

Dissociable Neural Systems Resolve Conflict from Emotional versus Nonemotional Distracters

The human brain protects the processing of task-relevant stimuli from interference (“conflict”) by task-irrelevant stimuli via attentional biasing mechanisms. The lateral prefrontal cortex has been implicated in resolving conflict between competing stimuli by selectively enhancing task-relevant stimulus representations in sensory cortices. Conversely, recent data suggest that conflict from emotional distracters may be resolved by an alternative route, wherein the rostral anterior cingulate cortex inhibits amygdalar responsiveness to task-irrelevant emotional stimuli. Here we tested the proposal of 2 dissociable, distracter-specific conflict resolution mechanisms, by acquiring functional magnetic resonance imaging data during resolution of conflict from either nonemotional or emotional distracters. The results revealed 2 distinct circuits: a lateral prefrontal “cognitive control” system that resolved nonemotional conflict and was associated with enhanced processing of task-relevant stimuli in sensory cortices, and a rostral anterior cingulate “emotional control” system that resolved emotional conflict and was associated with decreased amygdalar responses to emotional distracters. By contrast, activations related to both emotional and nonemotional conflict monitoring were observed in a common region of the dorsal anterior cingulate. These data suggest that the neuroanatomical networks recruited to overcome conflict vary systematically with the nature of the conflict, but that they may share a common conflict-detection mechanism.

Keywords: amygdala, cognitive control, conflict monitoring, emotion regulation, lateral prefrontal cortex, rostral anterior cingulate cortex

Introduction

The involuntary processing of task-irrelevant stimuli (distracters) can interfere with the performance of a task at hand (Stroop 1935). It is considered a primary function of the frontal lobes to selectively provide preferential processing to task-relevant over task-irrelevant stimuli (Miller and Cohen 2001), by biasing an inherent competition between stimuli for representation in sensory cortices (Desimone and Duncan 1995). A particularly potent way of gauging the efficiency of this selection process is found in tasks where task-irrelevant stimulus information directly conflicts with task-relevant stimulus information, such as when the 2 are semantically incongruent, or are associated with different, incompatible responses. In the classic color-word Stroop task (Stroop 1935; MacLeod 1991), for example, subjects are required to name the ink color of a word stimulus. Performance is impaired if the word-meaning is incongruent with the ink color (e.g., the word RED printed in green ink), relative to when ink color and word-meaning are congruent (e.g., the word RED printed in red ink) or unrelated (e.g., the word CAR printed in green ink). Interestingly, the interference (or “conflict”) gener-

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ated by incongruent task-irrelevant information with goal-directed processing is reduced if an incongruent stimulus is preceded by another incongruent stimulus, compared with when it is preceded by a congruent stimulus (Kerns et al. 2004; Egner and Hirsch 2005a; Notebaert et al. 2006). This finding suggests that, when exposed to conflict, the brain can rapidly adjust processing strategies to overcome that conflict (Gratton et al. 1992; Botvinick et al. 2001).

An influential model proposes that the phenomenon of superior conflict resolution following incongruent stimuli (the “conflict adaptation effect”) is mediated by a regulatory “cognitive control” loop (Botvinick et al. 2001). In this loop, conflict on an incongruent trial is detected by a “conflict monitor” that recruits “cognitive control” resources in order to resolve the conflict, which leads to a higher level of control (and thus superior conflict resolution) on the subsequent trial. The conflict adaptation effect has been exploited to dissociate brain regions involved in the monitoring of conflict from those involved in the resolution or control over conflict. This is done by contrasting neural activity on incongruent trials preceded by a congruent trial (high conflict, low control trials) with incongruent trials preceded by an incongruent trial (low conflict, high control trials) (Botvinick et al. 1999). Studies employing this logic have implicated the dorsal anterior cingulate cortex (dACC) in conflict monitoring (Carter et al. 1998; Botvinick et al. 1999; MacDonald et al. 2000; Kerns et al. 2004), and the lateral prefrontal cortex (LPFC) in conflict resolution processes (MacDonald et al. 2000; Kerns et al. 2004; Egner and Hirsch 2005a, 2005b).

Conflict resolution is thought to be mediated by top-down enhancement of task-relevant (i.e., ink color) relative to task-irrelevant (i.e., word form) stimulus representations in sensory cortices (Cohen et al. 1990; Botvinick et al. 2001). For instance, a recent study required subjects to categorize famous faces on the basis of whether they belonged to an actor or a politician, while trying to ignore category-congruent or -incongruent names that were written across the faces (e.g., an actor’s face with a politician’s name) (Egner and Hirsch 2005b). Improved conflict resolution on incongruent trials that followed other incongruent trials was associated with activity in the right LPFC, which was predictive of concomitantly enhanced activity in the fusiform gyrus (Egner and Hirsch 2005b), a visual region involved in representing information about facial identity (Kanwisher et al. 1997; Rotshtein et al. 2005). Thus, conflict adaptation paradigms have revealed a dACC-LPFC-sensory cortex cognitive control loop that ensures the protection of task-relevant processing from interference by task-irrelevant distracter stimuli.

However, all distracters may not be dealt with in the same way. Emotional stimuli in particular are thought to hold a

special status as distracters (Mathews and MacLeod 1985; Williams et al. 1996; Eastwood et al. 2001; Mathews and Ohman et al. 2001). For example, affective facial expressions (Breiter et al. 1996) and emotionally salient words (Isenberg et al. 1999) activate the amygdala and associated limbic structures. Engagement of the amygdala confers preferential processing to emotional stimuli (Vuilleumier et al. 2001, 2004), so that potential threats to the organism can be rapidly evaluated and responded to (LeDoux 1996). Accordingly, we have recently suggested that the neural circuitry recruited for emotional conflict resolution may differ from that used to resolve nonemotional conflict (Etkin et al. 2006). In this conflict adaptation experiment, which was modeled on the nonemotional face-categorization study described above (Egner and Hirsch 2005b), subjects were asked to categorize faces according to their emotional expression (happy vs. fearful), while trying to ignore emotionally congruent or incongruent affective labels (“HAPPY,” “FEAR”) written across the faces (see Fig. 1A, bottom panels). We found that incongruent emotional distracters produced conflict and trial-to-trial conflict resolution effects (Etkin et al. 2006) akin to those observed in the nonemotional task (Egner and Hirsch 2005b). However, in contrast to findings in the previous study, emotional conflict was associated with increased amygdalar activity, and the resolution of conflict was associated with activation of the rostral anterior cingulate cortex (rACC). Furthermore, increased activity in the rACC during conflict resolution was predictive of concomitant decreases in amygdalar activity, and this inhibitory relationship in turn correlated with successful behavioral conflict resolution, as well as a blunting of autonomic responses to emotionally incongruent stimuli. We concluded that interference from emotional distracters is resolved through rACC-mediated top-down inhibition of amygdalar responses to incongruent emotional distracters, counteracting the normal tendency to prioritize these emotional stimuli. Interestingly, this study also found that the monitoring of emotional conflict involved regions in more dorsal medial prefrontal cortex adjacent to the dACC, suggesting that this region may play a similar role in monitoring emotional and nonemotional conflict (Etkin et al. 2006).

