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Attentional capture by emotional stimuli is preserved in patients with amygdala lesions

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ABSTRACT

The importance of cues signaling reward, threat or danger would suggest that they receive processing privileges in the neural systems underlying perception and attention. Previous research has documented enhanced processing of motivationally salient cues, and has pointed to the amygdala as a candidate neural structure underlying the enhancements. In the current study, we examined whether the amygdala was necessary for this emotional modulation of attention to occur. Patients with unilateral amygdala lesions and matched controls completed an emotional attentional blink task in which emotional distractors impair the perception of subsequent targets. Emotional images proved more distracting across all participant groups, including those with right or left amygdala lesions. These data argue against a central role for the amygdala in mediating all types of attentional capture by emotional stimuli.

1. Introduction

Under optimal viewing conditions, an individual has time to examine each item within his or her visual environment, to decide which items are the most important for a particular goal, and to plan an appropriate response for achieving that goal. However, such conditions rarely occur; instead, individuals often have to allocate limited attentional resources, within a limited time, to particular stimuli at the expense of others. In these attentionally competitive situations, emotional stimuli tend to enter, capture, or hold attention to a greater degree than do non-emotional stimuli (e.g. Anderson, 2005; Arnell, Killman, & Fijavz, 2007; Barnard, Scott, Taylor, May, & Knightley, 2004; West, Anderson, & Pratt, 2009). This emotional modulation of attention allows for the preferential processing of emotional stimuli, thereby increasing the likelihood that these stimuli will be perceived and elicit an adaptive motor response (Anderson, 2005; Lang, Davis, & Öhman, 2000; Vuilleumier, Armony, Driver, & Dolan, 2001).

Neuroimaging studies have delineated much of the neural architecture underlying the facilitated processing of emotional stimuli. Both conditioned and intrinsically affective stimuli elicit increased activity concurrently in the amygdala and visual regions for faces, scenes and words compared to similar neutral items (Hamann, Ely, Hoffman, & Kilts, 2002; Isenberg et al., 1999; Morris et al., 1998a; Morris, Buchel, & Dolan, 2001; Padmala & Pessoa, 2008), consistent with neuroanatomical analyzes demonstrating robust amygdalar projections to areas along the visual hierarchy (Amaral, Behniea, & Kelly, 2003). Electrophysiological studies have provided further evidence consistent with an amygdalar modulation of visual cortex based on the specific time-course of perceptual enhancement (Münte et al., 1998; Pizzagalli et al., 2002). Critically, amygdala damage abolishes emotionally enhanced activity in perceptual regions, at least for face stimuli (Morris et al., 1998b; Sabatinelli, Bradley, Fitzsimmons, & Lang, 2005; Vuilleumier, Richardson, Armony, Driver, & Dolan, 2004). What is unclear from these studies, however, is whether the amygdala is necessary for the prioritized processing of emotional stimuli to occur, or if this structure is simply activated without playing a critical causative role in this process.

Data from neuropsychological patients suggests that the amygdala plays a crucial role in the emotional modulation of attention. Anderson and Phelps (2001) assessed attentional effects of emotional stimuli in patients with unilateral and bilateral amygdala damage using an "attentional blink" paradigm, where participants typically search for targets within a rapid serial visual presentation (RSVP) and have difficulty perceiving a second target if it appears less than 500 ms after the first target (see Broadbent & Broadbent, 1987; Raymond, Shapiro, & Arnell, 1992). Participants

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Table 1
Participant demographics and lesion volumes. The groups do not differ in respect to age ($p = .230$), the mean length of education ($p = .187$), the age at epilepsy onset for patients ($p = .557$), or the time between surgery and testing ($p = .146$). IQ values differ significantly for the groups ($F(2,41) = 12.22$, $p < .0005$), with planned comparisons indicating that healthy controls had a higher mean IQ than right resection patients ($t(41) = 3.1$, $p = .003$), and right resection patients a marginally higher IQ than left resection patients ($t(41) = 1.9$, $p = .059$). Performance impairment due to emotional distractors did not correlate with the age at epilepsy onset in patients ($r = -.154$; $p = .452$ and $r = -.017$; $p = .934$ for aversive and erotic distractors). It also did not correlate with time between surgery and testing ($r = .108$; $p = .606$ and $r = -.098$; $p = .640$ for aversive and erotic distractors). On the day of testing, the patients were taking the following anticonvulsant medications: levetiracetam (14 patients), lamotrigine (11), oxcarbazepine (7), carbamazepine (6), clonazepam (2), gabapentin (2), pregabalin (2), topiramate (6), zonisamide (1), other (14).

Group	Sex (m/f)	Age in years (SD)	Education in years (SD)	Age at onset of epilepsy	Time since surgery (weeks)	IQ	Left amygdala volume		Right amygdala volume	
							Mean (SD) (mm^3)	Range (mm^3)	Mean (SD) (mm^3)	Range (mm^3)
Healthy controls	(7/14)	37.9 (10.0)	14.8 (1.8)*			114.9 (13.1)*				
Right resection	(2/13)	40.8 (8.2)	14.8 (2.3)	9.2 (7.4)	106 (65)***	102.6 (10.5)	1580 (195)	688	126 (234)	657
Left resection	(5/6)	34.3 (9.3)	13.5 (1.8)	7.4 (7.4)	65 (68)	93.2 (8.6)**	307 (300)	823	1389 (171)	485

Available for: * $n = 20$, ** $n = 9$, *** $n = 14$.

were shown words within RSVP streams, and they were asked to detect two green words embedded among black words. In neurologically healthy individuals, aversive or taboo verbal stimuli broke through the attentional blink: they were perceived even when they appeared soon after the first target. However, patients with damage to the left amygdala did not show this effect, suggesting that the left amygdala plays a critical role in allowing emotional stimuli to preferentially gain access to attention (Anderson & Phelps, 2001). This study is notable in that the effects emerged following unilateral left, but not right amygdala lesions, suggesting the existence of an asymmetrical amygdalar influence on attention, at least in the case of affective word processing.

