PERGAMON

Neuropsychologia 39 (2001) 556–573

NEUROPSYCHOLOGIA

www.elsevier.com/locate/neuropsychologia

Differential amygdala activation during emotional decision and recognition memory tasks using unpleasant words: an fMRI study

Matthias H. Tabert [a,b,*], Joan C. Borod [a,b], Cheuk Y. Tang [c,d,e], Gudrun Lange [f], Tsechung C. Wei [c], Ray Johnson [b], Annette O. Nusbaum [d], Monte S. Buchsbaum [c]

[a] *Department of Neurology, Mount Sinai Medical Center, New York, NY, USA*
[b] *Department of Psychology, Queens College and The Graduate Center, City University of New York (CUNY), New York, NY, USA*
[c] *Department of Psychiatry, Mount Sinai Medical Center, New York, NY, USA*
[d] *Department of Radiology, Mount Sinai Medical Center, New York, NY, USA*
[e] *Department of Radiological Sciences, UC Irvine, Irvine, CA, USA*
[f] *Departments of Psychiatry and Radiology, UMDNJ – New Jersey Medical School, Newark, NJ, USA*

Received 14 October 1999; received in revised form 26 October 2000; accepted 17 November 2000

Abstract

This study used fMRI to examine the response of the amygdala in the evaluation and short-term recognition memory of unpleasant vs. neutral words in nine right-handed healthy adult women. To establish specificity of the amygdala response, we examined the fMRI BOLD signal in one control region (visual cortex). Alternating blocks of unpleasant and neutral trials were presented. During the emotional decision task, subjects viewed sets of three unpleasant or three neutral words while selecting the most unpleasant or neutral word, respectively. During the memory task, subjects identified words that were presented during the emotional decision task (0.50 probability). Images were detrended, filtered, and coregistered to standard brain coordinates. The Talairach coordinates for the center of the amygdala were chosen before analysis. The BOLD signal at this location in the right hemisphere revealed a greater amplitude signal for the unpleasant relative to the neutral words during the emotional decision but not the memory task, confirmed by Time Course × Word Condition ANOVAs. These results are consistent with the memory modulatory view of amygdala function, which suggests that the amygdala facilitates long-term, but not short-term, memory consolidation of emotionally significant material. The control area showed only an effect for Time Course for both the emotional decision and memory tasks, indicating the specificity of the amygdala response to the evaluation of unpleasant words. Moreover, the right-sided amygdala activation during the unpleasant word condition was strongly correlated with the BOLD response in the occipital cortex. These findings corroborate those by other researchers that the amygdala can modulate early processing of visual information in the occipital cortex. Finally, an increase in subject's state anxiety (evaluated by questionnaire) while in the scanner correlated with amygdala activation under some conditions.

Keywords: fMRI; Emotion; State anxiety; Amygdala; Occipital cortex; Unpleasant words; Neutral words; Emotional decision; Emotional memory

1. Introduction

Studies of patients with bilateral amygdala lesions have provided evidence that the human amygdala plays a role in the evaluation of emotional facial expressions, particularly those related to fear and anger [6–8,27,35,90,91]. Human bilateral lesion studies have also implicated the amygdala in the recognition of non-verbal threat-related sounds (e.g., screams and growling) [80] and in the evaluation of words [80] and sentences denoting negative emotions [4]. These findings are consistent with a large body of animal literature that implicates the amygdala in the evaluation of cues that predict danger to the organism [10,60]. These data also suggest that bilateral amygdala lesions in humans can result in a modality-independent impairment in the recognition of threat-related emotional expressions. Moreover, since the amygdala receives inputs from

* Corresponding author. Address: New York State Psychiatric Institute, 722 West 168th Street, Unit 126, Kolb Annex, Rm 417, New York, NY 10032, USA. Tel.: +1-212-543-5046; fax: +1-212-369-8764.

E-mail address: tabertm@pi.cpmc.columbia.edu (M.H. Tabert).

0028-3932/01/$ - see front matter
PII: S0028-3932(00)00157-3

multiple sensory modalities [12] and is capable of multimodal processing [11], these data argue that the amygdala is part of an underlying processing mechanism geared to interpret emotional signals of threat or danger regardless of their source.