Considered side by side, the results from these studies suggest the intriguing possibility that 2 dissociable neural mechanisms resolve conflict from different classes of distracters: a “cognitive control” circuit, wherein the LPFC amplifies the processing of task-relevant stimuli in sensory cortices to overcome conflict from nonemotional distracters (Egner and Hirsch 2005b), and an “emotional control” circuit, wherein the rACC resolves conflict by inhibiting amygdalar reactivity to emotional distracters (Etkin et al. 2006). However, this proposal remains untested, because no previous study has directly contrasted neural activity associated with the monitoring and resolution of nonemotional versus emotional conflict in the same subjects using directly comparable paradigms.

The suggestion that dissociable prefrontal regions may be dedicated to dealing with emotional versus nonemotional distracters is in line with the longstanding observation that the rACC is primarily involved in affective processing and regions of the dACC and LPFC are more closely associated with nonemotional cognitive processes (Vogt et al. 1992; Devinsky et al. 1995; Drevets and Raichle 1998; Bush et al. 2000). A number of studies employing a traditional “emotional Stroop” task, where subjects name the ink color of either emotionally neutral (e.g., “CAR”) or negatively charged words (e.g.,

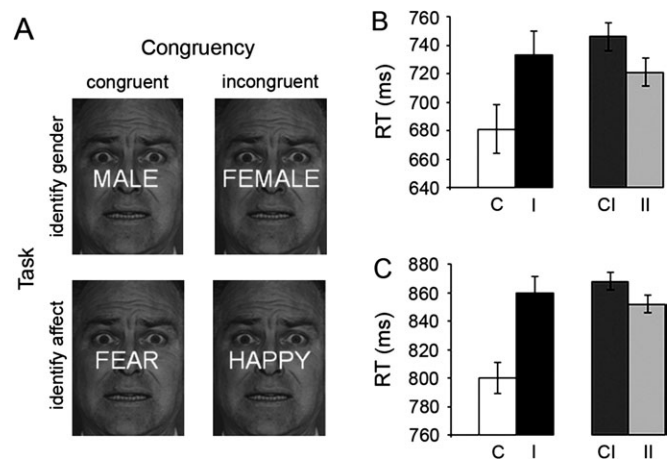


Figure 1. Experimental protocol and behavioral results. (A) The experimental design varied task (“nonemotional”: the identification of the gender of the faces, “emotional”: the identification of facial affect) and stimulus congruency (semantically congruent or incongruent distracter words), while keeping face stimuli identical. (B, C) Left panels: mean RTs (\pm standard error of the mean [SEM]) for congruent (C) and incongruent (I) trials. Right panels: mean RTs (\pm SEM) for incongruent trials, split up by whether the trials were preceded by a congruent trial (CI = low conflict resolution) or by an incongruent trial (II = high conflict resolution), plotted for (B) the nonemotional task and (C) the emotional task.

“DEATH”), also support this notion in showing that the rACC is activated during processing of task-irrelevant emotional stimuli (Bush et al. 1998; Whalen et al. 1998; Bishop et al. 2004; Mohanty et al. 2007). The precise implications of these results for rACC function are difficult to determine, however. First, task-irrelevant emotional stimuli in the emotional Stroop task do not directly conflict with task-relevant processing (Algom et al. 2004), and rarely produce behavioral costs in healthy subjects (Williams et al. 1996). Second, even if some form of emotional monitoring and control processes were to occur in this task, these previous studies would not have been able to detect them, because neutral and emotional stimuli were presented in separate blocks, which thus precluded the assessment of possible trial-to-trial fluctuations in regulatory processes. The current study set out to directly contrast neural activity related to emotional versus nonemotional conflict monitoring and conflict resolution processes. To do so, we employed comparable emotional and nonemotional conflict adaptation paradigms in the same subject cohort. Moreover, we assessed patterns of functional connectivity between sources of conflict resolution and their putative targets, in order to probe whether the modulatory mechanisms involved in non-emotional versus emotional conflict resolution could also be dissociated.

We devised an experimental protocol that varied the source of conflict, between nonemotional and emotional stimulus representations, while keeping task-relevant stimulus characteristics constant. Subjects performed 2 versions of a face-categorization task (Fig. 1A) while undergoing functional magnetic resonance imaging (fMRI). The task-relevant stimuli in both versions of the task consisted of images of male and female faces with either fearful or happy expressions (Ekman and Friesen 1976). In one version, subjects identified the gender of the face stimuli while trying to ignore congruent or incongruent gender labels displayed across the faces (“nonemotional task,” Fig. 1A top panels). In the second version, subjects identified the affect displayed on the faces while trying to ignore emotionally congruent or

incongruent affect labels written across the faces (Etkin et al. 2006) (“emotional task,” Fig. 1A, bottom panels). Thus, identical faces served as task-relevant stimuli in both conditions, but task-relevant processing could be selectively interfered with by either nonemotional or emotional task-irrelevant distracters. Behavioral and neural effects of conflict resolution were assessed by contrasting incongruent trials that were preceded by an incongruent trial (“high conflict resolution” trials) with incongruent trials that were preceded by a congruent trial (“low conflict resolution” trials) (Botvinick et al. 1999; Kerns et al. 2004; Egner and Hirsch 2005b; Etkin et al. 2006). This design allowed us to evaluate whether different brain regions are involved in resolving nonemotional versus emotional conflict, by testing for regions that display task-specific effects of conflict resolution.

Materials and Methods

Subjects

Twenty-two (14 females) right-handed healthy volunteers (mean age = 26.6 years, standard deviation [SD] = 5.4) gave written informed consent to participate in this study, in accordance with Columbia University’s institutional guidelines. All participants had normal or corrected-to-normal vision and were screened by self-report in order to exclude any subjects reporting previous or current neurological or psychiatric conditions, and current psychotropic medication use. Note that this sample does not overlap with that used in our earlier study (Etkin et al. 2006).

