Role of the inferior frontal cortex in coping with distracting emotions

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The role of inferior frontal cortex in coping with emotional distracters presented concurrently with a working memory task was investigated using event-related functional magnetic resonance imaging. The study yielded two main findings: (i) processing of emotional distracters was associated with enhanced functional coupling between the amygdala and the inferior frontal cortex and (ii) the inferior frontal cortex showed a left-lateralized activation pattern discriminating successful from unsuccessful trials in the presence of emotional distraction. These findings provide evidence that coping with emotional distraction entails interactions between brain regions responsible for detection and inhibition of emotional distraction, and identified a hemispheric specialization in the inferior frontal cortex in controlling the impact of distracting emotions on cognitive performance (left hemisphere) vs. controlling the subjective feeling of being distracted (right hemisphere). *NeuroReport* 17:1591–1594 © 2006 Lippincott Williams & Wilkins.

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Introduction

The available evidence suggests a role of the inferior frontal cortex in general inhibitory processes [1]. Its role in inhibitory processes that are specifically engaged to control the impact of potentially distracting emotional stimuli, however, remains largely unknown. Investigation of the neural mechanisms of coping with distracting emotions has relevance for understanding clinical conditions associated with increased susceptibility to emotional distraction, such as depression and posttraumatic stress disorder. Here, we used event-related functional magnetic resonance imaging (fMRI) to investigate the role of the inferior frontal cortex in coping with emotional distraction in healthy participants.

Patients with lesions in the lateral prefrontal cortex, including the inferior frontal cortex, are particularly sensitive to distracting information, possibly due to an inability to inhibit task-irrelevant information [2–4]. Recent functional neuroimaging studies of working memory have further supported a role for the inferior frontal cortex in inhibitory processes, in that experimental conditions requiring the highest level of inhibition produced the highest level of activity in the inferior frontal cortex ([5–8]; see also Ref. [9]).

Studies investigating the neural correlates of cognitive control of emotion also provide support for a role of the inferior frontal cortex in emotional control [10], but the precise role of this region in controlling the impact of emotion on ongoing cognitive processes is not as yet established. A recent study from our group investigating the neural systems mediating cognitive interference by emotional distraction showed that inferior frontal cortex activity correlated with subjective ratings of distractibility for task-irrelevant emotional stimuli presented during the delay interval of a working memory task [8]. Participants who showed greater inferior frontal cortex activity in the presence of emotional distracters also rated them as less distracting, possibly as a result of engaging inhibitory processes that reduced the subjective impact of emotional distraction. As activity in this region was not specifically linked to changes in working memory performance, it was not clear whether the inferior frontal cortex is only involved in controlling the subjective feeling of being distracted or was also involved in controlling the actual impact of emotional distraction on cognitive performance. Here, we report new analyses of these data to clarify this important issue.

A role for the inferior frontal cortex in controlling the impact of task-irrelevant emotional distraction on working memory performance would be well established if (i) emotional distraction triggers concomitant activity in the inferior frontal cortex, which is associated with the inhibition of task-irrelevant distraction [1], and in the amygdala, which is responsible for detection and processing of emotional, potentially distracting, information [11], and (ii) the inferior frontal cortex shows greater engagement during successful than unsuccessful maintenance of task-relevant information into working memory in the presence of emotional distracters. We therefore sought evidence for our hypothesis by comparing functional connectivity between the amygdala and the inferior frontal cortex in the presence of task-irrelevant emotional and neutral distracters, and by comparing the engagement of the inferior frontal cortex during trials associated with successful and unsuccessful working memory maintenance in the presence of emotional and neutral distracters. We made two predictions: (i) processing of emotional distracters would be associated with greater functional coupling between the amygdala and the inferior frontal cortex than processing of the neutral distracters and (ii) successful coping with emotional distraction would be associated with greater inferior frontal cortex activity for successful than for unsuccessful trials.

Materials and methods

Participants

Analyses were performed on data from 15 right-handed young (18–31 years; average age=22 years, SD=3.8) women. The experimental protocol was approved for ethical treatment of human participants by the Duke University Medical Center's Institutional Review Board.

Experimental procedures

Participants performed a delayed-response working memory task for faces, with emotional, neutral [12,13], and scrambled pictures presented as distracters during the delay interval between the memorandum and probe (see Fig. 1 from Ref. [8]); 40 experimental trials per distraction condition were acquired. Each trial started with a three-face memorandum (3.5 s), which participants encoded and maintained in working memory (11.5 s). Two seconds after the memoranda offset, two distracters of the same type were presented consecutively (3 s each). The probe consisted of a single face presented for 1.5 s. Participants were instructed to look at the distracters, but maintain focus on the working memory task, and to indicate whether the probe was part of the memorandum (old) or not (new); 50% of the probes were old and 50% were new. A 12.5-s fixation followed each probe. After scanning, participants rated the emotional and neutral pictures for distractiveness and emotional intensity using a 4-point Likert scale (1=lowest, 4=highest), and subjective indices of distractibility and emotional reactivity were calculated by averaging each participant's ratings.

