Year: 2010

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DOI: https://doi.org/10.1016/j.neuroimage.2009.12.089

Originally published at:
Herwig, Uwe; Kaffenberger, Tina; Jäncke, Lutz; Brühl, Annette Beatrix (2010). Self-related awareness and emotion regulation. NeuroImage, 50(2):734-741.
DOI: https://doi.org/10.1016/j.neuroimage.2009.12.089

Regular Article

Self-related awareness and emotion regulation

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July, 20th, 2009

Revised version: September, 28th, 2009

Second revision: November, 16th, 2009

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Abstract

The regulation of emotions is an ongoing internal process and often a challenge. Current related neural models concern the intended control of reactions towards external events, mediated by prefrontal cortex regions upon basal emotion processing as in the amygdala. Cognitive strategies to regulate emotions in the context of affective disorders or stress reduction, increasingly applied in clinical practice, are also related to mindfulness techniques. We questioned their effects on neural emotion processing and investigated brain activity during purely internal mental self-referential processes of making current emotions and self-related cognitions aware. Thirty healthy subjects performed a task comprising periods of cognitive self-reflection, of introspection for actual own emotions and feelings, and of a neutral condition, while they were scanned with functional magnetic resonance imaging. Brain activations of twenty-seven subjects during emotion-introspection and self-reflection, and also a conjunction of both, were compared with the neutral condition. The conditions of self-reflection and emotion-introspection showed distinguishable activations in medial and ventrolateral prefrontal areas, in parietal regions and in the amygdala. Notably, amygdala activity decreased during emotion-introspection and increased compared to 'neutral' during self-reflection. The results indicate that already the self-referential mental state of making the actual emotional state aware is capable of attenuating emotional arousal. This extends current theories of emotion regulation and has implications for the application of mindfulness techniques as a component of psychotherapeutic strategies in affective disorders and also for possible everyday emotion regulation.

Introduction

We constantly experience a stream of external and internal emotionally meaningful signals and events. Awareness of, and the self-regulation in context with these experiences are fundamental for coping with the resulting emotional consequences and for managing associated behavioral impulses. Main theories concerning the neural underpinnings of emotion regulation promote a neural system comprising medial and ventrolateral prefrontal cortical activations that exert control over basal emotion processing and emotion generating areas such as within the amygdala (Ochsner and Gross, 2005). This is well supported by neuroanatomical evidence (Quirk et al., 2003) and by functional neuroimaging (Johnstone et al., 2007; Ochsner and Gross, 2005; Phan et al., 2005). This system is also considered to form a basis for functional models of emotional disturbances in affective disorders such as depression and anxiety (Bishop, 2009; DeRubeis et al., 2008). The model mainly concerns external events and intended regulation, and it was derived from respective studies (e.g. Johnstone et al., 2007; Ochsner and Gross, 2005; Phan et al., 2005). However, unpleasant emotions often arise without an explicit external trigger and are experienced as internally generated, which is also the case in depression and anxiety. Further, as an initial step for emotion regulation, the actual emotional state has to be registered on the neural level and should be aware to the person.

Neurobiological aspects of self-referential awareness were investigated in the context of mindful introspection. Mindfulness comprises the actively maintained awareness and perception of present moment external or internal experiences without being judged or evaluated (Brown and Ryan, 2003; Stein et al., 2008). Subjects in a mindful state showed activations in medial and lateral prefrontal cortex (M/LPFC) areas during affect labeling of presented facial expressions, whereby more mindfulness was associated with less amygdalar activation (Creswell et al., 2007) indicating less emotional arousal or intensity (Anderson et al., 2003). These and other studies in this context (Brefczynski-Lewis et al., 2007; Farb et al., 2007; Stein et al., 2008) were related to external experiences and used cognitive tasks with external stimuli including reaction to them. Hence, the tasks themselves could have interfered with the 'mindful' state which was being attempted to be examined. Likewise, classic emotion regulation studies applied intended cognitive strategies towards external stimuli (Herwig et al., 2007a; Ochsner and Gross, 2005; Phan et al., 2005). Thus, the neural correlates of making oneself aware of purely internal self-referential cognitions and emotions, and their relation to the neural model for emotion regulation, remain undiscovered and were subject of this investigation.

We used a paradigm comprising cognitive self-reflection ('think': "who am I …", e.g. autobiographical contents) and emotion-introspection ('feel': making aware and focusing on current emotions and bodily feelings) as well as a neutral control condition (awaiting of the neutral distractor) during scanning with functional magnetic resonance imaging (fMRI; fig. 1). We expected to distinguish neural representations for both self-referential states in medial and lateral prefrontal cortex (Esslen et al., 2008; Moran et al., 2006; Northoff et al., 2006), and we considered influences on amygdalar activity indicating associations with emotion processing (Creswell et al., 2007).

Methods

Participants

Thirty healthy subjects (age 23-41, all right-handed, 17 female) were recruited via direct address and email-advertisement. All participants were right-handed according to the Annett hand preference scale (Annett, 1970). Subjects were pre-assessed with a semi-structured interview based on ICD-10 to exclude prior and current neurological or psychiatric illness and intake of any medication or other psychotropic substances. Exclusion criteria were pregnancy, excessive consummation of alcohol, cigarettes and caffeine, contraindications against fMRI. The study was approved by the local ethics committee. All subjects gave written informed consent. After scanning, the subjects were systematically asked within a post-experimental briefing about their performance of the task. Two subject reported sleepiness and non-concentration in the scanner and were therefore excluded from the analysis. One subject showed several movement artifacts (sudden head movements of more than 3 mm), so that 3 subjects in total were excluded. The other subjects confirmed that they were able to follow the instructions. During the 'think'-condition, they all thought about and reflected on themselves. For the 'feel'-condition, all subjects reported that they made themselves aware their actual emotions and feelings, and, to a lesser extent, also their bodily sensations, whereby the strategies ranged from a more verbal affect labeling to a preverbal introspection and awareness. However, we did not document detailed characteristics quantitatively. In total, 27 subjects were included in the analysis.