Experimental Paradigms and Procedure

Stimuli were presented with Presentation software (Neurobehavioral Systems, <http://nbs.neuro-bs.com>), and displayed on a back-projection screen that was viewed by the subjects via a mirror attached to the head-coil. Each trial consisted of a photographic stimulus on a black background, depicting either a happy or a fearful male or female face (Ekman and Friesen 1976). The stimulus set consisted of 5 male and 5 female faces. The nonemotional and emotional tasks each consisted of one run of 148 trials, with the order of runs counterbalanced across participants. Stimuli were presented for 1000 ms, with a varying interstimulus interval (ISI) of 3000–5000 ms (mean ISI = 4000 ms), during which a white central fixation cross was displayed on a black background. Stimuli were presented in pseudorandom order (counterbalanced for equal numbers of congruent-congruent, congruent-incongruent, incongruent-congruent, and incongruent-incongruent stimulus sequences). Gender and facial expression were counterbalanced across responses and trial types in both tasks. Alternative sources of trial sequence effects, other than conflict, notably repetition priming (Mayr et al. 2003) and “partial repetition” effects (Hommel et al. 2004), were controlled for in the current study, as target stimuli always alternated across trials, and the proportion of response repetitions to response alternations was the same (50%) for all trial sequence types. There were no direct repetitions of the same face with varying word distracters, thus avoiding negative priming effects. Furthermore, we have previously shown that these tasks do not incur “category-priming” effects stemming from repetitions of a given face category (for example, fearful) and word category (for example, “HAPPY”) (Egner and Hirsch 2005b; Etkin et al. 2006).

In the nonemotional task, faces were presented with either the word “MALE” or “FEMALE” superimposed in red letters (Fig. 1A, top panel), producing gender-congruent and -incongruent stimuli. Subjects were required to categorize the faces as being of either male or female gender while trying to ignore the task-irrelevant word stimuli. In the emotional version of the task, the same face stimuli were paired with the superimposed words “HAPPY” or “FEAR” to create emotionally congruent and incongruent stimuli (Fig. 1A, bottom panels), and subjects were required to categorize the facial expressions as happy or fearful while trying to ignore the task-irrelevant word stimuli. Responses consisted of manual button presses (right index finger for fearful/male, right middle finger for happy/female), and subjects were

instructed to respond as fast as possible while maintaining high accuracy. Behavioral data analyzed consisted of reaction times (RTs) (excluding error and posterror trials, and trimmed to exclude outlier values of more than 2 standard deviations from the mean). Accuracy in these tasks was very high (mean = 97.2%, SD = 2.2) and did not constitute a dependent variable of interest.

Subsequent to the main task, we acquired functional data during a standard fusiform face area (FFA) localizer task (Summerfield et al. 2006). Subjects viewed photographic face and house stimuli in 12 alternating blocks of 15 s, separated by 10 s resting (fixation) periods. Within each block, 15 faces/houses were presented for 750 ms with an ISI of 250 ms. Subjects were required to push a response button with their right index finger whenever they saw 2 identical stimuli presented in a row (1-back task). There were one to 2 such repetitions within each face and house block.

Image Acquisition

Images were recorded with a GE 1.5-T scanner. Functional images were acquired parallel to the anterior-posterior commissure line with a T_2^* -weighted echoplanar imaging sequence of 24 contiguous axial slices (time repetition [TR] = 2000 ms, time echo [TE] = 40 ms, flip angle = 60°, field of view [FoV] = 190 × 190 mm, array size 64 × 64) of 4.5 mm thickness and 3 × 3 mm in-plane resolution. Structural images were acquired with a T_1 -weighted SPGR sequence (TR = 19 ms, TE = 5 ms, flip angle = 20°, FoV = 220 × 220 mm), recording 124 slices at a slice thickness of 1.5 mm and in-plane resolution of 0.86 × 0.86 mm.

Image Preprocessing

All preprocessing and statistical analyses were carried out using Statistical Parametric Mapping 2 (<http://www.fil.ion.ucl.ac.uk/spm/spm2.html>). Functional data were slice-time corrected and spatially realigned to the first volume of the first run. The structural scan was coregistered to the functional images, and served to calculate transformation parameters for spatially warping functional images to the Montreal Neurological Institute (MNI) template brain (resampled voxel size: 2 mm³). Finally, normalized functional images were spatially smoothed with a 10-mm³ kernel. The first 5 volumes of each run were discarded prior to building and estimating the statistical models. In order to remove low-frequency confounds, data were high-pass filtered (128 s). Temporal autocorrelations were estimated using restricted maximum likelihood estimates of variance components using a first-order autoregressive model (AR-1), and the resulting nonsphericity was used to form maximum likelihood estimates of the activations.

Image Analyses

For each run, regressors for stimulus events (convolved with a canonical hemodynamic response function [HRF]) were created for congruent-congruent, congruent-incongruent, incongruent-congruent and incongruent-incongruent trial types, with error and posterror trials modeled separately. We further included a regressor-of-no-interest reflecting the mean whole-brain activity on an acquisition-by-acquisition basis. This model was applied to each subject’s data, followed by linear contrasts between events of interest, namely, contrasting low conflict resolution (congruent-incongruent) and high conflict resolution (incongruent-incongruent) trials in each task. The contrast (high conflict resolution > low conflict resolution) identifies regions associated with conflict resolution, whereas the reverse contrast (low conflict resolution > high conflict resolution) identifies regions implicated either in the generation or monitoring of conflict. Contrasts were then analyzed in random-effects analyses across subjects within anatomical regions of interest (ROIs). Given our focus on the roles of the rostral and ACC and the LPFC, and their potential influences on amygdala and FFA activity, the a priori search space consisted of a mask of lateral and medial prefrontal cortex, the anterior cingulate cortex, and the amygdala, all defined anatomically via the anatomical automatic labeling brain atlas (Tzourio-Mazoyer et al. 2002) and applied with the Wake Forest University Pickatlas toolbox (Maldjian et al. 2003), as well as the FFA, which was defined functionally via the FFA localizer task. Significance testing within these a priori ROIs was carried out at a combined voxel/cluster threshold

of voxel-wise $P < 0.005$ with a cluster extent of 20 voxels in the frontal and cingulate regions, and of 10 voxels in the smaller amygdala and FFA ROIs. To determine region and task specificity, mean activation estimates (beta parameters) were subsequently extracted from activated clusters, using Marsbar software (<http://marsbar.sourceforge.net/>), and submitted to 2 (region: LPFC vs. rACC) \times 2 (task: emotional vs. nonemotional) \times 2 (conflict resolution trial type: high vs. low) analyses of variance. Finally, the ROI analyses were complemented by exploratory, whole-brain analyses, where a false discovery rate (FDR) correction of $P < 0.05$ (Genovese et al. 2002) was applied, unless noted otherwise.

