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Neurobiology of Learning and Memory 79 (2003) 132–135

Neurobiology of
Learning and Memory

www.elsevier.com/locate/ynlme

Brief Report

Differential effects of emotional arousal in short- and long-term memory in healthy adults[☆]

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Received 25 July 2001; accepted 4 November 2002

Abstract

Recent studies demonstrated important differences between short- and long-term memory mechanisms. Besides, the emotional component has a crucial role in memory formation. This study was carried out to answer whether there is a differential influence of emotional arousal in short- and long-term memory in healthy adults. Thirty-one healthy volunteers were divided into two major groups. In the first group long-term memory (LTM) was evaluated, with the testing session one week after training. The second group was tested 1 h after training, where short-term memory (STM) was evaluated. Each group was divided in to two subgroups. One half of the volunteers was exposed to an emotionally neutral story, and the other half of each group was exposed to a closely matched but more emotionally arousing story. The testing session consisted of a questionnaire containing 80 questions of multiple choices. The results were evaluated through percentage of correct answers. Results showed that correct answers were increased, in LTM measures, in the subjects that were given the emotional version of the test. In STM measures, no differences were found between the emotional and neutral version. However, the presentation of emotional story caused an emotional reaction in both groups. The lack of effect of emotional arousal in STM suggests that amygdala is not related to STM mechanisms. Further studies using different approaches are needed to elucidate if STM processes are influenced by emotional arousal.

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There is little doubt that memory for emotional arousing events is better than for neutral stimuli. This is clearly adaptive, because emotional stimuli, whether pleasant or aversive are generally more important to species survival (Hamann, Ely, Grafton, & Kilts, 1999). Evidence indicates that emotional memories established through the amygdala are impervious to extinction and forgetting processes (Cahill, 1997; Ledoux, 1992). These findings are consistent with the hypothesis that emotional responses influence memory, at least in part, through amygdala by modulating long-term memory storage (Bianchin, Mello-e-Souza, Medina, & Izquierdo, 1999; Cahill & McGaugh, 1996). During and immediately after emotionally arousing or stressful situations,

several physiological systems are activated, including the release of many hormones (Roosendaal, Quirarte, & McGaugh, 1997; Stratakis & Chrousos, 1995). Several of these substances like adrenal hormones, corticotrophin, prolactin, vasopressin, and opioid peptides are known to modulate memory storage (Buchanan & Lovallo, 2001; Cahill, 1997; McEwen & Magarinos, 1997; McGaugh, 2000; Newcomer, Craft, Hershey, Askins, & Bardgett, 1994). Evidence indicates that epinephrine and glucocorticoid effects on memory are mediated by influences involving amygdala (Roosendaal, Sapalsky, & McGaugh, 1998). The basolateral nucleus of the amygdala is critically involved in the glucocorticoid influence since lesions or of infusion of B-adrenergic receptor antagonist at this area block the effects of glucocorticoids (McGaugh, 2000). Considerable evidence indicates that amygdala has a crucial role in enhancing the strength of long-term memory for

[☆] This work was supported by PRONEX and FIPE-HCPA, Brazil.

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emotional events through the interaction of peripheral adrenergic systems with cholinergic, opioid-peptidergic, and GABAergic systems (Hamann et al., 1999).

There is strong evidence that amygdala is involved in modulating long-term storage, for many reasons, like the compatibility between studies using human subjects and those of animal experiments (McGaugh, 2000). Studies using B-blockers and amygdala lesions showed a reduced effect of emotional arousal on memory (Cahill, Prins, Weber, & McGaugh, 1994). Most current evidence indicates that the amygdala is not a site of storage of memory processes, but has a modulatory function (McGaugh & Izquierdo, 2000). Barros et al. described that drugs that facilitate memory given 3 h posttraining into rat CA1 region reverse the amnesic effect of KN62, an inhibitor of calcium calmodulin kinase II, given into amygdala 0 h after training, but not that of KN62 given into CA1 0 h posttraining (Barros et al., 1999). Additionally, 3-week recall of emotional material is highly correlated with positron emission tomography activation of the right amygdala during encoding (McGaugh, Cahill, & Roozendaal, 1996). Furthermore, studies evaluating the consequences of visual cortex lesions on the acquisition and extinction of fear responses conditioned to visual stimuli showed that the animals failed to extinguish over the period of one month (Ledoux, 1992). This suggested that emotional memories involving subcortical inputs to the amygdala are highly resistant to extinction. The amygdala is believed to influence memory through its direct connection with hippocampus and entorhinal cortex (Izquierdo & Medina, 1997). This connection appears to have a time-limited role in memory formation.