Experimental design

Subjects underwent fMRI while performing a task comprised of three conditions in random order: cognitive self-reflection ('think'), emotion-introspection ('feel'), and indifference ('neutral'). The periods for the conditions were initiated by an indicating cue and ended by presenting a distracting neutral picture (fig. 1). The subjects were instructed and trained before scanning as follows: for the 'think'-condition: "Think about yourself, reflect who you are, about your goals, etc.", for the 'feel'-condition: "Feel yourself, be aware about your current emotions and bodily feelings", and for the 'neutral'-condition: "Do nothing specific, just await the neutral picture". The instructing cues: think ▲, feel▼, neutral ▄, were presented for one second. Including this cue, the conditions were of a period of 11880 ms, equivalent to 6 TRs (repetition time for the fMRI volumes). The distracting neutral pictures (Lang, 1995), indicating the end of each trial were presented for 3960 ms, equivalent to 2 TRs. Then, a baseline period of 8 TRs followed until the next trial started. 14 trials of each condition were performed per subject. The symbols were intuitively understandable, such that no interfering working memory activity had to be used. Intentionally, the task further did not comprise an interfering decisional or motor reaction component. The task was programmed with PresentationTM, Neurobehavioral Systems, USA.

Image acquisition

Imaging was performed with a 3.0 T GE SignaTM HD Scanner (GE Medical Systems, Milwaukee, USA, 8-channel head coil). Echo-planar imaging was performed for fMRI (TR/TE 1980/32 ms, 22 sequential axial slices, whole brain, slice thickness 3.5 mm, 1 mm gap, resulting voxel size 3.125×3.125×4.5 mm, matrix 64×64, FOV 200 mm, flip angle 70°). 676 volumes were obtained per subject, 16 per trial. The first four volumes were discarded to allow for T2 equilibration effects. High-resolution 3-D T1 weighted anatomical volumes were acquired (TR/TE 9.9/2.9 ms; matrix size 256×256; 1×1×1 mm resolution, axial orientation) for coregistration with the functional data. The stimuli were presented via digital video goggles (Resonance Technologies, Northridge, CA).

Data analysis

FMRI data were analyzed using BrainVoyagerTM QX 1.10.1 (Brain Innovation, Maastricht, The Netherlands). Preprocessing of the functional scans included motion correction, slice scan time correction, high frequency temporal filtering, and removal of linear trends. Functional images were superimposed on the 2D anatomical images and incorporated into 3D data sets. The individual 3D data sets were transformed into Talairach space (Talairach and Tournoux, 1988) resulting in a voxel size of 3×3×3 mm^3 and then spatially smoothed with an 8 mm Gaussian kernel for subsequent group analysis. Four predictors, representing the three conditions and the distractor (think, feel, neutral, presentation neutral picture), were used to build the design matrix. Single trials with fMRI signal artifacts of more than threefold mean signal change amplitude (e.g. due to head movements) were eliminated. The periods were modeled as epochs using a two-gamma hemodynamic response function adapted to the applied period duration provided by BrainVoyager.

The fMRI data analysis, based on the general linear model (GLM), comprised the following steps: First, fixed effects analyses were calculated separately for each subject for the three contrasts comparing the three conditions 'think versus feel', 'think versus neutral', 'feel versus neutral', resulting in summary images. The summary images were subjected to second level group analyses. Three-dimensional statistical parametric maps were calculated for the group with separate subject predictors (fixed effects). The statistical threshold for reporting results was set to $p<0.001$ corrected for multiple comparisons (Bonferroni) together with a cluster threshold of 10 voxel à 3×3×3 mm. The main interesting contrast for our study question concerned the comparison 'think versus feel'. From the resulting brain areas, we selected the amygdala region for additional region-of-interest GLM-analyses in order to differentiate the characteristics of activation: we compared the three conditions with each other, and further ‘think’ and ‘feel’ with baseline. This analysis was also performed with an anatomical cubic ROI above the amygdala region (middle coordinates x= -20, y= -7, z= -15). Finally, we performed a conjunction of both self-referential conditions versus neutral (‘think versus neutral’ & ‘feel versus neutral’) in order to reveal those areas which exhibited activation in both conditions.

Questionnaires and correlation analyses

The subjects completed the Freiburg mindfulness inventory (FMI [Walach et al., 2006], German version) and the Mindful Attention and Awareness Scale (MAAS [Brown and Ryan, 2003], German version) as self-ratings for trait mindfulness. Further, they completed a self-rating scale for depression (SDS [Zung, 1965]). One subject did not complete the questionnaires, one subject showed severe artifacts in the clusters (five or more spikes of more than three-fold average signal change) such that 25 subjects were included in the correlational analyses. The rating scores were correlated with the respective mean beta weights (Pearson’s correlations) of clusters with stronger activation during the ‘feel’- or the ‘think’-condition. Therefore, the betas for either the ‘feel’ or the ‘think’ condition, both versus baseline, and not the contrast betas, were considered. Further, the mindfulness scales were correlated with the depression scale. Also when considering the actual discussion concerning fMRI correlation analyses (Mander et al., 2008) and fMRI in general (Kriegeskorte et al., 2009), and that a priori formed anatomical ROIs would have be an even better basis for correlations, the principles of the presented approach have been approved to be fine (Herwig et al., 2007b; Mander et al., 2008).