Face-sensitive visual regions were identified by convolving regressors coding for face and house blocks from the FFA localizer task with the canonical HRF, and contrasting activity elicited by face blocks with that elicited by house blocks. Individual statistical maps of this contrast were entered into a random-effects group analysis, and, akin to the main task, the results were thresholded at a combined threshold of voxel-wise $P < 0.005$, with a cluster extent of >20 voxels. This analysis produced bilateral activated clusters in the fusiform gyrus. These clusters of activation were subsequently converted into an ROI search space.

Functional Connectivity Analyses

In order to assess functional connectivity between putative sources of top-down modulation (identified in the main task analyses above) and a priori targets of such modulation (the FFA and the amygdalae), we carried out psychophysiological interaction (PPI) analysis (Friston et al. 1997). PPI analyses assess the correlation of activity time courses between brain regions (the “physiological” variable), depending on experimental condition (the “psychological” variable), answering the question of whether the functional coupling between regions A and B differs between experimental conditions X and Y. Note that PPI results are therefore immune to spurious correlations between regions that can arise from global signal fluctuations, as the latter would affect all experimental conditions equally. We extracted in each subject the deconvolved activity time course (Gitelman et al. 2003) of the rACC and right LPFC regions identified in the main task analyses, based on a 5-mm-radius sphere around the peak-activated voxels from the emotional/nonemotional conflict resolution group analysis. We then calculated for each of these 2 ROIs in each of the 2 tasks the product of the deconvolved activation time course and the vector of the psychological variable of interest (incongruent-incongruent $>$ congruent-incongruent trials) to create the PPI term. For each ROI and task, new models were constructed for each subject including as regressors the PPI term, the physiological variable (the activation time course), and the psychological variable. We then tested whether activity in the amygdalae was predicted by the psychophysiological interaction terms of the rACC and LPFC ROIs, with the rACC/LPFC activity and the psychological regressors treated as variables of no interest. These analyses were carried out separately for both the emotional and nonemotional tasks. Analogous analyses were carried out on activity in face-sensitive visual cortex, as defined by the FFA localizer. Individual PPI results were then entered into random-effects group analyses, contrasting connectivity patterns between the emotional and nonemotional task, between rACC/LPFC and amygdalae/FFA. Considering the small search space of the amygdalae and FFA ROIs, and our strong a priori prediction concerning functional coupling (Egner and Hirsch 2005b; Etkin et al. 2006), this interaction was assessed at a combined statistical threshold of voxel-wise $P < 0.01$ with a cluster size of >10 voxels. Finally, we also carried out exploratory whole-brain searches for voxels that significantly covaried with activation in our source ROIs (LPFC and rACC) during conflict resolution, assessed at an FDR threshold of $P < 0.05$, unless otherwise noted.

Results

Behavioral Data

A 3-way task \times previous trial \times current trial congruency analysis of variance (ANOVA) on RT data (see Table 1 for descriptive statistics) revealed a main effect of congruency ($F_{1,21} = 20.5$,

Table 1
Descriptive statistics of behavioral data

Trial	Emotional task		Nonemotional task	
	RT (ms)	SD	RT (ms)	SD
CC	780	134	679	118
CI	868	168	746	191
IC	821	175	682	118
II	852	173	721	158

Note: Data are split up by previous and current trial congruency. CC = previous trial congruent-current trial congruent, CI = previous trial congruent-current trial incongruent, IC = previous trial incongruent-current trial congruent, II = previous trial incongruent-current trial incongruent.

$P < 0.001$), as incongruent trials were responded to slower than congruent trials. This conflict effect was found in both the nonemotional and emotional versions of the task (nonemotional task: $F_{1,21} = 9.5$, $P < 0.01$, Fig. 1B; emotional task: $F_{1,21} = 31.4$, $P < 0.001$, Fig. 1C), and the size of the conflict effect did not differ between tasks ($F_{1,21} = 0.3$, $P > 0.6$). The main effect of congruency was qualified by a significant previous trial \times current trial congruency interaction effect ($F_{1,21} = 22.1$, $P < 0.001$), as the congruency effect was smaller subsequent to incongruent trials than congruent trials. This interaction effect was evident for both the nonemotional task ($F_{1,21} = 6.9$, $P < 0.05$) as well as the emotional task ($F_{1,21} = 21.2$, $P < 0.001$). In both tasks, incongruent trials preceded by an incongruent trial (“high conflict resolution” trials) were processed faster than incongruent trials preceded by a congruent trial (“low conflict resolution” trials) (nonemotional task: $t_{21} = 2.4$, $P < 0.05$, Fig. 1B; emotional task: $t_{21} = 2.9$, $P < 0.05$, Fig. 1C). The overall rate of reduction in the congruency effect following incongruent compared with congruent trials was slightly more pronounced in the emotional compared with the nonemotional task ($F_{1,21} = 4.8$, $P < 0.05$). The difference in RT between low conflict resolution and high conflict resolution trials, however, which served as our behavioral metric of conflict adaptation, did not differ between the 2 tasks ($t_{21} = -0.7$, $P > 0.40$). Thus, we observed comparable behavioral conflict and conflict resolution effects across both nonemotional and emotional tasks. Finally, the ANOVA also revealed a main effect of task ($F_{1,21} = 68.5$, $P < 0.001$), as the nonemotional task was associated with faster responses than the emotional task. Because this effect suggests that the emotional task may have overall been more difficult than the nonemotional task, all imaging analyses reported below were carried out as analyses of covariance, where subjects’ between-task mean RT differences were employed as a covariate, thus ensuring that effects of task difficulty would not confound the interpretation of the fMRI data.

Neuroimaging Data

Next, we probed whether the superficially identical behavioral effects of conflict resolution across the 2 tasks (Fig. 1B,C) were nevertheless mediated by separable neural mechanisms. Regions that may underpin conflict resolution in each task were identified as areas that showed higher activity during high conflict resolution trials than during low conflict resolution trials, and regions that may mediate conflict generation/detection were identified by the converse contrast (Botvinick et al. 1999; Kerns et al. 2004; Egner and Hirsch 2005b; Etkin et al. 2006). Activity in regions identified in this manner was then interrogated for task specificity, by testing for task \times conflict resolution interaction effects. We first pursued these

analyses within a priori search spaces comprised of the lateral and medial frontal cortex, the anterior cingulate, and the amygdalae (all anatomically defined, cf. Etkin et al. 2006), as well as the FFA (functionally defined, see Materials and Methods). Within these ROIs, results were thresholded at (uncorrected) $P < 0.005$, with a cluster extent of 20 voxels in the frontal and cingulate regions, and of 10 voxels in the smaller amygdalae and FFA ROIs. These analyses were complemented by exploratory, whole-brain analyses, where an FDR correction of $P < 0.05$ (Genovese et al. 2002) was applied, unless noted otherwise.