Data acquisition and analysis

Scanning was conducted on a 4 T GE scanner (General Electric, Milwaukee, Wisconsin, USA). The imaging protocol, preprocessing steps, and the general methods used to investigate the neural systems mediating cognitive interference by emotional distraction were described elsewhere [8]. Here, we focus on analyses employed to further elucidate the role of the inferior frontal cortex during coping with emotional distracters.

To investigate whether inferior frontal cortex activity in the presence of emotional distracters covaries with activity in the amygdala, within-subject correlations between delay activity in these regions were performed. These analyses involved voxel-based correlations performed on a trial-by-trial basis between brain activity extracted from 'seed' regions of interest (ROIs) from the amygdala and activity in the inferior frontal cortex. The seed amygdala ROIs were identified bilaterally as the voxels showing maximum sensitivity to emotional over neutral distracters [i.e. as identified by the random-effects group analysis performed at the peak time point of the delay interval – 16 s after the memoranda onset – at $P<0.005$, $t(14)>3.0$]. These trial-based analyses were performed in each participant for both emotional and neutral distracters, and separately for the left and right amygdala ROIs. To identify the inferior frontal cortex regions systematically showing greater correlations with the amygdala, across-subject paired t comparisons of the individual correlation maps for emotional and neutral distracters were performed. Given our a priori hypotheses, these analyses were limited to activity in the inferior frontal cortex regions, which were identified on a high-resolution normalized brain image, using anatomical landmarks [14]. For this focused analysis, a threshold of $P<0.01$ was used [$t(14)=2.60$]. In addition, only data for trials during which it is more likely that participants were engaged in the task (i.e. successful trials) were included.

To investigate the role of the inferior frontal cortex in successful working memory maintenance in the presence of emotional distracters, delay activity for trials associated with correct and incorrect responses was compared with each other. Activity for the correct trials was identified by averaging fMRI data for Hits and Correct Rejections, and activity for the incorrect trials was identified by averaging fMRI data for Misses and False Alarms (for additional details, see Ref. [8]). Furthermore, to identify subregions of the inferior frontal cortex that are both sensitive to the presence of emotional distracters and contributing to successful maintenance of the memoranda in the presence of emotional distraction, a triple conjunction analysis was performed between (i) the activation map identifying greater trial-based amygdala–inferior frontal cortex correlations for emotional than for neutral distracters, resulted from the correlation analysis described above, (ii) the activation map identifying greater inferior frontal cortex activity for correct vs. incorrect trials in the presence of emotional distracters, and (iii) the activation map identifying greater successful working memory maintenance activity (correct vs. incorrect) to emotional than to the neutral distracters. For this analysis, a minimum threshold of $P<0.05$ was used in each of the contributing maps, and thus the significance threshold of the resulting conjunction map was set at an intensity threshold of $P<0.0002$ (0.05^3) [15]; an extent threshold of four contiguous voxels was also used. Finally, activity in the inferior frontal cortex identified with these conjunction analyses was subject to further investigations using analysis of variance (ANOVA) and Fisher's protected least significant difference post-hoc tests. For all statistics, the results of analyses performed on the fMRI signal from the delay peak time points (i.e. 12–16 s following the memoranda onset) are reported.

Results

Behavioral results

Emotional intensity and distractiveness ratings

Emotional distracters were perceived as both more emotional [2.89 vs. 1.25; $t(14)=11.33$, $P<0.0001$] and more distracting [2.71 vs. 1.45; $t(14)=8.30$, $P<0.0001$] than the neutral distracters. Moreover, subjective emotional intensity and distractibility scores were significantly correlated with each other for the emotional ($R = 0.72$, $P < 0.002$) but not for the neutral ($R = 0.22$, $P > 0.25$) distracters.

Working memory performance

Emotional distracters also produced greater impairment on working memory performance (emotional < neutral < scrambled). This effect was confirmed by ANOVAs performed on percentage of Hits [$F(2,14) = 9.30$, $P < 0.0008$], percentage of correct responses [Hits−Correct Rejections; $F(2,14) = 13.35$, $P < 0.0001$], percentage of corrected recognition scores [Hits minus False Alarms; $F(2,14) = 13.77$, $P < 0.0001$], and by post-hoc tests (all paired comparisons were significant; $P < 0.05$) [8].