Results

Brain activations during emotion-introspection and self-reflection

The comparison of the conditions of emotion-introspection (‘feel’) and self-reflection (‘think’) revealed areas with distinguishable activation concerning both conditions. The ‘feel’-condition was associated with posterior medial prefrontal activation in the superior frontal gyrus, with mid-cingulate cortex activation (Table 1a, Fig. 2a-b), with bilateral activity covering parts of the inferior frontal cortex/premotor/insular regions (fig. S1), and with the bilateral somatosensory cortex and the region of the intraparietal sulcus. The 'think'-condition was associated with activation of anterior prefrontal midline areas, showing a shift to relatively more prominent 'think'-related activities the more anterior the areas were (table 1b, fig. 2c-d, large regions were presented at a level $p<0.00001$ corr.). Further, 'think' was associated with activation of left-sided inferior frontal areas (ventrolateral prefrontal cortex, VLPFC; fig. S1), adjacent to and covering speech areas, with dorsolateral prefrontal areas (DLPFC), and also with parietal and occipital areas. The left amygdala was found to be activated with the 'think'-condition and, notably, deactivated during the 'feel'-condition (fig. 3). The 'feel'-related activity in the amygdala was lower compared to the 'think' condition ($t=-7.7$, $p<0.000001$), compared to the neutral condition ($t= -4.2$, $p<0.00002$) and it decreased against baseline ($t= -8.7$, $p<0.000001$). The 'think' activation was higher compared to neutral ($t=3.5$, $p=0.0005$) but not compared to baseline ($t=1.3$, $p=0.21$). These findings were qualitatively also confirmed by the analysis of an anatomical ROI placement above the amygdala as provided in the supplemental material (fig. S2).

The MPFC and left VLPFC regions were conjointly active with both conditions versus neutral (Table 2, Fig. 4).

Correlation with psychometric measures

The mean beta weights of the 'feel' condition were correlated inversely with the ratings of the FMI in those prefrontal midline regions that were more active during 'feel' compared to 'think' (Fig. 2a-b, 9 comparisons in total, 3 significant) and also in the left inferior frontal/premotor region ($r= -0.41$, $p=0.044$). The beta weights of the 'think' condition in those areas showing more activation during 'think' compared to 'feel', correlated inversely with the FMI in the anterior, and in trend with the medial midline PFC fig. 2c-d, 9 comparisons in total (thereof 2 significant and one trend), and also in the left VLPFC ($r= -0.40$, $p=0.049$). Further, the mindfulness scales were inversely correlated with the self rating depressiveness scale (SDS, FMI $r= -0.507$, $p=0.01$, fig S3, MAAS $r= -0.510$, $p=0.01$). We found no correlations of brain activity with the SDS scores.

Discussion

The results provide evidence that both self-related conditions, introspection for one's own present feelings and cognitive self-reflection, induce distinguishable brain activation. A main finding was that emotion-introspection was associated with a decreased activation of the left amygdala, indicating an attenuating influence on emotional arousal (Anderson et al., 2003; Stein et al., 2008). Dorsal midline and left ventrolateral prefrontal regions were activated conjointly with both conditions, suggesting a common mediating role for both conditions. The brain activations occurred through purely mental effort in naturalistic conditions applicable in every-day life without interfering experimental behavioral components.

Emotion regulation

The reduction of amygdalar activation during emotion-introspection is of particular importance. The amygdalar nuclei are known to be functionally involved in emotion processing (Baxter and Murray, 2002; LeDoux, 2000). Amygdala activation has been reported to be associated with fear (LeDoux, 2000; Phelps et al., 2001; Vuilleumier et al., 2001), but also with pleasant emotional stimuli and reward-related processing (Baxter and Murray, 2002; Synofzik et al., 2008). These and other findings lend support to the view that attributes the amygdalar function to have a more general role in emotion processing such as in emotional arousal and emotion intensity without valence specificity (Anderson et al., 2003).

In the context of emotion regulation, the amygdala was found to be a major recipient of activation associated with intended cognitive control of emotions mediated by medial prefrontal cortex areas leading to attenuation of amygdala activity (Herwig et al., 2007a; Johnstone et al., 2007; Phan et al., 2005). This is thought to result in reduced amygdala output towards midbrain and brainstem areas and accordingly in less physiological, for instance sympathetic activation (Bishop, 2009; Ochsner and Gross, 2005; Quirk et al., 2003). Disturbed emotion processing in the amygdala is also considered to be a pathophysiological feature of depression and anxiety (Bishop, 2009; DeRubeis et al., 2008), with implications of an impaired top-down control of amygdala activity (Johnstone et al., 2007).

Taken together, the amygdala can be regarded as a central processor of emotional arousal and intensity and as the target for emotion regulation by cognitive control due to for instance mid-prefrontal activation. Thus, it is well supported to consider occurring amygdala modulation as a neurobiological indicator for emotion regulation. Given these considerations for the amygdala function, our finding implicates the ability to attenuate emotional arousal related brain activation through the mental process of directing attention and awareness to actual emotions and bodily feelings, notably without the conscious intention to regulate emotions. This unintentionality of the approach differentiates it from usually applied emotion regulation strategies. Making oneself aware of how one feels may lead to an inner distancing from these feelings and thus may represent an important strategy for the self-regulation of emotions. This extends current neurobiological models of emotion regulation which are based on findings with intentionally applied regulation strategies for coping with external stimuli (Ochsner and Gross, 2005). It implies that emotion regulation mechanisms may work on an internal basis without external stimuli and without the intention to regulate. A core process may be a mid-prefrontal monitoring of actual emotions. This has further implications for attempts of treatment aimed at strengthening emotion regulation in depression and anxiety as the emotional symptoms in these disorders often lack an actual external trigger but can be characterized by internally elevated emotional arousal states.

