

# Enhanced selective memory consolidation following post-learning pleasant and aversive arousal <sup>☆</sup>

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Received 27 April 2007; revised 12 September 2007; accepted 13 September 2007

Available online 22 October 2007

## Abstract

It is well established that emotions modulate memory, typically enhancing consolidation through post-learning arousal. However, many aspects of this phenomenon have yet to be delineated. For example, it remains unclear whether or not the type of arousal is relevant (pleasant vs. aversive), whether arousal enhances memory selectively for some stimuli but not others (emotional vs. neutral), which specific aspects of the stimulus representation (gist vs. detail) are affected, and whether these mechanisms are sexually dimorphic. In order to explore these issues, 178 undergraduate participants viewed a series of negative, positive and neutral pictures. They were then subjected to a post-learning arousal manipulation in the form of a pleasantly arousing-, aversively arousing-, or neutral video. Free recall tests one week later indicated that both pleasant and aversive post-learning arousal enhanced memory consolidation for positive and negative but not neutral stimuli, independent of the participants' sex. Further analysis for gist and detail aspects suggests that post-learning arousal enhances memory for the gist of the stimuli. The study has implications for the understanding of healthy and pathological cognitive-affective processes in humans.

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**Keywords:** Emotion; Memory consolidation; Arousal; Valence; Anxiety disorders

## 1. Introduction

Although emotional arousal can have a detrimental effect on memory under some circumstances, e.g., during retrieval (De Quervain, Roozendaal, Nitsch, McGaugh, & Hock, 2000; Kuhlmann, Kirschbaum, & Wolf, 2005), most studies on emotional memory have offered substantial evidence for emotional memory enhancement (e.g., Cahill & McGaugh, 1998; LaBar & Cabeza, 2006). Emotional events are consequential to the individual, being more

closely related to one's goals and objectives (Reisberg & Heuer, 2004). From an evolutionary viewpoint, enhanced memory for emotional events therefore serves an adaptive function, highlighting salient stimuli and events important to the survival of an organism.

Memory enhancement for emotional events could be due to factors such as increased attention during encoding (Revelle & Loftus, 1992), increased rehearsal or elaboration (Neisser et al., 1996), and increased memory consolidation (Cahill & McGaugh, 1998; McGaugh & Roozendaal, 2002). The current study is concerned with the role of emotional arousal in memory consolidation, the post-learning process whereby memories become more stable over time (Phelps, 2006).

The memory consolidation phase is affected by arousal mechanisms involving endogenous stress hormones and neurotransmitters such as adrenaline, noradrenaline and

<sup>☆</sup> The authors thank Dr. Kristy Nielson for sending us the dental surgery and tooth-brushing videos and kindly giving us permission to use them in our study. The authors also thank Dr. Why Yong Peng for contributing his statistical expertise and the FSM for its general guidance and wisdom.

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cortisol (McGaugh, 2000). Adrenal stress hormones are released as a physiological response during emotionally arousing events and thus serve the organism's immediate adaptive needs such as flight-or-fight responses (Cahill & McGaugh, 1998). In addition, adrenal stress hormones also influence the memory consolidation phase, allowing the importance of an emotional experience, reflected by its level of triggered arousal, to determine the strength of memory for the experience (McGaugh, 2000). The critical role of adrenal stress hormones in the enhancement of memory for emotional events has been documented in various animal (Cahill & McGaugh, 1998; Roozendaal, 2000; Roozendaal, 2003; Zorawski & Killcross, 2002; Zorawski & Killcross, 2003) and human (Cahill, Prins, Weber, & McGaugh, 1994; van Stegeren, Everaerd, Cahill, McGaugh, & Gooren, 1998) studies involving the administration of drugs that either block or enhance the relevant endogenous stress hormone systems. One major limitation characterizing many of such studies in humans involves the fact that drug administration typically occurs prior to stimuli presentation, making it difficult to disentangle the effects on attention and encoding from effects on consolidation. More recently, some human studies have employed *post-learning* arousal manipulations to explore post-learning effects of emotional arousal on memory, utilizing pharmacological (Cahill & Alkire, 2003) or experimental (Cahill, Gorski, & Le, 2003; Nielson, Yee, & Erickson, 2005) means. For example, participants who received Cold Pressor Stress (CPS) after the presentation of picture stimuli experienced increased salivary cortisol levels and showed enhanced delayed memory for negatively arousing pictures relative to controls, an effect that was more pronounced for relatively more arousing pictures (Cahill et al., 2003). Similarly, post-learning arousal induced by having participants watch an aversively arousing dental surgery video enhanced memory for neutral word stimuli recalled one week later (Nielson et al., 2005). The few studies that have explored the role of post-learning arousal on memory consolidation in humans have predominately utilized aversively stressful events to induce arousal (Cahill et al., 2003; Nielson et al., 2005). However, an important study by Nielson and Powless (2007) recently showed that post-learning arousal stimulated by pleasant events can produce analogous results. In this study, participants learned a list of neutral words and were then presented with either a pleasantly or aversively arousing video clip after various time delays (0–45 min). Retrieval (recognition) after one week was enhanced for both the aversive and pleasant arousal groups as compared to control, as long as the manipulation took place within 30 min of learning.