Functional magnetic resonance imaging results

Amygdala–inferior frontal cortex interaction in the presence of emotional distraction

Confirming our first prediction, trial-based correlation analysis provided evidence for enhanced amygdala–inferior frontal cortex interactions during processing of emotional distracters. As illustrated by Fig. 1, specific regions of the inferior frontal cortex (Brodman area 45) showed bilateral greater positive correlations with the amygdala during processing of emotional than neutral distracters [left hemisphere: $t(14) = 3.91$, $P < 0.001$; right hemisphere: $t(14) = 3.15$, $P < 0.004$; Talairach [16] $x\ y\ z$ coordinates: −51 28 17/55 17 21). Interestingly, the inferior frontal areas showing enhanced functional coupling with the amygdala in the presence of emotional distraction overlap the inferior frontal cortex subregions whose delay activity correlated with the subjective ratings for distractibility and emotional intensity (see Fig. 5 from Ref. [8]).

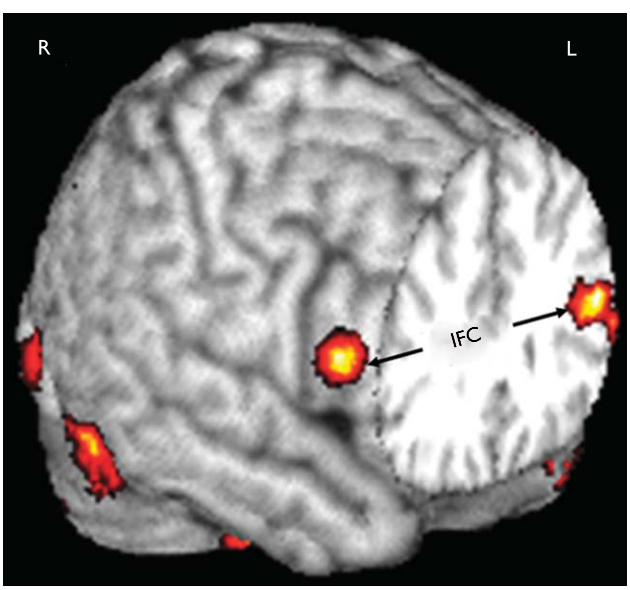

Fig. 1 Functional coupling between the amygdala and the inferior frontal cortex during processing of emotional distracters. The figure illustrates regions of the inferior frontal cortex that showed greater within-subject trial-by-trial positive correlations with the amygdala (left and right hemispheres merged) during processing of emotional than neutral distracters. IFC, inferior frontal cortex.

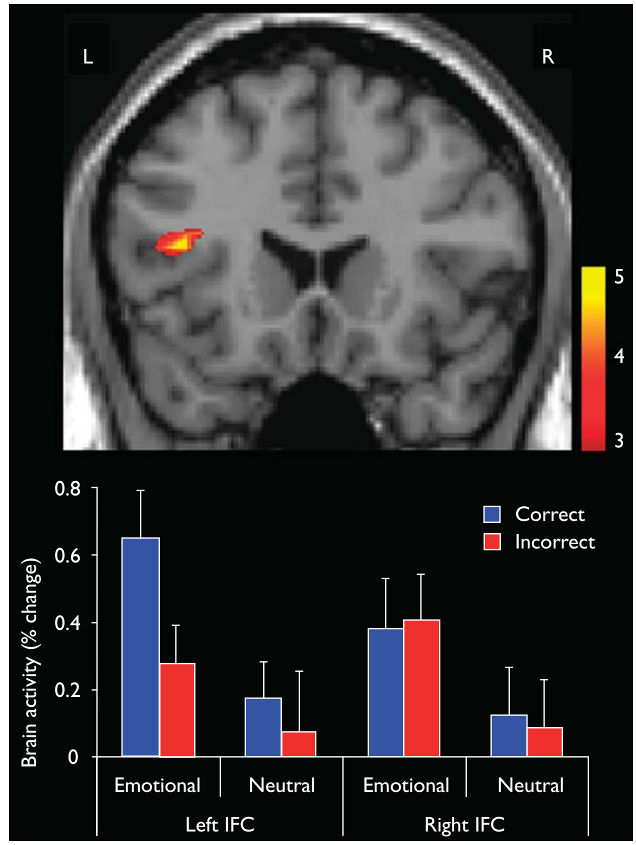

Fig. 2 Hemispheric asymmetry in the inferior frontal cortex during successful coping with emotional distraction. Activity in the left inferior frontal cortex (IFC) region (BA 45, Talairach [16] coordinates: $x\ y\ z = -44$ 28 13) was greater for correct than for incorrect trials in the presence of emotional distracters. In contrast, activity in a homologous region from the right hemisphere did not distinguish between correct and incorrect trials. The figure illustrates the left IFC region associated with successful working memory maintenance in the presence of emotional distracters, which also showed greater trial-by-trial correlation with the amygdala during processing of emotional than neutral distracters.