Neural Substrates of Conflict Resolution

Within the a priori ROIs, conflict resolution in the non-emotional task was associated with activation in the right dorsal LPFC (superior frontal gyrus) (Fig. 2A), whereas conflict resolution in the emotional task was associated with activation of the rACC (Fig. 2B). Crucially, the right LPFC displayed a task \times conflict resolution interaction, as it was involved in conflict resolution in the nonemotional, but not in the emotional task ($F_{1,21} = 4.2$, $P = 0.05$; Fig. 2A). By contrast, activity in the rACC showed the opposite interaction, as the rACC was involved in resolving conflict in the emotional, but not in the nonemotional task ($F_{1,21} = 6.1$, $P < 0.05$; Fig. 2B). We confirmed this functional dissociation between LPFC and rACC in a region \times task \times conflict resolution interaction analysis (3-way interaction: $F_{1,21} = 8.2$, $P < 0.01$). These results support the notion that there are dissociable, domain-specific neural mechanisms for the resolution of interference from nonemotional versus emotional conflicting distracter stimuli. In order to test whether there were nevertheless additional regions that were involved in both types of conflict resolution, we conducted a conjunction analysis. We found no regions that displayed common conflict resolution effects across both tasks, even when lowering the statistical threshold to a very liberal $P < 0.05$ (uncorrected). This finding further discounts the possibility that nonemotional and emotional conflict is resolved by a single, domain-general source of control. We found no effects of conflict resolution in the FFA or amygdala ROIs.

An exploratory whole-brain analysis revealed no voxels displaying significant conflict resolution effects at an FDR correction of $P < 0.05$. In order to detect potentially interesting activation foci for future exploration we conducted the same analyses at an uncorrected $P < 0.001$ threshold (with a cluster extent of > 20 voxels). These analyses indicated that emotional conflict resolution, in addition to recruiting the rACC, as described above, also activated a cluster of voxels ($N = 28$) in the right superior temporal gyrus (MNI $x 54$, $y -32$, $z 10$) and in the cuneus ($N = 21$, MNI $x 8$, $y -74$, $z 16$). Conflict resolution processes during the nonemotional task, on the other hand, were found to activate the bilateral inferior parietal lobule (left: $N = 28$, MNI $x 42$, $y -52$, $z 60$; right: $N = 34$, MNI $x -54$, $y -46$, $z 48$), as well as the right supramarginal gyrus ($N = 21$, MNI $x 60$, $y -52$, $z 38$). None of the regions identified in these exploratory whole-brain analyses displayed main effects or significant task \times conflict resolution interaction effects (all P s > 0.2). In other words, unlike the rACC and LPFC, none of these regions were exclusively associated with the resolution of nonemotional or emotional conflict.

Neural Substrates of Conflict Generation/Monitoring

Within the a priori ROIs, we found activity related to conflict in both tasks to be associated with activation in overlapping

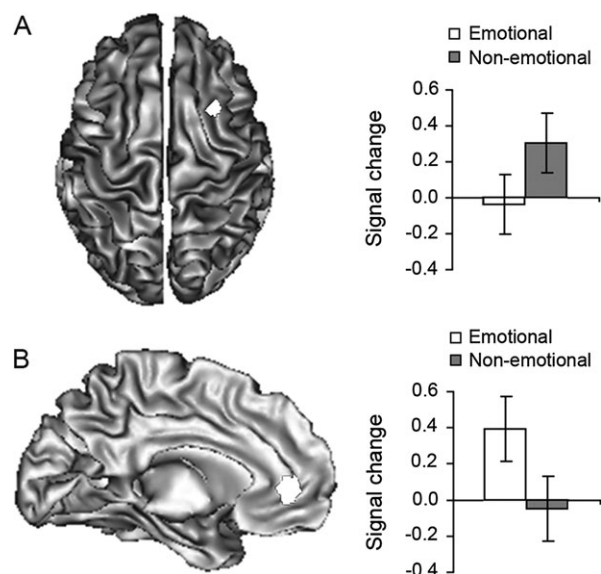


Figure 2. Effects of conflict resolution. (A) Left panel: an activation overlay for activity associated with conflict resolution (high conflict resolution [H] trials minus low conflict resolution [L] trials) during the nonemotional task in the right LPFC (MNI $x 38$, $y 16$, $z 54$; 39 voxels) is displayed on the dorsal cerebral surface (left is left), at $P < 0.005$ with a cluster size > 20 voxels. Right panel: mean cluster signal changes (beta \pm SEM) associated with conflict resolution (high conflict resolution minus low conflict resolution trials) are plotted as a function of task. The right LPFC was exclusively activated during conflict resolution in the nonemotional task. (B) Left panel: an activation overlay for activity associated with conflict resolution (high conflict resolution [H] trials minus low conflict resolution [L] trials) during the emotional task in the rACC (MNI $x -12$, $y 44$, $z -2$; 81 voxels) is displayed on the medial surface of the left hemisphere, at $P < 0.005$ with a cluster size > 20 voxels. Right panel: mean cluster signal changes (beta \pm SEM) associated with conflict resolution (high conflict resolution minus low conflict resolution trials) are plotted as a function of task. The rACC was exclusively activated during conflict resolution in the emotional task.

regions of the dorsalACC (Fig. 3A). In other words, this region of the dACC displayed a main effect of conflict monitoring ($F_{1,21} = 8.0$, $P = 0.01$) that did not interact with task. These results suggest the possibility that the dACC represents a general conflict-detection mechanism that is common to both nonemotional and emotional conflict. In addition to these findings, we also detected activation related to emotional conflict in the (left) amygdala. At a more liberal threshold ($P < 0.01$), this effect was also observed bilaterally (Fig. 3B). This region exhibited an effect of emotional conflict ($t_{21} = 2.9$, $P < 0.01$), but no effect for nonemotional conflict ($t_{21} = 1.3$, $P < 0.2$) (Fig. 3B). However, the interaction between task and conflict resolution was not significant ($P = 0.16$), that is, the amygdala response to emotional conflict was not significantly greater than that to nonemotional conflict, and therefore could not be said to be exclusive to emotional conflict. We obtained no conflict-related effects in the FFA.