Self-reference

Prefrontal midline structures represent key regions for self-referential activity (Moran et al., 2006; Northoff et al., 2006) and emotion regulation (Ochsner and Gross, 2005). We observed a ventral-dorsal shift of activation associated with emotion-introspection compared to activation associated with cognitive self-reflection: the latter was higher in anterior MPFC regions and relatively lower in posterior MPFC regions (fig.2). This supports consideration of a more anterior cortical representation of cognitive self-referential processes (Amodio and Frith, 2006; Esslen et al., 2008; Moran et al., 2006) in regions that might have developed at later evolutionary stages. Further, we found evidence for a lateralized distribution of self-related emotion processing and cognition. Thinking about oneself was associated with activation in the left VLPFC adjacent to and comprising speech-related inferior frontal regions. This makes sense as these regions are known for inner-speech functions which comprise thinking processes (Siegrist, 1995). Emotion-introspection activated more posteriorly bilateral inferior frontal/premotor regions and also minor parts of the middle insula. This was not fully in line with findings of activity in the relatively more anterior VLPFC during affect labeling in states of mindfulness (Brefczynski-Lewis et al., 2007; Creswell et al., 2007; Farb et al., 2007; Lieberman et al., 2007; Stein et al., 2008) but in part with interoception associated activity in the insula (Critchley et al., 2004).

Self-regulation is an essential feature of each living organism. It takes place on several levels, with higher levels controlling lower ones, and with an evolutionary development towards more conscious higher level processes (Churchland, 2002; Damasio et al., 2000). Introspection with awareness for inner feelings and emotions represents a key function within this self-regulating cascade. It supports gaining control over lower level circuits and restraining reflexive fear driven behavior. Making oneself aware of interoceptive or external signals is also the first step for their reappraisal (Gross and John, 2003) and for psychotherapeutic interventions as directing the awareness away from for instance painful feelings towards pleasant aspects. However, current models of emotion regulation using active regulative strategies may suggest that by just being aware of the emotions, representing a first step prior to emotion modulation, one might still be indifferent to possible effects on emotions (Ochsner and Gross, 2005; Koole, 2009). This is also implied by the concept of emotional sensitivity being antecedent to possible emotion regulation (Koole, 2009) when temporally unfolding emotional responses. Further, it was suggested that emotion regulation primarily occurs towards unwanted emotions (Koole, 2009). What is new now is that our data indicate that already directing attention onto the emotional state is capable of modifying emotional arousal and intensity related amygdala activation. This can be regarded as neurobiological evidence for incidental emotion regulation when we reflect our own emotional experience. Incidental emotion regulation previously has been demonstrated in the context of external world action (Berkman et al., 2009) and was suggested for internal emotion processes earlier in the context of expressive writing (Pennebaker and Beall, 1986) and is implied by concepts of open monitoring meditation (Lutz et al., 2008).

Interestingly, in this context we also found increased activation of the left amygdala during reflecting about oneself compared to the neutral condition. This makes sense when considering that thinking about oneself may be accompanied by an emotional evaluation of the contents of self-related thoughts, as for instance memories, future goals or cognitive self-evaluation which are associated with an emotional impact leading to higher arousal.

Finally, on the basis of a mindful awareness for interior and exterior stimuli, we are not only able to reappraise the meaning of the environment for ourselves, but we may finally also be able to modify our attitude towards ourselves or the environment in a well-being and health promoting way.

Apart from the effects of awareness on emotions and cognitive self, it is of interest which brain areas may be involved in association with the general induction of these high-level mindfulness processes. We found a prominent dorsal medial left prefrontal area to be strongly associated with both, the emotion introspection and the cognitive self-reflection (fig. 4). This region also has been reported earlier to be involved in emotion regulation (Herwig et al., 2007a; Ochsner and Gross, 2005) and in self-referential processes (Northoff et al., 2006). It may be assessed in further studies concerning a pivotal role in inducing conscious self-attentive processes.

Emotion introspection and clinical implications

Particularly the self-awareness component of emotion introspection in our task comprised elementary features of mindfulness. However, it was of course not representative for mindfulness in general. Mindfulness was closely associated with well-being (Brown et al., 2007; Kabat-Zinn, 1990; Shapiro et al., 2006; Tang et al., 2007) and represents the basis for psychotherapeutic concepts such as mindfulness based cognitive therapy for depression (MBCT, Teasdale et al., 1999) or mindfulness based stress reduction (Grossman et al., 2004), which are increasingly applied in psychotherapeutic and psychiatric practice (Allen et al., 2006).

Mindfulness has been defined as a receptive attention to and awareness of present experience (Brown and Ryan, 2003). A related description of mindfulness components comprised intention, attention and a non-judgmental attitude with an awareness for the present moment (Kabat-Zinn, 1990; Shapiro et al., 2006). Mindfulness can be directed to external or to interoceptive experiences. For therapeutic purposes, mindfulness is predominantly applied with a focus on interoception (Kabat-Zinn, 1990; Teasdale et al., 1999). Our revealed inverse relation of the mindfulness scores (FMI and MAAS) with the depressiveness scores (SDS), indicating less depressiveness with a higher trait of mindfulness, which supports a relation between mindfulness and well-being. Apart from being long practiced within Buddhist meditation (Brown and Ryan, 2003), the potential impact of mindfulness for daily-life well-being and for treatment of affective disorders and stress symptoms has gained increasing attention in the last years (Brown et al., 2007).

Its neural underpinnings and possible explanations for its effectiveness have been the subject of recent investigations. Ventrolateral prefrontal and midline prefrontal areas and also the amygdala were identified to be important components of mindfulness mediating networks (Brefczynski-Lewis et al., 2007; Creswell et al., 2007; Farb et al., 2007; Stein et al., 2008). Subjects in mindful states showed activations in medial and lateral prefrontal cortex during affect labeling of presented facial expressions (Creswell et al., 2007). In parallel, amygdalar activation as an indicator for emotional arousal (McClure et al., 2004) was diminished during affect labeling of external cues with increasing mindfulness (Creswell et al., 2007). Novices in mindfulness strategies showed functional connectivity between MPFC and insula (Farb et al., 2007), the latter indicating an association with bodily signals (Critchley et al., 2004). Training of mindfulness was reported to increase LPFC–insular connectivity during word reading (Farb et al., 2007), with complex activation modifications in expert meditators compared to novices (Brefczynski-Lewis et al., 2007). Mindfulness related meditation short-term training further lead to improved attention and self-regulation in the sense of stress control (Tang et al., 2007).

