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Attention to aversive emotion and specific activation of the right insula and right somatosensory cortex

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ABSTRACT

The evaluation of emotional stimuli is based on different levels of information processing, ranging from rather automatic processes to focused attention to the emotional relevance of stimuli. The role of specific brain areas for these processes is a matter of debate. In this event-related fMRI study, we varied the information processing mode of participants exposed to aversive and neutral pictures. Based on four different tasks, participants' attentional focus onto the emotional quality of the stimuli and the own emotional involvement was increased systematically across tasks. Regardless of task, stronger activation to threatening vs. neutral pictures was found in several regions such as the amygdala, anterior insula, anterior cingulate cortex, primary somatosensory cortex and medial prefrontal cortex. However, there was a parametric increase of activation with increasing attention to one's own emotion specifically in the right posterior insula and right primary and secondary somatosensory cortex, i.e. in areas implicated in self-awareness of a person's own body. These findings are in accordance with theories suggesting a crucial role of the perception of bodily states for emotional experiences.

Introduction

The processing of emotional stimuli is associated with different stages of information processing. While implicit processing modes are related to rather automatic responses to emotional stimuli, explicit processing requires that subjects' attention is directed to the emotional significance of stimuli or to one's own emotional involvement, i.e. to own feelings (e.g., LeDoux, 1996; Damasio, 1999). These different levels of information processing seem to depend partially on different neural systems (e.g., LeDoux, 1996; Damasio, 1999; Phan et al., 2002). Several prefrontal areas and the anterior cingulate cortex were suggested to be involved in cognitive-emotional interactions, such as certain high level appraisal processes, as well as in the generation and regulation of emotional responses (e.g., Lane et al., 1998; Phan et al., 2002; Ochsner et al., 2004; Straube et al., 2006, 2009a). In contrast, subcortical areas such as the amygdala have been proposed to mediate the rapid processing of emotional, especially of threatening stimuli, given a minimum of processing resources (Vuilleumier et al., 2001; Pessoa et al., 2002; Straube et al., 2007).

Besides these areas, brain regions that are involved in the direct representation of bodily states, such as the insula and the somatosensory cortex, were also proposed to be relevant for emotion processing (Damasio, 1999; Adolphs et al., 2000; Craig, 2002, 2009). This hypothesis is based on the idea that the perception of real or simulated bodily responses is an important factor for emotional experiences (James, 1884; Damasio, 1999; Craig, 2002, 2009). While the anterior insula has been suggested to serve as an integrative center for the representation and evaluation of interoceptive information, posterior areas of the insula, and the primary and secondary somatosensory cortex are more strongly involved in general awareness of the own body and several visceral and somatosensory sensations (Craig, 2002; Adolphs et al., 2000; Karnath et al., 2005; Khalsa et al., 2009).

While several brain areas have been proposed to participate in different aspects of emotion processing, the effect of the processing mode on brain activation warrants further examinations. To elucidate the specific role of a brain region as a function of the information processing mode, it is necessary to systematically vary of the level of evaluation of emotional stimuli and to control for other factors (see also Lieberman et al., 2007). In the present event-related fMRI-study, we systematically increased subjects' attention to one's own emotional involvement by means of four different tasks. If the experience of emotion is closely linked to the perception of bodily responses, increasing attention to own feelings should be associated with increased activation of relevant brain structures, such as the insula or the somatosensory cortex, which are involved in the processing of bodily states. In contrast, those areas that are involved in other or more general processes should not show an increase of brain activation across tasks.

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Materials and methods

Subjects

Sixteen healthy, right-handed, female volunteers (mean age: mean = 20.7 years, range = 18–28 years) provided informed consent to participate in the study. All participants had normal or corrected-to-normal vision. All experimental procedures were approved by the Ethics Committee of the University of Jena.