In conducting exploratory whole-brain analyses, we detected no voxels that displayed significant conflict-related effects at a whole-brain FDR correction of $P < 0.05$. In order to detect potentially interesting activation foci for future exploration we also conducted these analyses at an uncorrected $P < 0.001$ threshold (with a cluster extent of > 20 voxels). It was found that, in addition to the conflict effects in the dACC and amygdalae described above, emotional conflict activated a cluster of voxels ($N = 46$) in the lingual gyrus (MNI $x 2$, $y -96$, $z -2$) in early visual cortex. Furthermore, emotional conflict was also associated with activation of a large cluster of voxels

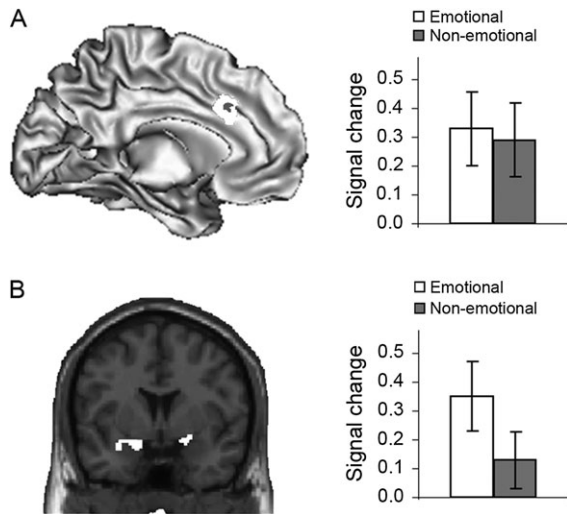


Figure 3. Effects of conflict generation/conflict monitoring. (A) Left panel: activation overlays for nonemotional and emotional conflict-related activity (low conflict resolution [CI] trials minus high conflict resolution [II] trials) are displayed on the medial surface of the left hemisphere, at $P < 0.005$ with a cluster size > 20 voxels. The left dACC was susceptible to conflict in both the emotional task (white cluster, MNI x 12, y 28, z 24; 288 voxels) and the nonemotional task (gray cluster, MNI x -6, y 12, z 40; 25 voxels). Right panel: mean cluster signal changes (beta \pm SEM) associated with conflict processing (low conflict resolution minus high conflict resolution trials) are plotted as a function of task. (B) Left panel: an activation overlay for conflict-related activity during the emotional task in the amygdala (left: MNI x -14, y 4, z -16; 81 voxels; right: MNI x 20, y 0, z -10; 56 voxels) is displayed on a rostral brain slice (left is left), at $P < 0.01$ with a cluster size of > 10 voxels. Right panel: mean cluster signal changes (beta \pm SEM) associated with conflict processing (low conflict resolution minus high conflict resolution trials) are plotted as a function of task.

($N = 246$) in the right superior parietal lobule (MNI x 30, y -64, z 48). Conflict in the nonemotional task, on the other hand, was associated with activation in the precuneus ($N = 91$, MNI x -10, y -88, z 38) as well as in the lingual gyrus ($N = 87$, MNI x 22, y -78, z -16), at a more anterior and more lateralized location than that activated by emotional conflict. None of the regions identified in these exploratory whole-brain analyses displayed main effects or significant task \times conflict resolution interaction effects (all P s > 0.3). In other words, none of these regions were commonly associated with both types of conflict, or exclusively associated with emotional or nonemotional conflict.

In summary, the current results suggest that the right LPFC and the rACC have fully dissociable roles in resolving nonemotional versus emotional conflict, respectively, whereas the dACC seems to be involved in monitoring either type of conflict.

Connectivity Analyses

Previous work suggests that the LPFC resolves nonemotional conflict by amplifying task-relevant stimulus representations in sensory cortices (Egner and Hirsch 2005b), whereas the rACC resolves emotional conflict by inhibiting amygdalar responses to incongruent emotional distracters (Etkin et al. 2006). In order to probe whether the proposed modulatory mechanisms by which the LPFC and rACC resolve conflict could also be dissociated, we conducted a set of psychophysiological interaction (PPI) functional connectivity analyses (Friston et al. 1997). The PPI analyses assessed trial-by-trial covariation in activity between control-related regions in our task (LPFC, rACC) and putative a priori target regions, namely

the amygdalae (defined via an anatomical mask) and the FFA (Kanwisher et al. 1997) (defined functionally via an independent FFA localizer task), during conflict resolution (high conflict resolution trials $>$ low conflict resolution trials). Considering the small search space of the amygdala and FFA ROIs, and our strong a priori prediction concerning functional coupling (Egner and Hirsch 2005b; Etkin et al. 2006), these analyses were carried out at a threshold of uncorrected $P < 0.01$, and a cluster size of > 10 voxels.

We found that LPFC activity during conflict resolution was associated with a simultaneous increase in activity in the FFA in the nonemotional relative to the emotional task ($F_{1,21} = 10.1$, $P < 0.005$), whereas rACC activity did not covary in a task-specific manner with FFA activity ($F_{1,21} = 2.1$, $P > 0.15$) (3-way interaction: $F_{1,21} = 8.1$, $P = 0.01$) (Fig. 4A). It is noteworthy that this effect was driven in part by the predicted positive coupling between LPFC and FFA activity during conflict resolution in the nonemotional task ($t_{21} = 2.3$, $P < 0.05$), but also in part by an unpredicted negative coupling between LPFC and FFA activity during conflict resolution in the emotional task ($t_{21} = 2.4$, $P < 0.05$). In contrast with the connectivity findings involving the FFA, we found that increased rACC activity during conflict resolution was associated with a simultaneous decrease in amygdalar activity in the emotional relative to the nonemotional task ($F_{1,21} = 7.6$, $P < 0.05$), whereas activity in the LPFC displayed no task-specific association with amygdalar activity ($F_{1,21} = 0.1$, $P > 0.7$) (3-way interaction: $F_{1,21} = 6.5$, $P < 0.05$) (Fig. 4B). Interestingly, the areas of the amygdala that exhibited a negative coupling with the rACC (Fig. 4B) appeared to be situated more laterally than the amygdala regions that displayed activity related to emotional conflict (Fig. 3B). A conjunction analysis between these 2 results confirmed this lack of overlap. In summary, the results of our hypothesis-driven PPI analyses show that the functional associations between source and target areas of conflict resolution are task and region specific, with the LPFC predicting increased activity in the FFA during nonemotional conflict resolution, and the rACC predicting reduced activation of the amygdalae during emotional conflict resolution. These findings further support the existence of dissociable neural circuits mediating nonemotional versus emotional conflict resolution.