In our task, the activation of prefrontal midline areas with distinguishable activation in both conditions, ‘think’ and ‘feel’, showed correlations with the trait mindfulness questionnaire FMI.

Interestingly, the correlations were inverse, meaning less activation was associated with higher traits of mindfulness. This may be explained by less necessary neural resource consumption in applying the task in persons being more skillful in mindfulness. This is in line with propositions of 'effortless concentration' with reduced activation in corresponding neural systems in subjects or experts that are skillful in applying mindfulness related meditation (Lutz et al., 2008). In this context it appears contra-intuitive on the first sight that apart those midline regions being stronger activated with 'feel', also the 'think' related activation in the more anterior midline regions were inversely correlated with the FMI, though the 'think' condition was not meant to be associated with 'mindfulness'. However, this may be explained by the suggestion that those people with dispositional mindfulness also might need less neuronal effort to focus cognitively on themselves. Principally, the correlation analyses findings are to be regarded as preliminary, as they were not reflected in the MAAS. That may have been due to a more resources and strength oriented character of the FMI and a more deficit oriented view of the MAAS, with possibly the first being more sensible to traits in our healthy subjects. On the other hand, affect labeling compared to gender labeling under a mindfulness condition showed increased activation in dispositional mindfulness (Creswell et al., 2007), which may be due to the active character of that task. In any event, training of mindfulness techniques appears to result in neuroplastic adaptations (Farb et al., 2007) that may also account for treatment effects in, for instance, affective disorders.

Depression, the most debilitating affective disorder (Lopez and Murray, 1998), has been associated with reduced prefrontal control onto downstream areas as the amygdala (DeRubeis et al., 2008) and with the need to restore dysfunctional neural networks (Castren, 2005). In depressed patients, amygdala activity was found to be increased and prefrontal functions to be disturbed (DeRubeis et al., 2008). Mindfulness might for instance interrupt negativity promoting feedback loops by decreasing amygdala activity. Training of mindfulness may lead to neuroplastically strengthened connections between hereby activated prefrontal areas and amygdala with regaining cortical control over dysfunctional limbic emotion circuits. A cognitive characteristic of depression is the often quick negative evaluation of oneself and one's own situation, leading to negative ruminating. MBCT can prevent this by building primary nonevaluating awareness of oneself and the situation, which can then be the basis for further cognitive control and modification of own feelings and for a reappraisal of the actual situation. In this context, our finding of an inverse correlation between the trait of mindfulness and actual depressed mood indicates a beneficial influence of mindfulness on mood and provides an explanation for its effectiveness.

Methodological issues

Researching mindfulness in the lab with tasks that classically comprise a behavioral component such as a motor reaction with an answer to exterior stimuli may deteriorate the mindfulness state and may not reflect mindfulness effects directly. In that case, the subject of investigation could be disturbed by any control condition. Here, we attempted to investigate purely mental self-referential awareness. We therefore intentionally dispensed of using a behavioral control. As this might be interpreted as a limitation, other criteria served as a control for the plausibility of our results: the identification of predicted brain regions as those revealed in earlier studies, the implementation of a neutral condition, the ability to discriminate brain activation during the 'feel' and the 'think' condition, the correlation with psychometric mindfulness scales, and the subjects' self-report after scanning. The advantage of this approach consists in applying naturalistic self-referential awareness conditions that can be easily performed by untrained persons in everyday life not comprising reactions onto exterior stimuli.

Another issue is the transfer of the amygdalar modulation due to emotion-introspection from the isolated situation in the current study onto stronger, more arousing emotional stimuli and situations. In the current study, we analyzed emotion-introspection as a process itself, not during the confrontation with emotional stimuli. The application of mindful awareness for own emotions as an intended strategy of emotion regulation could be a next step to investigate. Finally, one might argue that the 'think' task could be experienced as being more difficult compared to the 'feel' task and thus being associated with more arousal. However, the subjects trained the task prior to the experiment and could for instance decide for contents to reflect on such that they did not have any stress to select the contents. Further, they did not report any difficulties in the task after scanning. And reversely, one might also argue, the 'think' condition could lead to focusing on cognitions and release from emotional arousal. Anyhow, the central finding of decreased amygdala activity in the 'feel' condition further was observed also compared to 'neutral' and to baseline such that it cannot be accounted solely to task difficulties.

Conclusion

The presented data provide evidence that making oneself aware about one's own emotions is capable of attenuating emotional arousal related brain activation in the amygdala. This effect was demonstrated as incidental emotion regulation here, but of course may also be explicitly intended. Such, this easily applicable strategy may reduce emotions associated with high arousal such as anger, fear or depressiveness. The associated neural pattern may provide an explanation for mindfulness associated psychotherapeutic effects that may consolidate neuroplastically and result in regaining prefrontal control over dysfunctional emotion circuits. In this context, medial prefrontal regions may act as central inductors or mediators of concerning processes representing a high level of self-regulation. This extends current models of emotion regulation towards their validity also for non-intended regulation of purely internal processes. A practical implication is to regulate emotions by non-judgmentally making them aware, an intervention which can be applied in each present moment.

Acknowledgements:

The study was supported by the Swiss National Foundation No. 3200B0-120518 (UH).

