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Distinct brain systems underlie the processing of valence and arousal of affective pictures

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Valence and arousal are thought to be the primary dimensions of human emotion. However, the degree to which valence and arousal interact in determining brain responses to emotional pictures is still elusive. This functional MRI study aimed to delineate neural systems responding to valence and arousal, and their interaction. We measured neural activation in healthy females ($N = 23$) to affective pictures using a 2 (Valence) $\times$ 2 (Arousal) design. Results show that arousal was preferentially processed by middle temporal gyrus, hippocampus and ventrolateral prefrontal cortex. Regions responding to negative valence included visual and lateral prefrontal regions, positive valence activated middle temporal and orbitofrontal areas. Importantly, distinct arousal-by-valence interactions were present in anterior insula (negative pictures), and in occipital cortex, parahippocampal gyrus and posterior cingulate (positive pictures). These data demonstrate that the brain not only differentiates between valence and arousal but also responds to specific combinations of these two, thereby highlighting the sophisticated nature of emotion processing in (female) human subjects.

1. Introduction

Humans are characterized by a wide variety in emotional experiences. One widely accepted theory of emotion states that emotional experience can be reduced to two almost independent dimensions, namely arousal and valence. Valence refers to the pleasantness of a stimulus, whereas arousal reflects the intensity of an event, varying from calming to exciting (Lang, Greenwald, Bradley, & Hamm, 1993; Russell, 1980).

Over the last decade, a growing number of functional neuroimaging studies have been devoted to the identification of the neural substrates of different human emotions (see for reviews: Murphy, Nimmo-Smith, & Lawrence, 2003; Phan, Wager, Taylor, & Liberzon, 2002; Sergerie, Chochol, & Armony, 2008; Wager, Phan, Liberzon, & Taylor, 2003). More recently, neuroimaging studies started to explicitly examine the contribution of valence and arousal to neural activation supporting human emotion. This work has concentrated mainly on a limited number of brain regions, namely the amygdala and the prefrontal cortex.

With respect to the amygdala, the traditional view poses that this region is part of a brain system specialized in the detection of threatening stimuli (LeDoux, 1996), supported by studies indicating that fearful visual stimuli (regardless whether faces or pictures were used) induced increased activation in the amygdala (Baas, Aleman, & Kahn, 2004; Phan et al., 2002). Subsequent work provided evidence that the role of the amygdala is perhaps less specific, as this region also responds to other negative emotions such as sadness and disgust (Goldin et al., 2005; Stark et al., 2007; Wang, McCarthy, Song, & Labar, 2005) and even to *positively* valenced stimuli (Beauregard, Levesque, & Bourgouin, 2001; Ferretti et al., 2005; Fitzgerald, Angstadt, Jelsone, Nathan, & Phan, 2005; Garavan, Pendergrass, Ross, Stein, & Risinger, 2001; Hamann & Mao, 2002; Kensinger & Schacter, 2006). This has led to the suggestion that the amygdala is not specifically sensitive to the emotional valence of a visual stimulus per se but instead to its intensity, or level of arousal (Phan et al., 2002, 2003; Wager et al., 2003). Indeed, studies controlling for possible confounding effects of valence have generally demonstrated amygdala activation related to the level of arousal of pictorial stimuli (Garavan et al., 2001; Kensinger & Schacter, 2006; Lane, Chua, & Dolan, 1999).

In contrast to the amygdala, which tends to be associated with quick and primary emotional responses, the prefrontal cortex (PFC) is generally associated with higher-order regulation (or evaluative aspects) of emotion (Ochsner & Gross, 2005). Evidence from

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neuroimaging studies suggests that different parts of the PFC play distinct roles in emotional evaluation. The medial PFC would be dominant for appetitive or rewarding stimuli (Elliott, Newman, Longe, & Deakin, 2003; O'Doherty et al., 2001) whereas the lateral orbital PFC is associated with processing of aversive stimuli (Kensinger & Schacter, 2006; O'Doherty et al., 2001; Small, Zatorre, Dagher, Evans, & Jones-Gotman, 2001, but see Northoff et al., 2000, who found evidence for the opposite pattern). A second dominant hypothesis is that positive emotions tend to be lateralized towards the left hemisphere while negative emotions are associated with the right hemisphere (Davidson & Irwin, 1999), a notion that is supported by recent neuroimaging data (Murphy et al., 2003; Wager et al., 2003; Dolcos, LaBar, & Cabeza, 2004; Grimm et al., 2006; Nitschke et al., 2004), although there are negative findings as well (Lane et al., 1997; Teasdale et al., 1999). Concerning arousal, evidence points to involvement of the medial prefrontal cortex (Lane et al., 1999), in particular the dorsomedial regions (Anders, Lotze, Erb, Grodd, & Birbaumer, 2004; Dolcos et al., 2004; Grimm et al., 2006; Kensinger & Schacter, 2006). Finally, for regions outside amygdala and prefrontal cortex, there is evidence that the insula is particularly sensitive to negatively valenced stimuli (Anders et al., 2004; Lewis, Critchley, Rotshtein, & Dolan, 2007) and that the response of the extrastriate occipital cortex is modulated by both valence and arousal (Bradley et al., 2003; Lane et al., 1999; Mourao-Miranda et al., 2003).