Paradigm

Stimuli consisted of 20 threat-related and 20 neutral pictures taken from the International Affective Picture System (IAPS; Lang et al., 1999). In the center of the pictures either animals, plants, or humans (10 pictures per valence category), or a nonliving object (10 pictures per valence category) were shown. Furthermore, in the foreground of the pictures, a small line was displayed (see for examples Fig. 1). The line could have either a vertical or a horizontal orientation (see also Straube et al., 2006, 2008). For half the pictures the line was horizontal and for the other half the line was vertical. During scanning, pictures were presented via a back-projection screen onto an overhead mirror during two runs. During each run, subjects had to solve four different tasks (see below) with 20 trials per tasks, thus 160 trials altogether during two runs. The same pictures were shown twice in each task per run, altogether four times in each task (according to the tasks described below). Each task started with a cue (duration: 7000 ms) indicating, through verbal instruction, the kind of task that had to be performed while watching the next 10 neutral and 10 threat-related pictures. These pictures were shown in random order. Each picture was presented for 750 ms. Stimulus onset asynchrony (SOA, time between onset of the previous and onset of the current stimulus) was 4200 ms. Between the tasks (this means between the last picture for a given task and the cue indicating the next task) a fixation cross was shown for 11.2 s. Additionally, 10 null events [a fixation cross, presented for 750 ms with 4200 ms SOA, indistinguishable from the fixation cross seen during the inter-stimulus intervals (the time between the presentation of the pictures; see also Josephs and Henson, 1999)] were randomly intermixed into the sequence of stimuli per task and run. According to the suggestions by Josephs and Henson (1999) there were no constraints regarding the number of successive null events, which resulted in blocks of null events with three or more null events in sequence.

The tasks varied according to subjects' attention to the stimuli per se, the emotional relevance of stimuli and one's own emotional involvement. Thus, the task conditions were associated with increasing attention to one's own emotional involvement. In the first task, the level-1 task, subjects had to decide whether the line in the foreground of the pictures was shown in vertical or horizontal orientation. This task distracted subjects' attention from the background picture. In the second task, the level-2 task, subjects were asked to determine whether a non-living object or a living being was shown in the center of the picture. This task focused subjects' attention onto the emotional pictures, but not explicitly to its emotional content. In the third task, the level-3 task, subjects had to decide whether the pictures displayed a threatening or a non-threatening content. This task requested a conceptual decision on the emotional significance of the picture, but subjects were not forced to attend to their own emotional response. In the last task, the level-4 task, subjects had to indicate whether they experienced the exposure to the picture as rather unpleasant or not unpleasant. Obviously, this task explicitly required that subjects referred to their own emotional involvement. For judgement, subjects pressed one of two buttons of an optic fibre response box with either the first or the middle finger of the right hand. The order of tasks and assignment of response buttons to the answer alternatives were counterbalanced across subjects. Prior to scanning, subjects were familiarized with the tasks using stimuli not shown in the later experiment proper. After the fMRI-session, participants rated the pictures of each category using a 9-point Likert scale to assess valence (1 = very pleasant to 9 = very unpleasant) and arousal (1 = not arousing to 9 = very arousing).

Behavioural data were analysed by means of repeated measures analysis of variance (ANOVA) using SPSS (Version 16; SPSS, INC., Chicago). A probability level of $p<0.05$ was considered statistically significant. All data are expressed by mean ± SEM (standard error of means). For analysis of reaction times and response accuracy, two subjects had to be excluded due to technical problems during registration of button presses.

fMRI

In the 1.5 T magnetic resonance scanner ("Magnetom Vision plus", Siemens, Medical Systems, Erlangen, Germany), 2 runs of 197 volumes were measured using a T2*-weighted echo-planar sequence (TE = 50 ms, flip angle = 90°, matrix = 64 x 64, FOV = 192 mm, TR = 2800 ms). Each volume comprised 28 axial slices (thickness = 3 mm, gap = 1 mm, in plane resolution = 3 × 3 mm) being acquired with a tilted slice orientation to reduce susceptibility artifacts in inferior parts of anterior brain areas (Deichmann et al, 2003). Additionally, a high-resolution T1-weighted anatomical volume was recorded. Preprocessing and analysis of functional data was performed using the software Brain Voyager QX (Version 1.7; Brain Innovation, Maastricht, The Netherlands). The volumes were realigned to the first volume in order to minimize effects of head movements. Further data pre-

Fig. 1. Examples of stimuli (left: neutral; right: threatening). Subjects had to indicate the orientation (vertical, horizontal) of the lines displayed in the foreground of the pictures during the level-1 task. During the other tasks, the same pictures, including the foreground lines were shown; only the task instruction was varied across tasks.