It should be noted, however, that not all patients with bilateral amygdala damage demonstrate selective emotional processing impairments. A number of studies have demonstrated that bilateral amygdala damage does not necessarily impair the ability to evaluate facial [9,48,49,51] or prosodic [5,13] emotional expressions. Moreover, amygdala lesions do not appear to block normal autonomic [19,84] or self-reported reactions [2,31,49] to salient emotional stimuli. While reasons for this discrepancy in the bilateral amygdala lesion literature are not fully understood (for possible explanations, see Refs. [1,5,6,27,48,51]), there is overall convincing evidence from animal and human studies that the amygdala does play a role in selectively processing emotional, particularly threatening, information [1,9,11,86].

PET and fMRI studies investigating the perception and evaluation of prototypical emotional facial expressions (e.g., fear, anger, disgust, and happiness) in normal individuals have provided further evidence that the amygdala plays a role in the evaluation of emotional information. In a PET-O^{15} study, Morris and colleagues [68] observed increasing amygdala activation as a function of the intensity of fearful facial expressions. Interestingly, in a subsequent analysis of these data, Morris et al. [67] found that amygdala activation in response to fearful expressions was strongly correlated with activity in the occipital cortex, suggesting that the amygdala can modulate early processing of visual information. Using fMRI, Breiter et al. [26] also observed amygdala activation to fearful facial expressions. In the studies of Morris et al. [67] and Breiter et al. [26], subjects passively viewed facial expressions or made judgments as to the gender of the posers. Whalen et al. [88] presented fearful faces to subjects below the threshold of conscious awareness, using a backward masking procedure, and found that the amygdala revealed a significant increase in activation to masked fearful expressions. Phillips and coworkers [73,74] and Baird et al. [17] have also reported amygdala activation to facial expressions of fear.

Imaging studies have investigated brain activation in response to emotionally intoned vocal expressions and to the emotional content of negatively valenced words. Phillips et al. [73] reported right amygdala activation in response to vocal expressions of fear (e.g., screams) in normal subjects. Kiehl et al. [55] reported right amygdala activation in response to viewing, rehearsing, and recalling negatively valenced emotional words. These studies provide further evidence that the amygdala is involved in processing negatively valenced stimuli, regardless of presentation modality.

A large body of behavioral, pharmacological, lesion, and imaging data also suggests that the amygdala plays an important role in memory processes related to emotion [1,72]. Normal subjects generally show superior memory for emotionally arousing stimuli relative to emotionally neutral stimuli (for review, see Ref. [44]). Lesion and functional neuroimaging findings have illuminated the importance of the amygdala in facilitating the acquisition of emotional memories (reviewed by Phelps and Anderson [72]). Adolphs et al. [2], Babinsky et al. [16], Cahill et al. [31] and Markowitsch et al. [64] have all reported selective long-term memory impairment for verbal and non-verbal emotional materials following bilateral amygdala lesions. Cahill et al. [32] (using FDG-PET) and Hamann et al. [50] (using PET-O^{15}) have also found that increases in amygdala activity in subjects viewing emotional and neutral stimuli are strongly correlated with performance on long-term but not short-term free recall and recognition memory tasks for emotionally arousing relative to neutral information.

Together, these findings support the memory modulatory theoretical framework of amygdala function, developed by McGaugh and colleagues [30,33,65,66] in experimental animal research. This view suggests that when the human amygdala becomes active in the presence of emotionally arousing stimuli (e.g., during encoding), it weighs conscious memory for the triggering stimuli in proportion to their salience by influencing long-term memory storage and consolidation via interactions with neurotransmitter systems, particularly the adrenergic system, and via anatomical connections to the hippocampus, striatum, and other brain regions [66]. An important aspect of this view is that the amygdala's role in declarative memory is unrelated to memory for non-emotional material. Moreover, with respect to emotional material, this view emphasizes that the amygdala's involvement is time dependent in that its memory-enhancing effects only become apparent after enough time (i.e., several hours to days) has passed to allow for memory consolidation in remote brain regions to occur [30,65,66]. The amygdala itself is, therefore, not thought to be the site where actual emotional memories are stored and is not thought to participate directly in the retrieval or recall of emotional information [70]. In this vein, a recent study by Bianchin et al. [20] demonstrated that the administration of several drugs into the rat amygdala at the time of training in a one-trial, step-down, inhibitory avoidance paradigm had no effect on either working memory (tested at 3 s post-training) or short-term memory (tested at 1.5 h post-training). However, all drugs had strong modulatory effects on long-term memory (tested at 24 h post-training), some enhancing (e.g., norepinephrine) and others impairing performance.