Hemispheric asymmetry in the inferior frontal cortex during successful coping with emotional distraction

Confirming our second prediction, delay activity in the inferior frontal cortex distinguished between successful and unsuccessful trials in the presence of emotional distracters, and this effect was left-lateralized (Fig. 2). This finding was validated by a three-way ANOVA, including hemisphere (left vs. right), memory (remembered vs. forgotten), and distracter type (emotional vs. neutral vs. scrambled) as within-subject factors, which further investigated activity in the inferior frontal cortex region identified by the subsequent memory and conjunction analyses. This ANOVA yielded a significant hemisphere × memory × distracter type interaction [$F(2,18) = 4.6$, $P < 0.025$], and post-hoc analyses confirmed that only the left inferior frontal cortex distinguished between trials associated with successful vs. unsuccessful working memory maintenance in the presence of emotional distracters [$F(1,9) = 17.10$, $P < 0.0025$]. Notably, this left inferior frontal subregion was part of the inferior frontal cortex areas also showing greater trial-by-trial correlation with the amygdala (Fig. 2).

Discussion

Amygdala–inferior frontal cortex interaction in the presence of emotional distraction

Enhanced amygdala–inferior frontal cortex correlation in the presence of emotional distraction suggests that these two regions are part of a neural network responsible for detection and processing of emotional, potentially distracting, information. Although correlation does not prove causation, given the undisputed role of the amygdala in the processing of emotional stimuli [11], it is reasonable to posit that these effects reflect processing that originates in the amygdala, which exerts influence upon inferior frontal cortex activity. Anatomical data show substantial amygdala–inferior frontal cortex connections [17], and hence support this interpretation. Thus, the present results provide support for the idea that enhanced trial-based amygdala–inferior frontal cortex correlations in the presence of emotional distracters reflects the engagement of a neural circuit in which the amygdala plays the role of an 'emotional detector' that signals the inferior frontal cortex about the presence of transient emotional distraction.

Hemispheric asymmetry in the inferior frontal cortex during successful coping with emotional distraction

The hemispheric asymmetry observed in the inferior frontal cortex provides direct evidence for differential involvements of left and right inferior frontal cortex during coping with emotional distraction. The fact that delay activity in the right inferior frontal cortex did not differ for trials associated with correct compared with incorrect responses, along with our previous finding that enhanced activity in this region was associated with lower distractiveness ratings [8], suggests that the right inferior frontal cortex is involved in controlling the subjective feeling of being distracted. In contrast, the fact that the activity of the left inferior frontal cortex was greater for correct than for incorrect trials in the presence of emotional distracters suggests that this region is involved in controlling the impact of emotional distraction on working memory. Given the evidence linking the inferior frontal cortex with inhibitory processes [1], greater involvement of the inferior frontal cortex during processing of trials associated with correct than incorrect responses may reflect the engagement of inhibitory processes that diminish the influence of emotional distraction, and thus contribute to successful maintenance of working memory memoranda.

Collectively, the present findings provide novel insights concerning the role of the inferior frontal cortex in controlling the impact of goal-irrelevant emotional distraction on goal-oriented behavior. The present findings extend the evidence from studies of cognitive control of emotion by showing for the first time that this brain region is involved not only in controlling the emotional response induced by potentially distracting emotional stimuli [8,10] but also in diminishing the negative impact of distracting emotions on ongoing cognitive processes. The left-lateralization of this effect is consistent with recent findings identifying a role of the left inferior frontal cortex in controlling the impact of emotion on executive processes [18], and provide an additional explanation for the prevalence of depression symptoms in frontal patients with left hemisphere lesions [19] that may stem not only from a hemispheric asymmetry in the processing of negative emotions [20] but also from an impaired ability to control negative emotions.

Conclusion

The present findings clarify the role of the inferior frontal cortex in controlling the impact of task-irrelevant emotional distraction on cognitive performance by showing for the first time that this region is part of a neural circuit in which the amygdala informs about the presence of emotional distraction, and the inferior frontal cortex controls the impact of task-irrelevant distracting emotions on ongoing cognitive behavior.

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