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The influence of directed covert attention on emotional face processing

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A B S T R A C T

Activation of the amygdala and the fusiform face area (FFA) are consistent findings in imaging studies on emotional face processing. There is evidence that these activations occur even when emotional faces are unattended; however, it was also shown that amygdala and FFA activation were modulated by the attentional resources allocated to these stimuli. Attentional resources might thereby not only depend on task demands but also on varying degrees of covert attention processes induced by the task. To address this issue we examined the isolated effect of covert shifts of spatial attention on emotional face processing using functional magnetic resonance imaging during a modified spatial cueing paradigm. Directional spatial and neutral cues were presented superimposed on neutral, happy, sad and fearful faces. Subjects performed a target detection task, while fixation was controlled by simultaneous eye tracking. Reaction times showed a strong cue validity effect across all emotions (i.e., faster responses for directional cues). Comparing directed to nondirected attention revealed a significantly reduced signal in the FFA irrespective of the emotional expression. This effect was also seen in bilateral amygdala, but only in trials including fearful faces. Our findings suggest that covert shifts of attention toward a specific location result in reduced face processing independent from task demands. Furthermore, our data show a task-irrelevant amygdala response specific to fearful faces under a wide attentional focus. Attentional disengagement from the faces led to a suppression of this amygdala response and thus provides further evidence that amygdala activation depends on the focus of attention.

Cognitive behavioural data in healthy subjects and mood-disordered patients have documented a capture of attention by task-irrelevant emotional stimuli, particularly when these stimuli are threat-related (Schmidt and Saari, 2007) or congruent to mood disorders like anxiety (Ouimet et al., 2009) or depression (Fritzsche et al., 2009). Furthermore, some emotional biases have been proposed to depend on the attentional maintenance of these stimuli (Caseras et al., 2007). Exploring the neural basis of these behavioural phenomena might have implications for our understanding of functional and dysfunctional processing of task-irrelevant but emotionally salient stimuli. An increasing number of researchers have now focused on this issue, but controversial results have brought up a debate on whether the neural processing of emotional stimuli such as fearful faces depends on the attentional resources allocated to these stimuli (Adolphs, 2008; Anderson et al., 2003; Ohman et al., 2007; Pessoa et al., 2006; Pessoa et al., 2002; Vuilleumier et al., 2001). Most studies contributing to this discussion have compared amygdala responses during two tasks in which attention was either focused on the processing of emotional faces (e.g., gender discrimination; match of faces) or on a non-emotional condition (e.g., bar orientation task; match of houses). Some authors (Anderson et al., 2003; Vuilleumier et al., 2001) reported amygdala activation during the presentation of fearful faces irrespective of whether the task explicitly necessitated emotional processing. Others (Pessoa et al., 2002) observed amygdala responses only when attention was focused on emotional faces by the study task but not when shifted away to the non-emotional task. Both findings have been brought in line by accounting for different attentional load due to study differences regarding task demands (Lavie, 2005). In detail, it has been demonstrated that different levels of task difficulty influence amygdala responses to unattended fearful faces (Pessoa et al., 2005) and it has been speculated that comparing two houses (Vuilleumier et al., 2001) leaves enough attentional resources for processing peripherally presented task-irrelevant faces in contrast to a highly demanding bar orientation task (Bishop et al., 2007; Pessoa et al., 2002; Pessoa et al., 2005).

Another potential factor influencing the amount of available attentional resources might be the degree of covert shifts of spatial attention implicitly induced by the task. Covert spatial attention produces biases in perceptual performance and neural processing of behaviourally relevant stimuli in the absence of overt orienting movements (Moore et al., 2003). In most of the above-mentioned studies, participants were instructed to keep fixation throughout the experiment, thus covert attentional shifts were necessary to accomplish the primary task (Carrasco and Yeshurun, 2009). The degree of this covert orienting and its influence on task-irrelevant

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face processing might depend on task demands but also on the spatial location of the primary task. For instance, it could be speculated that the house/face task (Vuilleumier et al., 2001) with a relatively compact localisation of all stimuli induced covert shifts of attention to a lesser extent than the more demanding bar orientation task (Pessoa et al., 2002) which was presented in the upper part of the screen and which therefore might have left not enough attentional resources to process task irrelevant emotional faces in the middle of the screen. The explicit influence of covert spatial attention on emotional face processing has not been studied so far. To address the question whether covert shifts of spatial attention away from emotional faces lead to a reduction of emotional face processing, we modified a spatial cueing paradigm that was originally described by Posner et al. (1980). Spatial cueing paradigms are able to assess covert attention effects as cue validity effects that arise from the facilitation of stimulus detection when a target appears at a validly cued location. Previous studies proposed that this effect depends on attentional disengagement from the current focus and covert orienting, both mediated by a fronto-parietal network (Corbetta and Shulman, 2002; Vossel et al., 2006). By keeping the task (target detection) constant over the whole experiment we were able to explicitly manipulate covert spatial attention and examine its effect on emotional processing in isolation. By using not only directing valid and invalid cues but also neutral, non-informative cues we were able to differentiate between a focused, directed and a spread, undirected covert attention condition.