In sum, the general picture that emerges suggests that (i) the amygdala and perhaps occipital cortex primarily support processing of arousal (as they seem to respond to both valences), (ii) the prefrontal cortex is most responsive to valence differences, and (iii) the insula is specifically involved in the processing of negative valence. So far, however, the majority of these studies did not consider the possibility that valence and arousal may interactively determine neural responding to emotional pictures. That this issue is not trivial is demonstrated by a recent fMRI study on olfactory processing showing that the effect of odor intensity on amygdala activation depended on whether the smell was pleasant, unpleasant or neutral (Winston, Gottfried, Kilner, & Dolan, 2005). Based on these data, the authors suggest that the amygdala is not specifically sensitive to either arousal or valence as such, but instead to a combination of these parameters that may reflect the overall emotional value of a stimulus (Winston et al., 2005). Using emotional words, similar findings were reported by Lewis et al. (2007), who demonstrated that the amygdala responded to increasing arousal but only for negative words. With respect to the pictorial domain, most neuroimaging studies used designs that did not allow the investigation of interactions between valence and arousal. Only recently studies started to control explicitly for possible confounding effects of arousal on valence (Dolcos et al., 2004; Kensinger & Schacter, 2006) and vice versa (Garavan et al., 2001; Mourao-Miranda et al., 2003). We know of two studies that explicitly considered valence-by-arousal interactions and these reported negative results (although it should be noted that these studies were performed with lower-resolution PET (Lane et al., 1999) or focused on the amygdala only (Garavan et al., 2001)).

Taken together, the number of studies examining the brain systems coding for valence and arousal in picture processing is increasing rapidly. However, few of these have attempted to investigate to what extent activity in these regions (and elsewhere in the brain) is influenced by arousal-by-valence interactions. The presence of such interactions may imply that emotion processing in the brain has a greater complexity than suggested previously. Therefore, the aims of this fMRI study were (i) to tease apart activity associated with processing valence and arousal at the level of whole-brain function, and (ii) to determine in which regions arousal-by-valence interactions take place. To this end, we used event-related functional MRI to measure whole brain responses to affective pictures in a sample of healthy female volunteers. We included only females as there is increasing evidence that men and women show distinct neural activations to emotional stimuli (e.g. Hagemann et al., 1999; Caseras et al., 2007; Hofer et al., 2006). A 2 (Valence) $\times$ 2 (Arousal) design allowed us to determine not only main effects of arousal/valence, but interaction effects as well. Based on the literature, we expected to find valence-specific responding in prefrontal cortex (with lateral regions responding to negative valence and medial regions activated by positive valence) and predominantly arousal-specific activations in amygdala and occipital cortex. Furthermore, we hypothesized that the most likely regions to find possible valence-by-arousal interactions are the amygdala, insula and occipital regions.

2. Materials and methods

2.1. Subjects

Twenty-three right-handed female subjects (age: 20–25 years) were recruited by means of campus advertisements. Before scanning, participants completed the Dutch version of the Symptom Checklist (SCL-90) to screen for the presence of psychopathology. None of the subjects used psychotropic medication or had a history of psychiatric or neurological illness. All subjects had normal or corrected-to-normal vision. To ensure the effectiveness of the erotic pictures, we included only subjects who identified themselves as heterosexual. The ethical review board of the VU Medical Centre approved of the study and all subjects provided written informed consent (according to the Declaration of Helsinki) after the study procedure had been explained to them. Subjects were paid €15 for their participation.

2.2. Experimental task

Subjects viewed pictorial stimuli that were selected from the International Affective Picture System (IAPS; Center for the Study of Emotion and Attention Lang, Bradley, & Cuthberg, 1997). We selected four categories of stimuli: (1) high arousal-negative valence (HN, e.g. angry faces, frightening animals; nos. 1030, 9621, 9250, 1110, 6020, 1200, 1220, 1275, 1300, 1302, 1390, 1931, 2100, 2661, 3060, 3250, 3280, 3400, 4770, 5940, 6200, 6211, 6230, 6250, 6900, 9005, 9042, 9230, 9452, 9490), with a mean valence score of 3.25 (SD = 0.70) and a mean arousal score of 6.13 (SD = 0.67); (2) high arousal-positive valence (HP, e.g. sports, erotica; nos. 1650, 4530, 4572, 4599, 4609, 4611, 4658, 4660, 5260, 5450, 5470, 5621, 5623, 5628, 5950, 7400, 8031, 8034, 8041, 8090, 8180, 8200, 8220, 8340, 8370, 8400, 8460, 8490, 8500, 8502) with a mean valence score of 7.00 (SD = 0.60) and a mean arousal score of 5.97 (SD = 0.52); (3) low arousal-negative valence (LN, e.g. freeway; nos. 1230, 2206, 2230, 2440, 2490, 2590, 2682, 2722, 2752, 2810, 4004, 4180, 4233, 4274, 4279, 5120, 7060, 7180, 7234, 7700, 8010, 9000, 9080, 9110, 9190, 9220, 9270, 9290, 9331, 9700) with mean valence = 3.80 (SD = 0.72) and mean arousal = 3.82 (SD = 0.62); and (4) low arousal-positive valence (LP, e.g. scenes of nature, neutral faces; nos. 1440, 1590, 1602, 1604, 1740, 1920, 2010, 2030, 2057, 2080, 2092, 2370, 2720, 2880, 4150, 4536, 4605, 5220, 5410, 5594, 5750, 5820, 5831, 7100, 7280, 7320, 7340, 8320, 8497, 8600) with mean valence = 6.92 (SD = 0.99) and mean arousal = 3.91 (SD = 0.65). Stimulus categories were based on the ratings by female subjects provided in the IAPS database.

In the scanner, subjects performed a stimulus-classification task on the IAPS pictures, which was followed by a surprise recognition task. Only data of the classification task will be described here. We used a non-emotional classification task given that emotional