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Legends for Figures and Tables

FIGURE 1. Experimental task. Three conditions were cued: periods of emotion-introspection ‚feel' (awareness of actual emotions), of cognitive self-reflection ‚think' ("who am I …"), and a neutral period. Neutral pictures served to indicate the end of the periods and as a distractor. Durations indicated in milliseconds.

FIGURE 2. A-D Results of contrast 'feel'>'think'. Left column: coronal slices with significant regions indicated red and by crosshair, significance level $p<0.001$ or $p<0.00001$, both corrected (Bonferroni); color bars represent t-values. Middle: time-courses (with standard errors), task-period between the two grey bars. Right: correlation of mean beta-weights of 'feel' or 'think' condition within the cluster with mindfulness score (FMI). A. Posterior medial prefrontal cortex (MPFC), B. medial cingulate cortex (MCC), C. mid-anterior MPFC and D. anterior MPFC and anterior cingulate cortex (ACC). y: Talairach coordinate indicating position of coronal slice.

FIGURE 3 A-C Activations in amygdala with time courses and graph of beta-weights. A. Fixed effects GLM of the contrast 'feel'>'think' with separate subject predictors in the amygdala ROI. Beta-statistics with mean and standard error. Amygdala activity (yellow circles) during the emotion introspection is reduced compared to 'think' and 'neutral': 'feel' vs 'think' $p<0.000001$ (*), 'feel' vs 'neutral' $p=0.00002$ (**), 'think' vs. 'neutral' $p=0.0005$, and, not indicated here, also compared to baseline ($p<0.000001$).

FIGURE 4 Conjunction of 'feel' and 'think'. Conjunction analysis of 'feel>neutral & think>neutral' with prominent activation in the medial prefrontal cortex as also indicated by the time-course.

TABLE 1. Activated regions with contrast 'feel' versus 'think'. Areas with an extension of more than 3000 mm^3 on the level $p<0.001$ corrected are reported with the data of a level of $p<0.00001$ corrected and indicated with an asterisk (*).

TABLE 2 Activated regions in the conjunction analysis of 'feel>neutral & think>neutral'.

Tables

TABLE 1. Activated regions with contrast ‘feel’ versus ‘think’.

Anatomic regions	Brodmann area	Cluster size mm3	Talairach coordinates			t-max
			x	y	z	
a. ‘feel > think’						
Medial prefrontal cortex R	6/8 (Fig. 2a)	1363	15	-10	57	9.8
Middle cingulate gyrus	24 (Fig. 2b)	2093	6	-3	43	8.4
Inferior frontal gyrus L posterior*	44	1242	-47	-2	11	8.2
Inferior frontal/premotor/insula R*	43/6/13	2401	50	-2	6	9.5
Middle temporal gyrus L	37	1355	-52	-57	-1	10.4
Somatosensory cortex L*	3/7/40	5661	-57	-31	26	12.8
Somatosensory cortex R*	3/7/40	12445	53	-33	29	15.2
Intraparietal sulcus region R*	5/7	6089	15	-47	51	9.8
Intraparietal sulcus region L*	5/7	5951	-16	-53	51	9.0
b. ‘think > feel’						
Medial prefrontal cortex mid-ant*.	6/8/32 (Fig. 2c)	3298	-9	14	52	11.1
Medial prefrontal cortex anterior*	9 (Fig. 2d)	6988	-7	43	25	12.9
Dorsolateral prefrontal cortex L	6/8/9*	3181	-31	11	47	9.8
Amygdala/parahippocamp. gyrus L	(Fig. 3)	445	-26	-7	-15	7.6
Middle temporal gyrus L	37	1994	-53	-34	-1	-8.7
Inferior frontal gyrus/insula L ant.*	13/45/47	5891	-43	24	2	14.3
Posterior cingulate ctx./precuneus*	23/30/31	9848	-5	-55	18	12.5
Lateral occipital cortex L*	39	2597	-44	-62	23	10.7
Posterior occipital cortex L>R*	18	2431	-22	-87	-5	10.2

TABLE 2 Activated regions in the conjunction analysis of ‘feel>neutral & think>neutral’.

Conjunction *feel>neutral & think>neutral*						
Anatomic regions	Brodmann area	Cluster size mm3	Talairach coordinates			t-max
			x	y	z	
Medial prefrontal cortex	8/32 (Fig. 4)	7208	-4	9	47	12.6
Ventrolateral prefrontal cortex L	44/45/47	916	-44	18	6	6.7

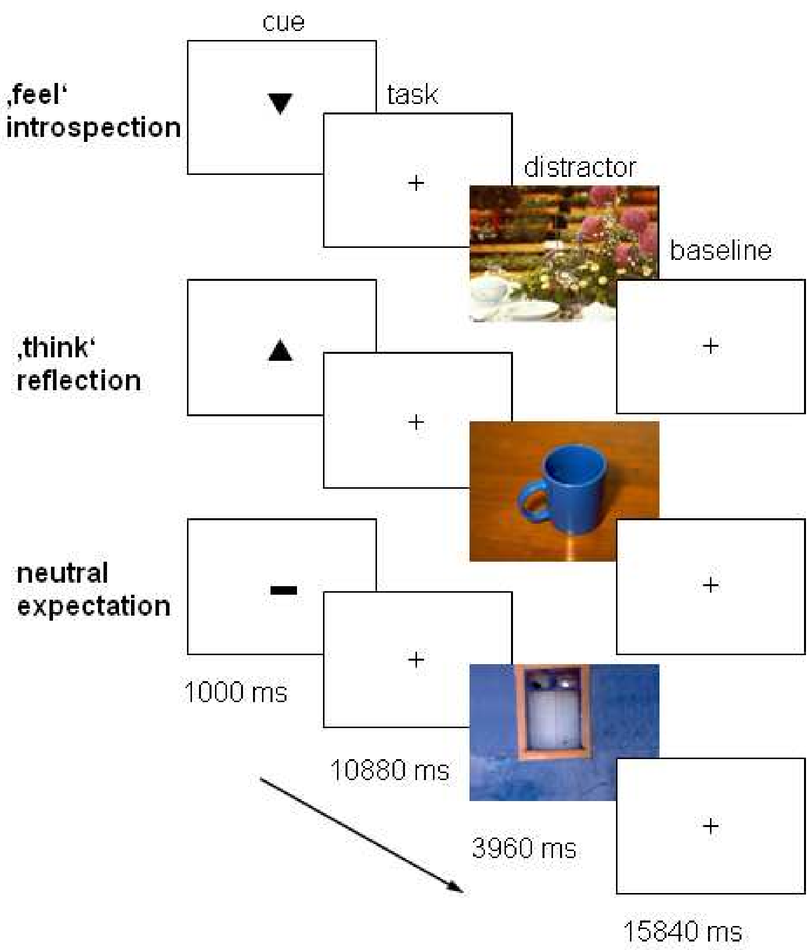
cue
task
distractor
baseline
‚feel'
introspection
‚think'
reflection
neutral
expectation
1000 ms
10880 ms
3960 ms
15840 ms