processing comprised a correction for slice time errors and spatial [8 mm full-width half-maximum isotropic Gaussian kernel (FWHMK)] as well as temporal (high pass filter: 5 cycles per run; low pass filter: 2800 ms FWHMK) smoothing. Anatomical and functional images were coregistered and normalized to the Talairach space (Talairach and Tournoux, 1988). Statistical analysis was performed by multiple linear regression of the signal time course at each voxel including a correction for serial correlations. The expected blood oxygen level-dependent (BOLD) signal change for each event type (= predictor) was modeled by a canonical hemodynamic response function. Within- and between-group statistical comparisons were conducted using a mixed effect analysis, which considers inter-subject variance and permits population-level inferences. In the first step, predictor estimates were generated for each individual. In the second step, predictor estimates were analyzed across subjects. First, we investigated the main effect of emotion across task. In the parametric analysis, we modeled a linear increase of activation to threat vs. neutral pictures depending on the tasks [balanced contrast values (threat, neutral) for *Level-1, Level-2, Level-3, Level-4:* −4 1, −2 1, 2 −1, 4 −1]. Activation was analyzed in regions of interest (ROI) according to our previous studies (e.g., Straube et al., 2004, 2006, 2007, 2008, 2009b, 2010b; Quadflieg et al., 2008; Schmidt et al., 2010). The following ROIs were defined *a priori* using Talairach daemon software (Lancaster et al., 2000): dorsomedial prefrontal cortex (DMPFC), ventromedial prefrontal cortex (VMPFC), anterior insula, ACC, amygdala, posterior insula/secondary somatosensory cortex (posterior insula/ S2), and primary somatosensory cortex (S1). Statistical parametric maps resulting from voxelwise analysis were considered statistically significant for clusters that survived a correction for multiple comparisons. We used the approach as implemented in Brain Voyager (Goebel et al., 2006) which is based on a 3D extension of the randomization procedure described by Forman and colleagues (Forman et al., 1995). First, voxelwise analysis was performed at any point and voxel-level threshold was set at $p<0.001$ (uncorrected). Thresholded maps were then submitted to a correction for multiple comparisons based on the search space for each ROI. The correction criterion was based on the estimate of the map's spatial smoothness and on an iterative procedure (Monte Carlo simulation) for estimating cluster-level false-positive rates. After 1000 iterations, the minimum cluster size threshold that yielded a cluster-level false-positive rate of 5% was applied to the statistical maps (for the ROIs were the thresholds, given in 3x3x3mm voxel, as follows: DMPFC, 3 voxel; VMPFC, 4 voxel; anterior insula, 4 voxel; ACC, 4 voxel; amygdala, 2 voxel; posterior insula/S2, 4 voxel; S1, 3 voxel.

Results

Behavioral data

Accuracy, i.e., the number of correct responses, was high during both the Level-1 (95.18 ± 1.52 % and 96.25 ± 1.10% for threat-related and neutral pictures) and the Level-2 task (95.18 ± 1.52 % and 97.14 ± 0.51 % for threat-related and neutral pictures) and did not differ significantly between valence categories for either task [$t=0.86$ and $t=1.49$; each analysis: $p>0.05$]). Analysis of subjective judgements showed that negative but not neutral pictures were classified as threatening (Level-3: 92.93 ± 2.92 % of the threat-related pictures vs. 2.57 ± 1.51 % of the neutral pictures) and unpleasant (Level-4: 90.64 ± 3.06 % of the threat-related pictures vs. 3.29 ± 1.37 % of the neutral pictures). For reaction times (see Table 1 for descriptive data) the ANOVA revealed significant effects of Task [$F(2.33,39)=10.37$, $p<0.0001$) and Emotion ($F(1,13)=6.85$, $p<0.05$]. These main effects were due to decreased reaction times in the *level 1 task* compared to the other tasks (all $p<0.05$) and increased reaction times to threat as compared to neutral pictures across tasks. There was no significant interaction of Task by Emotion [$F(2.59, 39)=2.74$, $p>0.05$].

Table 1
Reaction times: descriptive data.

Task	Valence	Mean (ms)	SD (ms)
Level 1	negative	734.60	182.42
	neutral	736.93	176.27
Level 2	negative	855.36	263.99
	neutral	784.13	247.74
Level 3	negative	831.51	249.01
	neutral	786.14	206.97
Level 4	negative	859.45	259.30
	neutral	830.55	182.42

SD, standard deviation.