Recent findings described differences between short-term memory (STM) and long-term memory (LTM) in step-down inhibitory task, suggesting that different mechanisms are involved in each one (Izquierdo et al., 1998a; Izquierdo, Medina, Vianna, Izquierdo, & Barros, 1999). Short-term memory was defined as that measured while LTM becomes effectively consolidated, i.e., in the first 3–6 h after acquisition (Izquierdo & Medina, 1997). During this time, biochemical events take place in the hippocampus and elsewhere, which culminate by gene transcription and protein synthesis that are necessary for LTM consolidation. This definition of STM stems from the classical studies of James and McGaugh (James, 1890; McGaugh, 1966). Long-term memory becomes fully consolidated only several hours after acquisition. Many studies suggest that this process involves hippocampus, entorhinal cortex, and other cortical regions and that it is modulated early after training by the amygdala (Cahill & McGaugh, 1996; Izquierdo & Medina, 1997). Emerging evidence from Bianchin et al. suggests that the influence of amygdala on long-term memory occurs independent of working memory and short-term memory and that amygdala is

uninvolved in the last two kinds of memory in step-down inhibitory avoidance task (Bianchin et al., 1999).

Considered together, these findings provide support to investigate the influence of emotional arousal on STM and LTM in healthy adults. Since amygdala, that appears to mediate most of the emotional influence on memory, have been shown different involvement in STM and LTM, this allows to evaluate the importance of the emotional content to memory formation in these two different moments in the time window. According to the memory consolidation hypothesis and experimental animal data, we expect that emotional arousing increases long-term memory, possibly through amygdala modulation of hippocampal activity, but do not affect short-term memory, since little consolidation has taken place at this period and the two kinds of memory may have different mechanisms.

Thirty-one healthy volunteers (male, University students, age between 18 and 30) had an individual explanation about study objectives, which persuade the subjects to believe it was a cardiologic physiology evaluation in variable conditions. Then, the informed consent was obtained. University Hospital Ethics Committee approved the protocol. Subjects were exposed to an emotionally neutral story, or a closely matched but more emotionally arousing story (Cahill et al., 1994). The stories were presented as a brief (about 5 min) narrated slide show. The entire presentation consisted of 11 slides accompanied by narration, which could be emotional or neutral (Cahill et al., 1994). The story was divided into three phases: the first including the slides 1–4, the second including slides 5–8, and the final with slides 9–11. In phase 1 the narration was identical in the neutral and in the emotional version of the story, in phase 3 it was nearly identical. The emotionally arousing narration occurred in the middle (phase 2) of the story. Immediately after training, each subject was asked to match in a 0–10 scale how emotional he thought the story was. Subjects watched the slide presentation individually and heart rate and blood pressure were measured while viewing the story. They were told that the study was conducted in order to evaluate physiological responses to different types of stimuli. One hour or one week later volunteers were submitted to a surprise memory-recall test. Subjects were divided into two major groups in which the difference between them was the time they did the testing session. In the first group ($n = 14$) long-term memory was evaluated, with the testing session one week after slide show. The second group ($n = 17$) was tested 1 h after training, considering STM. In the period of time between slide presentation and test session, the group that had to wait 1 h was conducted to a neutral environment where they were allowed to read books or previous selected magazines and watch some documentary on VCR. The group that performed the memory

test one week later went back home and came next week at right time of testing. Both groups were recommended not to comment about the presentation they had just seen. The testing session consisted of a questionnaire containing 80 questions of multiple choices. The questionnaire consisted of 5–8 questions for each slide, and was presented in the same order of the story. The questions were presented only once and the subject was asked to choose one answer and then go on to the next one.

Results are presented as length measure in centimeters for self-rating emotional scale and as percentage of correct answers for the questionnaire of multiple choices. Data for emotional scale and percentage for correct answers are shown as mean \pm SEM. Comparisons between emotional and neutral groups were performed using an independent *t*-test. Differences between each phase were performing using a paired *t*-test. In all comparisons, $p < .05$ was considered to indicate statistical significance.

The results for LTM are shown in Fig. 1. Percentage for correct answers was enhanced in phase 2 of emotional version ($p < .05$). Phase 1 and phase 3 have similar percentage for correct answers ($p > .05$).

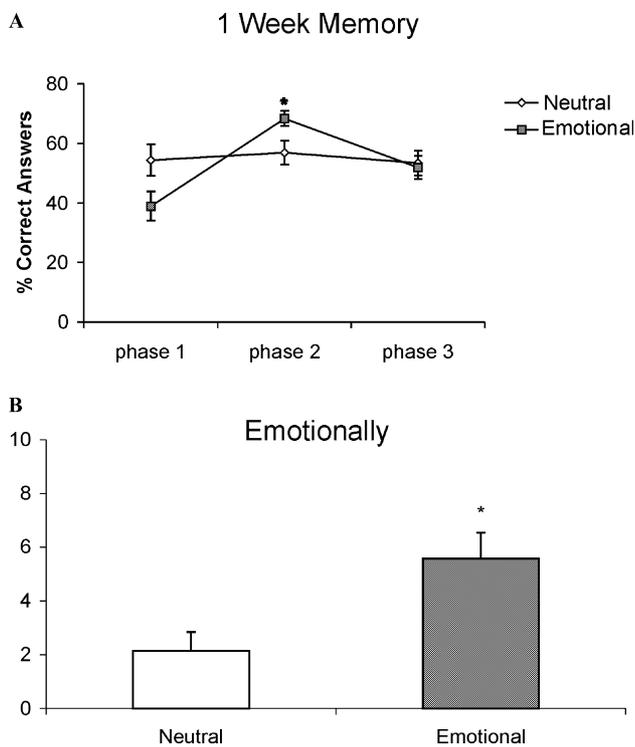


Fig. 1. Long-term memory was measured (i.e., test session after one week). (A) There was a significant ($p < .05$) difference between the group that attempted to neutral version and the group that saw emotional version in relation to percentage of correct answers during phase 2. (B) In the self-rating scale about emotional impact of the story, there was a significant ($p < .05$) difference between neutral and emotional group.