Furthermore, support for post-learning memory modulation by pleasant arousal also comes from basic animal research. First, stress hormones such as cortisol, adrenaline and noradrenaline can also be released in response to pleasant events (e.g., Merali, McIntosh, Kent, Michaud, & Anisman, 1998; Piazza & Le Moal, 1997). Second, modulation of memory has also been demonstrated by administra-

tion of amphetamine, (Krivanek & McGaugh, 1969; McGaugh, 2004; Packard, Cahill, & McGaugh, 1994; Soetens, Casaer, D'Hooge, & Hueting, 1995; Soetens, D'Hooge & Hueting, 1993), which up-regulates dopamine transmission, a neurotransmitter associated closely with pleasant experiences. Finally, it has been shown that post-learning stress hormone administration enhances memory consolidation in both appetitive and aversive learning procedures (Zorawski & Killcross, 2002, 2003). While studies in humans by Nielson and Bryant (2005) and Nielson and Powless (2007) have demonstrated enhanced memory consolidation following positive post-learning arousal in the form of positive affect and humor, respectively, both studies utilized only neutral, non-arousing stimuli to be remembered and employed an intentional memory test. Moreover, Nielson and Bryant (2005) induced positive affect by rewarding participants with either praise or money. Hence, enhanced memory in this study could also be attributed to motivational factors.

Furthermore, it is still unclear whether the memory-enhancing effects of post-learning arousal occur selectively (or at least more readily) for emotional material. Some of the studies cited below (Abercrombie, Kalin, Thurow, Rosenkranz, & Davidson, 2003; Buchanan & Loyallo, 2001; Lupien, Gillin, & Hauger, 1999; Lupien et al., 2002; Maheu, Joober, Beaulieu, & Lupien, 2004) employed pre-learning manipulations which nevertheless could be interpreted as reflecting post-learning arousal effects. According to behavioral (Cahill et al., 2003) and drug studies (Buchanan & Loyallo, 2001; Cahill & Alkire, 2003), post-learning stress hormone activation interacts with the degree of arousal induced by stimuli at encoding, enhancing memory for emotional stimuli only. In contrast, other studies have demonstrated that memory enhancement also occurs for neutral stimuli semantically unrelated to the arousal source (Abercrombie et al., 2003; Lupien et al., 1999; Lupien et al., 2002; Maheu et al., 2004; Nielson & Bryant, 2005; Nielson & Powless, 2007; Nielson, Radtke, & Jensen, 1996; Nielson et al., 2005). Hence, the interaction between the valence of post-learning arousal (pleasant or aversive) and the valence of to-be-remembered stimuli (positive, negative or neutral) remains to be delineated.

### 1.1. *Gist and detail aspects in emotional memory modulation*

It is possible that different aspects of the to-be-remembered stimuli, namely the *gist* (i.e., the central aspects of a stimulus), and the *detail* (i.e., additional sensory information) may be differentially affected by emotional arousal. Research on the effects of emotion on memory for gist and detail has focused mainly on attentional mechanisms. The Easterbrook hypothesis states that physiological arousal leads to the “narrowing” of attention, thereby reducing memory for the stimuli's periphery and increasing memory for its gist (Easterbrook, 1959, as cited by Burke, Heuer, & Reisberg, 1992). Although various studies have documented this “memory narrowing” effect (Christianson &

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