Fig. 1

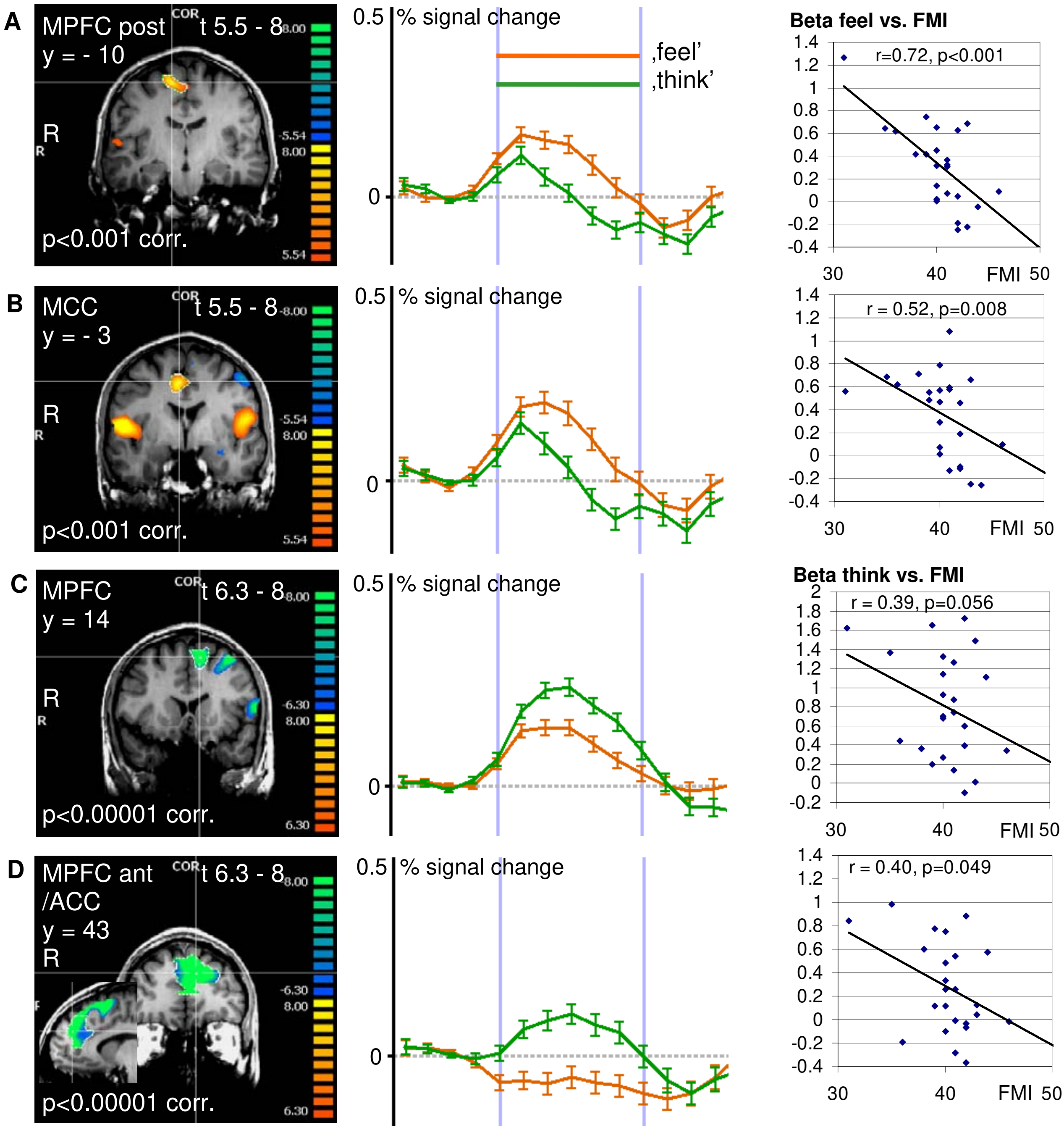
A
MPFC post
y = - 10
t 5.5 - 8
R
p<0.001 corr.
0.5
% signal change
0
,feel'
,think'
Beta feel vs. FMI
r=0.72, p<0.001
FMI
B
MCC
y = - 3
t 5.5 - 8
R
p<0.001 corr.
r = 0.52, p=0.008
C
MPFC
y = 14
t 6.3 - 8
R
p<0.00001 corr.
Beta think vs. FMI
r = 0.39, p=0.056
D
MPFC ant
/ACC
y = 43
R
t 6.3 - 8
p<0.00001 corr.
r = 0.40, p=0.049

