question assessing episodic or semantic memory was then presented for 6 seconds, during which participants had to respond; failure to respond was recorded as an incorrect answer. Each trial was separated by a 1-second blank grey screen. Images were each presented twice in non-consecutive order to ensure long-term memory engagement and equal presentation across the two memory conditions (28).

The experimental session lasted a maximum of 5 minutes. Upon completion, participants were fully debriefed about the study's aims and background through a debriefing document. The study received ethical approval from the supervising professor and conformed to the ethical standards of the University of Derby and the British Psychological Society (BPS).

Results

The mean response times for correct answers in each experimental condition are shown in Table 1.

Table 1. Mean response time of correct answers (sec.) for all conditions: a) Positive-Episodic, b) Positive-Semantic, c) Neutral-Episodic, d) Neutral-Semantic (with standard deviations).

	Episodic-Retrieval	Semantic-Retrieval	TOTAL
Positive/ (High-Arousal)	2,44(0,64)	2,71(0,72)	2,58(0,69)
Neutral/ (Low-Arousal)	2,41(0,50)	2,71(0,67)	2,56(0,61)
TOTAL	2,42(0,57)	2,71(0,69)	

There was a significant main effect of Memory on the response time of correct answers, with a fairly large effect size (Cohen, 1988), $F(1,46) = 44.647$, $p < 0.001$ ($< \alpha = 0.05$), $\eta^2 = 0.26$ (Appendix 11). However, there was no significant main effect of Arousal, $F(1,46) = 0.170$, $p = 0.682$ ($> \alpha = 0.05$), $\eta^2 = 0.001$ (Appendix 11), nor a significant Memory × Arousal interaction, $F(1,46) = 0.356$, $p = 0.554$ ($> \alpha = 0.05$), $\eta^2 = 0.001$ (Appendix 11).

The mean response time for correct answers was almost identical for high-arousal questions (2.58 sec) and low-arousal questions (2.56 sec). However, episodic questions were answered significantly faster (2.42 sec) than semantic ones (2.71 sec).

Discussion

Not all hypotheses were supported. There was a significant main effect of Memory on the response times of correct episodic/semantic answers, consistent with Constantinou et al. (28), with episodic questions being answered faster than semantic ones. In fact, it appeared that 26% of the variance in the results could be explained by the Memory variable. However, there was no significant main effect of Arousal on the response times of correct answers, which is contrary to previous literature (19, 28, 63). Finally, there was no significant effect of the Memory × Arousal interaction, which was hypothesized (28). Participants answered (correctly) in almost the same time for questions related to positive/high-arousal images and neutral/low-arousal ones. Remarkably, the mean response time for correct semantic answers was exactly the same for both high- and low-arousal images.

The fact that arousal did not have a significant effect on episodic response times could be explained in line with prevailing literature, which emphasizes that the arousal-related enhancement of episodic memory increases over time, and in many cases is diminished or even reversed when memory is tested immediately after encoding (30–36). In contrast, memory for neutral/low-arousal stimuli tends to be better immediately after encoding (36, 37). In any case, this assumption—neurophysiologically explained by the modulated consolidation model (7) and the emotion-binding model (35), among others (98)—should be approached with caution, since the present study did not test memory at a later time point.

Furthermore, the absence of an arousal effect on episodic responses could be attributed to the fact that positive/neutral stimuli are not remembered as vividly as negative ones (37, 69–71), due to the involvement of different brain regions during encoding (66–68) and/or retrieval (17). Therefore, they may not have been able to produce significantly shorter response times, as was observed in the study by Constantinou et al. (28).

Moreover, the results are contrary to studies that reported an enhancement of episodic memory after immediate testing (48–52, 59, 108). Specifically, it appeared that the positive arousing/sensual images used in the present study may not have captured participants' attention at the expense of neutral/low-arousal images, as current literature suggests (Arousal-Competition Model (55-60, 66) — even though the majority of participants were men. This could be explained by the fact that arousal decreases after extended habituation (99–101), something highly likely to have occurred given that pornography consumption (a stimulus far more arousing than the material used in this study) now appears to be extremely widespread across all age groups (>85%), particularly among young adults (men: 97.4% and women: 75.3%) (102).

Furthermore, the convergence of mean semantic response times for positive and neutral images could be accounted for by the "emotion-as-information" hypothesis (72–79) and the "Mood-and-General-Knowledge" hypothesis (84–86). Neutral images are not capable of inducing a negative mood and thus do not cultivate in participants the sense that they are in a potentially dangerous environment, which would make it unsafe to rely on available general knowledge from semantic memory. In this sense, they more closely resemble positive images, which may explain the similarity in response times.

A limitation that would be useful to address in future related studies, for the sake of "clarity" of results, is that the difficulty level of the questions was not experimentally controlled, although an effort was made to keep them equally difficult. In addition, we cannot know with certainty whether participants relied exclusively on semantic memory to answer semantic questions, or whether they also drew on episodic memories (27), in the sense that they may have answered not only on the basis of general knowledge but also by relying on stored contextual experiences. However, it is argued that episodic memories gradually transform into semantic ones over time (semanticization) (103).

Finally, it would be useful in future research to replicate the present study using film clips or moving images, which have been shown to capture attention and induce arousal more effectively than static images (104–106).

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