Preferential processing of emotional stimuli is not always beneficial. Such stimuli can capture attention even when they are irrelevant to current goal-directed behavior, as demonstrated by the emotional blink of attention (EBA) paradigm (Most, Chun, Widders, & Zald, 2005; Most, Smith, Cooter, Levy, & Zald, 2007). In this paradigm a RSVP stream of landscape pictures is presented with a single target per trial. If an emotionally arousing picture is introduced into the stream prior to the target, it spontaneously disrupts the subjects' ability to detect the target. That is, the emotional distractors capture attention, resulting in an attentional blink even though these distractors are irrelevant to the subject's task goals.

Given the proposed role of the amygdala in modulating attention, it might be predicted that the amygdala would play a causal role in directing the capture of attention in the EBA paradigm. However, recent studies have raised questions about the generalizability of the amygdala's role in directing attention. Two recent studies indicate that the amygdala is not essential for the preferential detection of threat-related stimuli during visual search (Piech et al., 2010a; Tsuchiya, Moradi, Felsen, Yamazaki, & Adolphs, 2009). In addition, Pessoa and Adolphs (2010) recently challenged the established view of the amygdala's role in evaluating biological significance in general, and suggested that a number of structures and pathways might be responsible for such functions.

Consistent with this multiple pathways hypothesis, a recent fMRI study by Schwabe et al. (2011), emphasized two principally different processes involved in emotional modulation of attentional blink. They compared the capability of emotional stimuli to break through an existing attentional blink ('capturing attention', as described by Anderson and Phelps (2001))[1] to the potential of emotional stimuli to create and prolong a blink after their presentation (similar to the EBA paradigm used here). They found that while amygdala activity correlated with the breaking through effect, prolonged holding of attention by emotional stimuli was associated with activity in cortical regions including the anterior cingulate, insula, and orbitofrontal cortex.

As such, it is unclear whether the amygdala plays a necessary role in all aspects of attentional modulation by emotional stimuli. In order to specifically test the role of the amygdala in the capture of attention by emotional stimuli, we examined the performance of patients with unilateral lesions of the amygdala on an EBA paradigm, similar to that described by Most et al. (2005). If the amygdala is critical in mediating the attentional capture observed in the EBA, lesions of the amygdala should substantially reduce this effect. In contrast, if amygdala lesion patients show an EBA, then it would suggest that this type of attentional capture does not depend upon the amygdala, and refinements will be necessary for theories attempting to explain how emotional stimuli gain preferential access to attention.

2. Methods

2.1. Participants

Participants in the study belonged to three groups: participants with lesions to the left amygdala ('left resection', $n = 11$), participants with lesions to the right amygdala ('right resection', $n = 15$), and a control group of healthy participants matched for age, education, and sex ('healthy controls', $n = 21$). Table 1 contains participant demographics. Patients were recruited from the Vanderbilt University Medical Center Epilepsy Surgery Program; these patients had undergone neurosurgery in order to alleviate the symptoms of pharmacologically intractable medial temporal lobe epilepsy. The neurosurgical procedure consisted of either a selective resection of the amygdala and anterior parts of the hippocampus using a transcortical approach (left resection patients $n = 7$; right resection patients $n = 5$), or a temporal lobectomy that included the amygdala, as well as the temporal pole, and anterior temporal cortex (left resection patients $n = 4$; right resection patients $n = 10$). Patients with brain damage outside the focus area, neuropsychiatric conditions other than epilepsy, and with general cognitive impairment (IQ < 80) were excluded from the study. Control participants were recruited from the Nashville community, primarily through web listings for paid research volunteers with specific age, sex and education (matched to the surgery patients). The study was approved by the Vanderbilt University Institutional Review Board, and all participants gave written informed consent to take part in the study.

2.2. Structural MRI data acquisition and analysis

High-resolution T1-weighted images (TR = 8.97 ms; TE = 4.6 ms; in-plane resolution = 1 mm^2; slice thickness = 1 mm) were acquired on a 3T Philips Intera Achieva scanner and used to identify the resected area and determine the remaining amygdala volumes in the resection groups (Table 1). The structural image for one participant was acquired on a 1.5T Philips scanner (in-plane resolution = 1 mm^2; slice thickness = 1.2 mm). Structural images from 15 controls in the current study and 33 additional healthy adults who participated in other studies were used in the lesion identification analysis (total $N = 48$). Images were normalized to MNI space at 1 mm^3 resolution using the unified segmentation and normalization procedure in SPM5 (Ashburner & Friston, 2005), as this method has been shown to

[1] Anderson and Phelps (2001) refer to this 'breaking through' as capturing attention. To avoid confusion, we will refer to the phenomenon described in the present study, attentional capture that prevents detection of subsequent stimuli, as attentional capture, and to the phenomenon described by Anderson and Phelps as 'breaking through'.