Fig. 2

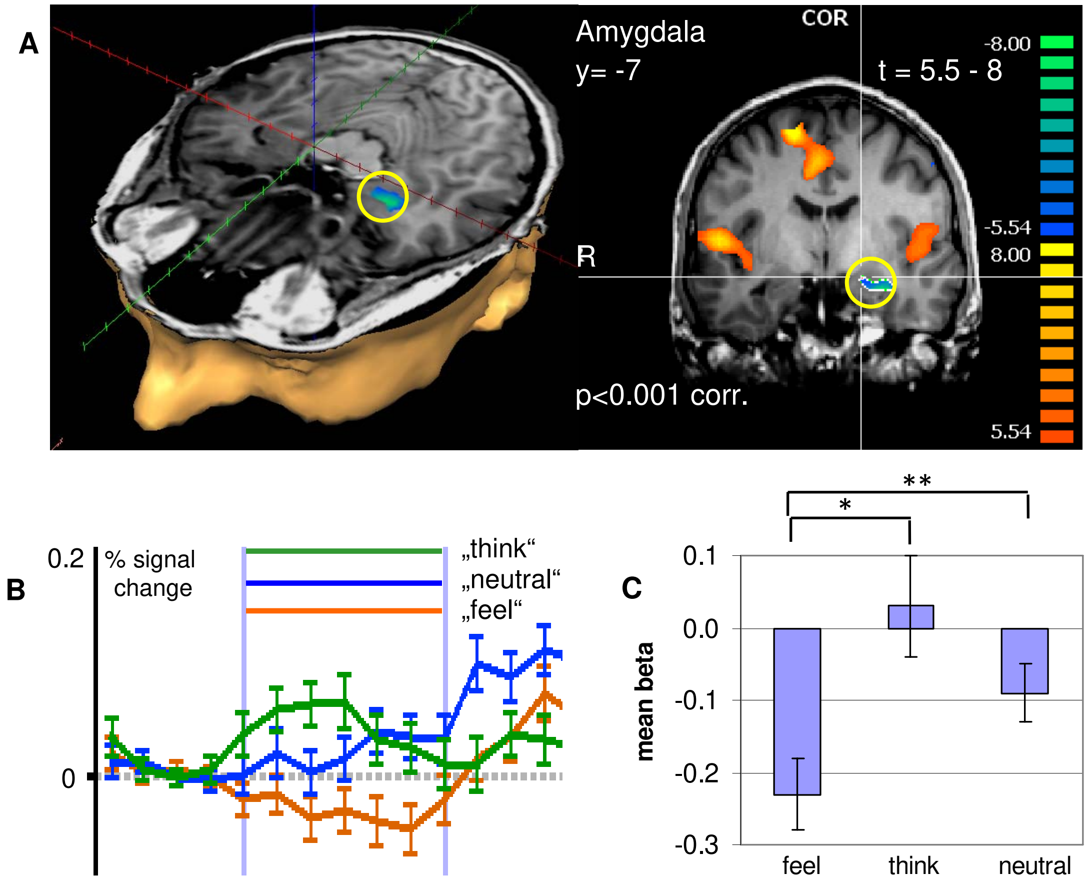
A
Amygdala
y= -7
COR
t = 5.5 - 8
-8.00
-5.54
8.00
5.54
R
p<0.001 corr.
B
0.2
% signal change
0
„think“
„neutral“
„feel“
C
**
*
0.1
0.0
-0.1
-0.2
-0.3
mean beta
feel
think
neutral

Fig. 3

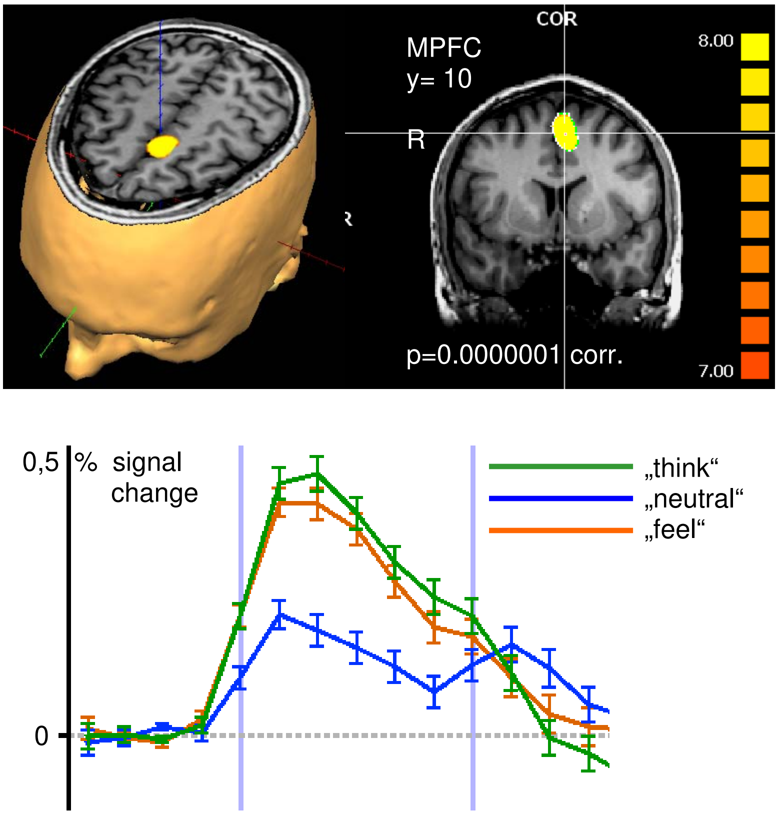
COR
MPFC
y= 10
R
8.00
7.00
p=0.0000001 corr.
0,5
% signal
change
0
„think“
„neutral“
„feel“

Fig. 4