Analysis of post-scanning arousal and valence ratings of pictures indicated that negative pictures were rate as more arousing (negative: 7.0 ± 0.21, neutral: 1.63 ± 0.17, $t=20.25$; $p<0.0001$) and more unpleasant (negative: 7.9 ± 0.18, neutral: 4.36 ± 0.16); $t=16.88$; $p<0.0001$) than neutral pictures.

fMRI data

Main effect of emotion

Across tasks, threatening as compared to neutral pictures induced increased activation in all ROIs except for the posterior insula/S2. Thus, we detected activation for this contrast in the DMPFC (Coordinates of peak voxel [x, y, z] = -1, 40, 41; $t=6.31$, $p<0.05$, corr.), VMPFC (x, y, $z=1$, 39, −6; $t=5.93$, $p<0.05$, corr.), dorsal ACC (x, y, $z=-5$, 18, 30; $t=7.07$, $p<0.05$, corr.), rostral ACC (x, y, $z=6$, 32, 32; $t=5.87$, $p<0.05$, corr.), amygdala (left: x, y, $z=-26$, −2, −6; $t=6.48$, $p<0.05$, corr.; right: x, y, $z=28$, −5, −11; $t=5.89$, $p<0.05$, corr.), anterior insula (left: x, y, $z=-32$, 13, −6; $t=6.57$, $p<0.05$, corr.; right: x, y, $z=36$, 5, 14; $t=6.50$, $p<0.05$, corr.), and S1 (right: x, y, $z=47$, -17, 37; $t=4.48$, $p<0.05$, corr.). Fig. 2 illustrates the activation. The activation plots in Fig. 2 show for the right S1 a clear task-related pattern with a systematic increase of activation across tasks.

Parametric analyses

The main aim of this study was to identify areas which showed an association with the task-induced increase of attention to the emotional relevance of pictures. Based on the linear parametric analysis, only the activation in the right primary somatosensory cortex (coordinates of peak voxel [x, y, z] = 45, −13, 35; $t=4.07$, $p<0.05$ corr.) and in the right posterior insula/S2 (coordinates of peak voxel [x, y, z] = 45, −21, 17; $t=6.02$, $p<0.05$, corr.) were associated with increasing attention to the emotional relevance of the pictures. The coordinate for the somatosensory cortex is nearly the same as the coordinate for the main effect analysis (see above). Fig. 3 illustrates the systematic increase of activation across tasks in both ROIs.

Discussion

This study investigated the effects of the information processing mode on brain activation to emotional vs. neutral pictures. We used a design in which we kept all experimental conditions constant, with the exception of the task instruction. By means of different tasks, the attentional focus of the participants onto the emotional quality of stimuli and the own emotional involvement was increased systematically across tasks. The results show a main effect of emotion in several areas, including the amygdala, DMPFC, VMPFC, ACC, insula and the primary somatosensory cortex. Most importantly, there was a systematic increase of brain activation with increasing attention to one's own emotion specifically in the right posterior insula/S2 and the right primary somatosensory cortex.