We focused our analyses on the amygdale, which has been consistently defined as a key neural substrate for processing facial displays of affect (e.g., Adolphs, 2008; Fitzgerald et al., 2006 and on the fusiform face area FFA; Kanwisher and Yovel, 2006) which responds preferentially to faces relative to other stimuli. Both regions have been found to respond differentially to attentional manipulation (Pessoa et al., 2002; Vuilleumier et al., 2001).

Because of recent reports suggesting that the amygdala has no specialized role in processing signals of threat like fear or anger but rather may have a more general-purpose function in processing salient information from faces (Fitzgerald et al., 2006; Sander et al., 2003), we included not only fearful and neutral but also happy and sad faces in the study.

Methods

Subjects

Twenty-three healthy volunteers (11 male), aged 25.4 ± 2.4 years (mean age ± SD) without history of neurological or psychiatric diseases participated in the study. The local ethics committee approved the study and all participants gave written informed consent and were financially compensated for participation.

Task

Subjects performed a spatial cueing paradigm modified from a published procedure by Posner et al. (1980). The task was set up as a rapid event related fMRI paradigm: After a fixation period of 1000 ms, valid, invalid or neutral cues were centrally presented superimposed on neutral, happy, sad or fearful faces (5° of visual angle) for a jittered interval of 1050–1500 ms. Then a dot target appeared on the left or right side (horizontally displaced by 7° of visual angle from the cue position) of the screen for 200 ms. Subjects had to react as quickly as possible by button press with the right or left index finger according to the side of target presentation. The trial ended with a randomly chosen intertrial interval in the range from 1000 to 1500 ms (Fig. 1). Central fixation was required throughout the experiment. To avoid eyestrain we ran two sessions, each consisting of 144 trials, which were separated by a pause of 1 min in which subjects could close their eyes. In two thirds of all trials, a white arrowhead pointing to the left or right side was used as directional cue. The arrowhead either pointed to the side where the target appeared (valid trial) or to the opposite side (invalid trial). Across all trials with such a directional cue, 83% of the cues were valid and 17% were invalid. This ratio is in accordance with previous spatial cueing paradigms (e.g. Thiel et al., 2004). In the other third of all trials, a neutral cue was presented. Neutral cues consisted of two arrowheads pointing in both directions, indicating that the target was equally likely to occur at both possible locations. These neutral cues span a wide attentional focus including the centrally presented emotional face and thus allow us the comparison between distributed spatial attention including the emotional face versus directed spatial attention away from the emotional face.

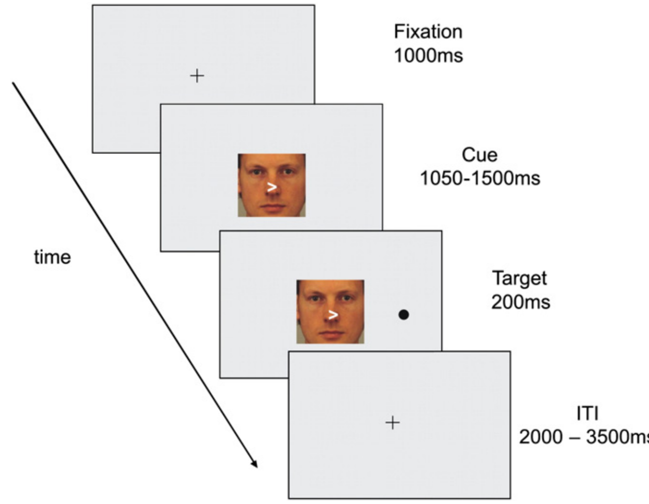

Fig. 1. Experimental paradigm. Eye tracking was assessed simultaneously. For illustration purposes stimuli are not drawn to scale.

The design was fully counterbalanced and trial order was randomized in both experimental sessions. Overall, there were 18 facial identities (9 female, 9 male) chosen from the Karolinska Directed Emotional Faces (KDEF) set (Lundqvist et al., 1998) on the basis of a validation study (Goeleven et al., 2008). Each identity displayed each of the four emotional expressions (neutral, happy, sad and fearful). Within each session there were 36 trials per emotional category showing each emotional face twice. Within each emotional category, there were 20 valid, 4 invalid and 12 neutral trials with counterbalanced side of target appearance (left/right: 10/10, 2/2, and 6/6, respectively). Subjects performed a training session of the task outside the scanner. They were told that the faces play no role for the experiment. Furthermore, participants were thoroughly instructed to keep fixation throughout the task. After scanning subjects performed a valence and arousal rating for all faces presented and were then debriefed on the background of the experiment.

Eye movement control

Eye position was monitored online during scanning using an MR-compatible infrared eye tracker (NordicNeuroLab AS, Bergen, Norway). The camera was directly mounted to the headcoil and oriented toward the right eye. To ensure that participants were able to maintain fixation during stimulus presentation, we analyzed the eye tracking data in a period from -500 ms to 2000 ms in relation to stimulus onset. To determine whether cue presentation systematically affected gaze direction, we calculated the mean gaze change in a period of 0 to 1050 ms relative to the 500 ms baseline. Subsequently, a