In addition to these a priori analyses, we also conducted exploratory whole-brain searches for clusters that significantly covaried with activation in our source ROIs (LPFC and rACC) during conflict resolution. There was no significant covariation observed with LPFC or rACC activity at a corrected FDR $P < 0.05$ threshold. In order to identify potentially interesting activation foci for future exploration we conducted the same analyses at an uncorrected $P < 0.001$ threshold (with a cluster extent of > 20 voxels). We found that during nonemotional conflict resolution, activation in the left middle frontal gyrus ($N = 30$, MNI x -26, y 4, z 68) and the right postcentral gyrus/inferior parietal lobule ($N = 54$, MNI x 42, y -32, z 50) covaried positively with activity in the LPFC ROI. Furthermore, during resolution of emotional conflict, activity in the rACC ROI covaried positively with activity in the cuneus ($N = 91$, MNI x -12, y -100, z -6), and negatively with activity in the precuneus ($N = 244$, MNI x 10, y -75, z 50) as well as the left middle temporal gyrus ($N = 189$, MNI x 60, y -32, z 4). However, none of the regions reported here displayed significant differences in their connectivity with LPFC and rACC during conflict resolution (all P s > 0.4).

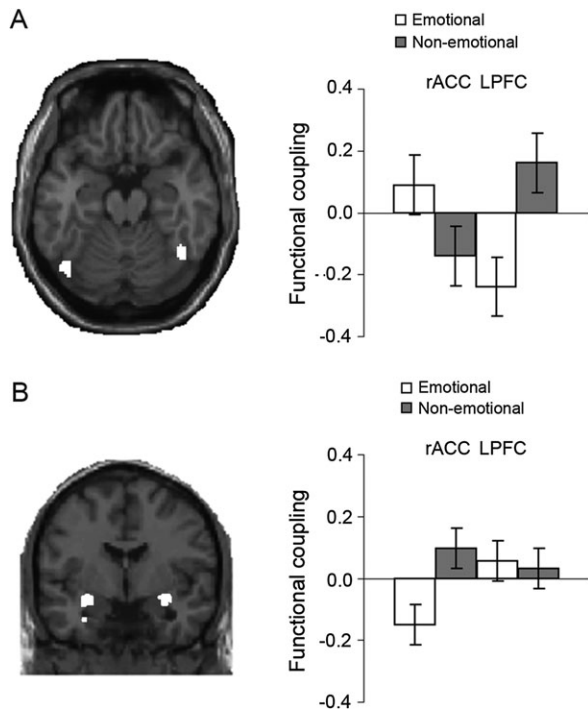


Figure 4. Functional connectivity of conflict resolution. (A) Left panel: an activation overlay of voxels in the FFA (left: MNI $x = -46, y = -70, z = -20$; 64 voxels; right: MNI $x = 46, y = -52, z = -24$; 42 voxels) that covary positively with LPFC activity during the resolution of nonemotional conflict is displayed on an axial brain slice (left is left), at $P < 0.01$ with a cluster size > 10 voxels. Right panel: mean cluster functional coupling (beta \pm SEM) during conflict resolution is plotted as a function of task (emotional vs. nonemotional) and source region (rACC vs. LPFC). (B) Left panel: an activation overlay of voxels in the amygdala (left: MNI $x = -30, y = -6, z = -14$; 78 voxels; right: MNI $x = 32, y = 0, z = -12$; 71 voxels) that covary negatively with rACC activity during the resolution of emotional conflict is displayed on a rostral brain slice (left is left), at $P < 0.01$ with a cluster size > 10 voxels. Right panel: mean cluster functional coupling (beta \pm SEM) during conflict resolution is plotted as a function of task (emotional vs. nonemotional) and source region (rACC vs. LPFC).

Discussion

We examined the hypothesis that there are 2 dissociable neural mechanisms for overcoming conflict from task-irrelevant distracter stimuli, depending on whether distracters are non-emotional or emotional in nature. By varying the source of conflict, between nonemotional and emotional, and assessing behavioral and neural effects of conflict monitoring and conflict resolution by means of a conflict adaptation paradigm, we obtained 4 main findings. First, both the nonemotional and emotional tasks were associated with significant and comparable behavioral conflict and conflict resolution effects. Second, the brain regions associated with top-down resolution of conflict in the 2 task contexts were fully dissociable, in that the LPFC was implicated exclusively in the resolution of non-emotional conflict, whereas the rACC was implicated exclusively in the resolution of emotional conflict. Third, results from functional connectivity analyses suggest that the modulatory targets and mechanisms by which LPFC and rACC resolve conflict are also dissociable: during resolution of non-emotional conflict, activity in LPFC (but not the rACC) was associated with enhanced activation of face-sensitive visual cortex, whereas during resolution of emotional conflict, activity in the rACC (but not the LPFC) was associated with decreased activation of the amygdalae. Fourth, the monitoring

of conflict across both tasks was associated with activity in an overlapping region of the dACC.

The behavioral results obtained in this study replicate congruency sequence effects found in previous studies that used identical or highly similar stimuli and paradigms (Egner and Hirsch 2005b; Etkin et al. 2006), and in standard Stroop and flanker tasks (Gratton et al. 1992; Botvinick et al. 1999; Kerns et al. 2004; Egner and Hirsch 2005a). We interpret the sequence effects in the current tasks as reflecting the workings of 2 distinct conflict-driven regulatory control loops, because our design has explicitly controlled for other, nonconflict variables that can produce identical data patterns (Mayr et al. 2003; Hommel et al. 2004) (see Materials and Methods). The comparable behavioral conflict and conflict resolution effects between the 2 tasks suggest that nonemotional and emotional conflict resolution mechanisms were engaged to a similar degree, even though the emotional task was associated overall with slower responses, thus facilitating the direct comparison of their neural substrates in the fMRI analysis.

The main goal of this study was to probe whether there are 2 dissociable neural circuits for resolving conflict from non-emotional versus emotional distracters. Our fMRI results clearly support this proposal. The resolution of nonemotional conflict was exclusively associated with activity in right dorsolateral prefrontal cortex, which covaried with increased activation in the FFA, directly replicating previous results with a similar nonemotional face-word conflict paradigm (Egner and Hirsch 2005b). Note, however, that the precise location of LPFC activity related to nonemotional conflict resolution in the current study (MNI $x = 38, y = 16, z = 54$) was more dorsal and posterior to that reported in our previous study (MNI $x = 40, y = 38, z = 20$) (Egner and Hirsch 2005b). The current results lend further support to the notion that the LPFC is involved in resolving conflict between competing stimuli by amplifying task-relevant relative to task-irrelevant stimulus representations in sensory cortices (MacDonald et al. 2000; Botvinick et al. 2001; Miller and Cohen 2001; Kerns et al. 2004; Egner and Hirsch 2005b). An unexpected finding was that LPFC activation also covaried negatively with FFA activity during emotional conflict resolution. This result is difficult to interpret, because the LPFC itself was not activated during emotional conflict resolution. It would therefore be hard to argue that the LPFC played a top-down modulatory role in this condition. An alternative possibility is that this negative relationship was a passive consequence of a relatively suppressed LPFC during emotional conflict resolution, coinciding with a relatively activated FFA in this condition.