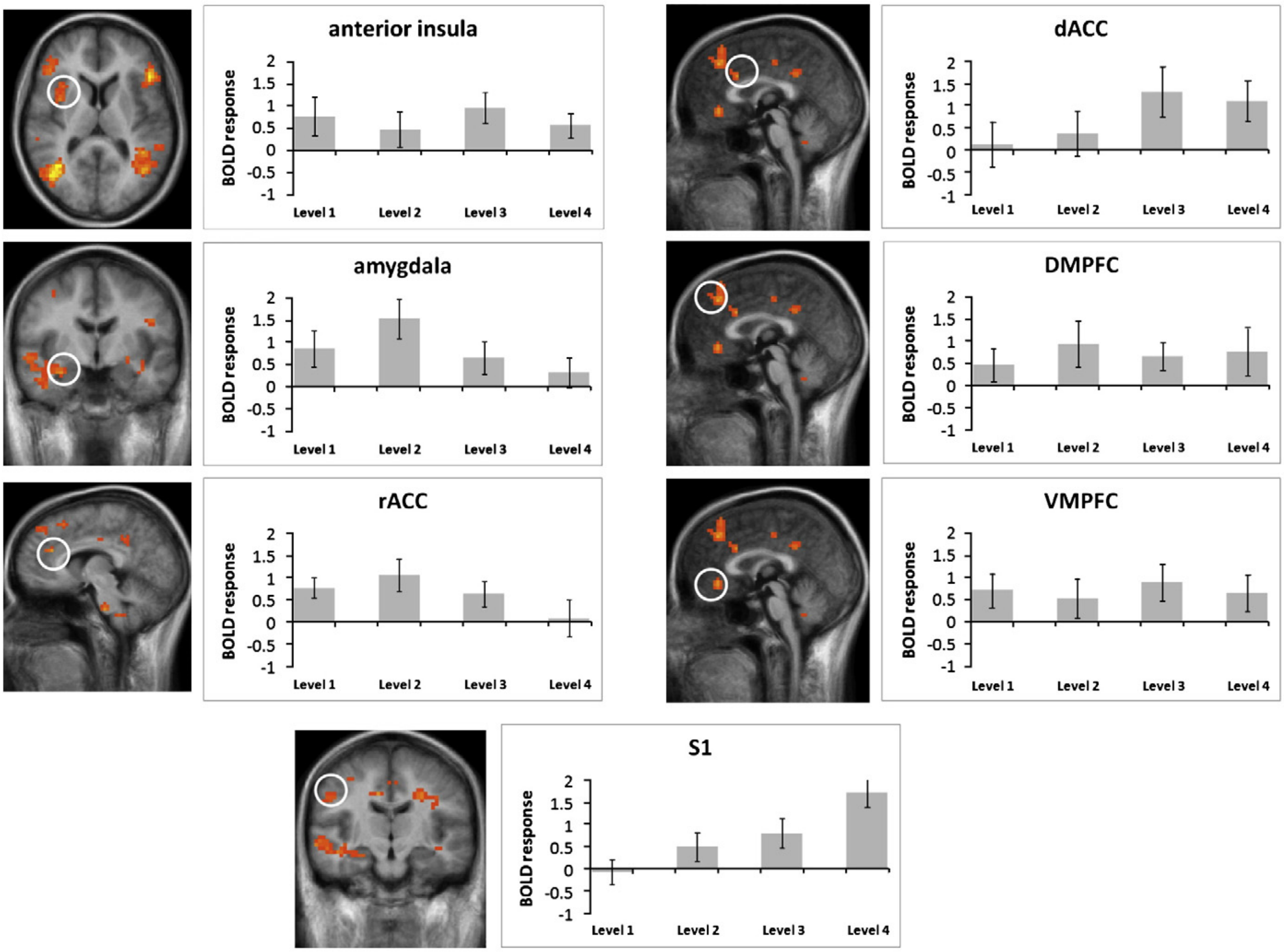

Fig. 2. Main effects to threatening vs. neutral pictures across tasks in several areas. Statistical parametric maps are overlaid on a T1 scan (radiological convention: left = right). The plot shows the difference of parameter estimates (threat vs. neutral; mean and standard error) for the maximally activated voxel in the ROI.

The results for the somatosensory areas support the notion that these regions are involved in the constitution of emotional feelings, as suggested by theoretical accounts (James, 1884; Damasio, 1999).

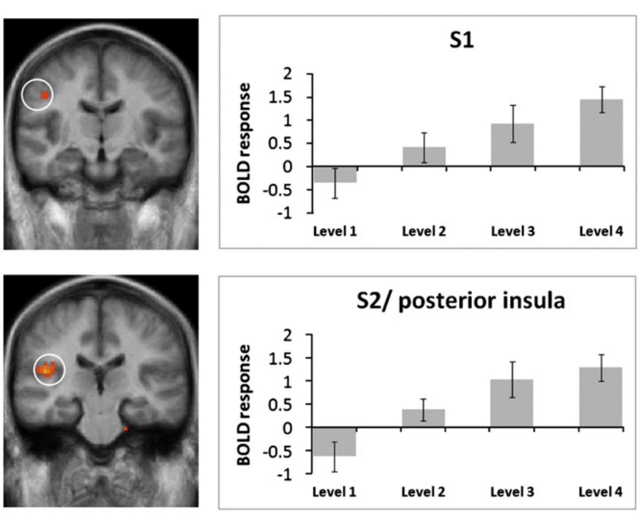

Fig. 3. Systematic increase of activation in the right primary somatosensory cortex and right posterior insula/ S2 across tasks. Statistical parametric maps are overlaid on a T1 scan (radiological convention: left = right). The plot shows the difference of parameter estimates (threat vs. neutral; mean and standard error) for the maximally activated voxel in the ROI.