Comparisons within groups showed similar percentage for correct answers across phases in neutral version, while percentage for correct answers in phase 2 of emotional version was enhanced when compared to phase 1 and 3. Self-rating for emotionally shown an enhancement of subjective emotion for subjects submitted to emotional version ($p < .05$).

Fig. 2 presents the results for STM. There were no differences in percentage for correct answers between groups and across phases within groups. However, self-rating for emotionally shown an enhancement of subjective emotion for subjects submitted to emotional version ($p < .05$).

Our results demonstrated that emotional arousal enhanced LTM but not STM. Emotional arousal (Cahill & McGaugh, 1998) and stress hormones (McGaugh et al., 1996) play a crucial role in modulation of human long-term memory (Buchanan & Lovaglio, 2001). A previous study from Soetens and co-workers showed a pharmacological dissociation between short- and long-term memory in human subjects because post-learning amphetamine injections only enhanced long-term, but not short-term, memory performance (Soetens, D'Hooge, & Huetting, 1993).

Several lines of evidence indicates that amygdala play a key role in modulation of emotional memory (Cahill &

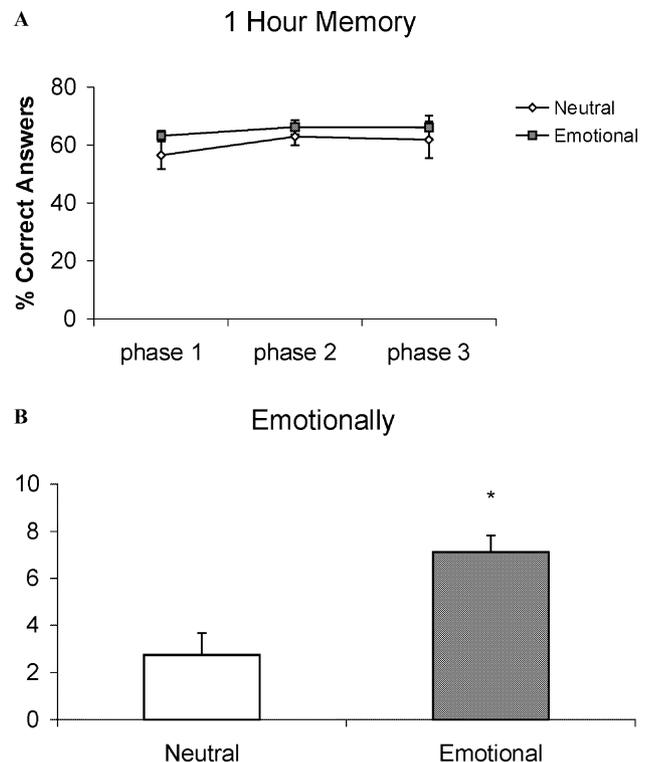


Fig. 2. Short-term memory was measured (i.e., test session after 1 h). (A) There was no ($p > .05$) difference between the neutral group and the emotional group in relation to percentage of correct answers. (B) In the self-rating scale about emotional impact of the story, there was a significant ($p < .05$) difference between neutral and emotional group.

McGaugh, 1996; Ledoux, 1992) for both human (Cahill & McGaugh, 1998; McGaugh et al., 1996) and non-human subjects (Barros et al., 1999; Bianchin et al., 1999). Recent data from our demonstrated that STM and LTM require different neuroanatomical (Bianchin et al., 1999) and biochemical (Izquierdo et al., 1998b; Medina, Schröder, & Izquierdo, 1999) components. Consistent with studies of patients with amygdala lesions, positron emission tomography (PET) studies provide additional support for the hypothesis that the amygdala is selectively involved with long-term memory for emotionally arousing events. Studies using PET scans to assess amygdala activity induced by emotionally arousing stimuli found that long-term memory correlates with the degree of amygdala activation during original encoding (Cahill & McGaugh, 1998; Hamann et al., 1999; McGaugh, 2000). Other PET study demonstrated that viewing emotionally arousing films activated amygdala, but recall of previous learned emotional events does not, consistent with the time limited role of amygdala in memory formation (Cahill & McGaugh, 1998). Results from Bianchin et al. (1999) using step-down inhibitory avoidance paradigm showed an absence of involvement of amygdala for both work and short-term memory despite a strong role for LTM. The lack of effect of emotional arousal in STM points an additional evidence to theory of a non-involvement of amygdala in STM mechanisms. Further studies using different approaches are needed to elucidate if STM processes are influenced by emotional arousal.

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