According to this theoretical framework, emotional stimuli evoke bodily responses, which lead to bodily sensations that are represented by the somatosensory and insular cortex. The perception of these bodily changes contributes to the conscious experience of an emotion. Here, we show that increased attention to one's own emotion seems to be associated with increased processing of bodily states during the processing of emotional pictures.

The findings for the somatosensory areas and the posterior insula were in clear contrast to activation profiles in other areas, which did not show a comparable almost linear task-dependent BOLD-signal function. For these other areas, an involvement in different aspects of emotion processing has been proposed. These functions comprise rapid detection of stimuli (amygdala), generation of autonomic responses (amygdala, VMPFC, ACC), general evaluation of stimuli and responses, and initiation and control of emotional responses (VMPFC, DMPFC, ACC) (e.g., LeDoux, 1996; Damasio, 1999; Phan et al., 2002; Ochsner et al., 2004; Straube et al., 2006, 2008, 2009a,b, 2010a,b), which are–at least partially–relevant also during the other tasks. Even though there was also a main effect in S1 and not in posterior insula/S2, this difference was simply due to a threshold effect. Since activation in S1 was stronger across all levels, a main effect was detected. Nevertheless, this effect was clearly based on the systematic increase of activation across tasks.

The current results are in accordance with recent data from lesion studies showing impairments in the recognition and experience of emotions after lesions of the right insula and somatosensory cortex

(SI and SII) as well as adjacent polymodal regions (Adolphs et al., 2000; Johnsen et al., 2009). However, it should be noted that lesions of the right insula and right somatosensory areas seem to induce rather subtle impairments in emotional tasks and experiences (Adolphs et al., 2000, 2003; Straube et al., 2010b). Thus, it is rather unlikely that emotional experiences are simply based on activation in insular and somatosensory areas. Rather, subjects may use perceived bodily states to infer (the intensity of) their emotions. This might be one important but not the only basis for emotional feelings. The final representation of affective intensity might be associated with activation of other areas beyond the somatosensory cortices or the insula, most likely prefrontal areas (Lane et al., 1998; Damasio, 1999; Phan et al., 2004; Straube et al., 2009a, 2010a). Emotional appraisals are strongly context-dependent and even the same intensity of perceived bodily sensations might lead to different emotional feelings depending on further appraisal steps and concurrently activated mental associations (Leventhal and Scherer, 1987). Activation in relevant areas would be therefore rather related to interindividual and trial-related differences in affective verbal responses (e.g., Straube et al., 2009a, 2010a).

It is remarkable that findings for the parametric analysis were restricted to the right hemisphere. This finding is in accordance with theories suggesting a dominance of the right hemisphere in emotion processing (see also Adolphs et al., 2000), even though we cannot reject the possibility that our findings are dependent on valence, since we only used threat-related pictures as emotional stimuli.

It should be noted that we did not find a parametric effect in the anterior insula, although the right anterior insula has been proposed being involved in the processing of interoceptive information and emotional states (Craig, 2002, 2009). One explanation is that the anterior insula seems to be generally more responsive to emotional stimulation than the posterior areas across tasks. Furthermore, the absence of a parametric effect in the right anterior insula might be based on the kind of sensations subjects used to decode the stimulus relevance and their own feelings during the brief picture presentation. Thus, with other–rather prolonged or more intense–emotion provoking designs, the subject's attention focus might shift, for example, to their own heart beat (e.g., Critchley et al., 2004), which might result in additional task-dependent activation of relevant more anterior insular areas that are involved in the representation of such sensations. The latter point however is completely speculative and should be investigated in future studies. Future studies could include also self-report measures to investigate in more detail the subjective attentional focus and the feelings of participants.

In conclusion, our study revealed stronger activation to threatening vs. neutral pictures in several emotion-related regions under different conditions of subjects' attentional focus. However, there was a parametric increase of activation with increasing attention to own emotion specifically in the right posterior insula and primary and secondary somatosensory cortex, i.e. areas implicated in self-awareness of the own body. These findings strongly support theories suggesting a role of the perception of bodily states for emotional experiences.

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