The resolution of conflict from emotional distracters was exclusively associated with activation in the rACC, and conflict resolution was accompanied by a negative coupling between activity in the rACC (which increased) and activity in the amygdalae (which decreased). These data replicate results from our previous study employing the same emotional conflict paradigm in a different cohort of subjects (Etkin et al. 2006). In fact, the locus of rACC activation reported in the current paper (MNI $x = -12, y = 44, z = -2$) corresponds very closely to the loci of activations observed in our previous study (MNI $x = -10, y = 48, z = 0$ and $x = -10, y = 36, z = 2$) (Etkin et al. 2006). Furthermore, the current results corroborate the proposal that interference from emotional distracters may be overcome by an inhibitory rACC-amygdala interaction, wherein the rACC dampens amygdalar responsiveness to task-irrelevant emotional stimuli (Etkin et al.

2006). Crucially, the current data demonstrate that these effects are fully dissociable from conflict resolution involving nonemotional distracters.

These results offer support for the longstanding view that the rACC is involved in affective processing (Vogt et al. 1992; Devinsky et al. 1995; Drevets and Raichle 1998; Bush et al. 2000). The current results furthermore substantiate previous data indicating that the rACC is involved in processing task-irrelevant emotional stimuli (Bishop et al. 2004), and that its processing may be exclusive to the affective domain (Bush et al. 1998; Whalen et al. 1998; Mohanty et al. 2007). Most importantly, however, the current study provides a more fine-grained characterization of the type of affective processing carried out by the rACC, namely, the inhibition of emotional distracter processing through top-down modulation of amygdalar responsivity. These data suggest a crucial role for an inhibitory rACC-amygdala interaction in emotion regulation.

This emerging view of rACC function receives considerable support from various lines of research. A suppressive influence of the rostral and ventral medial prefrontal cortex on amygdalar processing has been demonstrated in animal studies showing that direct electrical stimulation of this region decreases amygdalar responsiveness (Rosenkranz and Grace 2002; Quirk et al. 2003). Furthermore, clinical studies have suggested that depression and post-traumatic stress disorder (PTSD), both of which involve a failure of emotion regulation, are associated with a hyperactive amygdala (Davidson et al. 2002; Hull 2002; Etkin and Wager, Forthcoming), and with a hypoactive rACC (Hull 2002; Shin et al. 2005; Etkin and Wager, Forthcoming). A recent meta-analysis confirms that rACC hypoactivation may be particularly characteristic of emotional dysregulation in PTSD, compared with several other anxiety disorders (Etkin and Wager, Forthcoming). An interesting issue of great practical relevance is whether direct stimulation of the inhibitory rACC-amygdala loop may have a positive impact on emotion regulation in this clinical group, similar to the benefit reported for deep-brain stimulation of the subgenual cingulate in depression (Mayberg et al. 2005).

Replicating our previous work (Etkin et al. 2006), the amygdala was found to be activated by emotional conflict in the current study. In both studies, amygdala regions susceptible to emotional conflict were situated relatively medial, with peak activity evident in the right amygdala in the previous experiment (MNI x 18, y 2, z -16), and the left amygdala in the current one (MNI x -14, y 4, z -16). Considering the role of the amygdala in the processing of emotional stimuli in general, and the inhibitory relationship between amygdalar activity and the rACC during emotional conflict resolution in particular, we interpret this finding as indicating that the amygdala is directly involved in the generation of emotional conflict. However, amygdalar responses to emotional conflict were not statistically dissociable from those to nonemotional conflict, such that we cannot definitively conclude that amygdala activity is solely driven by emotional conflict in the current study. This is not surprising, because the amygdala is prominently involved in face processing (see e.g., Vuilleumier and Pourtois 2007), which constituted the task-relevant feature in both of versions of the conflict task, and is furthermore responsive to decision uncertainty (Hsu et al. 2005), which was greater in low conflict resolution trials for both the nonemotional and the emotional tasks.

A perhaps counterintuitive finding in the current study was that the more medially located amygdala regions responsive to emotional conflict were not identical to the more laterally located regions that were negatively coupled to the rACC during emotional conflict resolution. Because in our previous study we did observe substantial overlap between active voxels across these analyses (Etkin et al. 2006), it would be premature to draw strong conclusions from this finding. It is of course possible, however, that the rACC influences neurons in one region of the amygdala, which in turn modulates processing in neurons in another part of the amygdala.

An intriguing question arising from these data concerns how the proposed rACC-amygdala emotion regulation circuit relates to a previously described circuit for the “cognitive” control of emotion, which is thought to involve indirect amygdala modulation by the LPFC (Ochsner and Gross 2005). One major methodological difference that may account for the differential involvement of the rACC versus LPFC in top-down amygdalar modulation is that cognitive emotion regulation studies explicitly ask subjects to engage in deliberate cognitive strategies for reappraising (Ochsner et al. 2002) or distracting themselves from upcoming emotional stimuli (Kalisch et al. 2006). By contrast, in the current emotional conflict paradigm, subjects are not encouraged to engage in any such strategy, and the suppression of amygdalar activity arises in a “reactive” fashion, triggered by previous trial conflict. This distinction points to the possibility that amygdala inhibition by the rACC may constitute a relatively reflexive emotion regulation mechanism, as compared with the involvement of the LPFC in “cognitive control” over emotion.

Our imaging results also show that the dorsal anterior cingulate was involved in conflict monitoring during both the nonemotional and emotional tasks, suggesting that it may have a conserved role in conflict monitoring across different types of conflict. The locus of dACC activation during emotional conflict monitoring in the current study (MNI x 12, y 28, z 24) was about 10 mm more lateral, posterior, and inferior to the dorsomedial PFC activation (MNI x -2, y 38, z 38) that we reported for this condition previously (Etkin et al. 2006). The common dACC activations among nonemotional and emotional conflict conditions could reflect the detection of conflict between competing response tendencies (Botvinick et al. 2001), which occur in both tasks. Alternatively, it may relate to the detection of semantic stimulus conflict (van Veen and Carter 2005), regardless of whether this conflict is of a non-emotional or emotional nature. A major question arising from these data is whether the dACC is causally involved in the conflict-resolution loop for both nonemotional and emotional conflict, by flexibly recruiting the LPFC or rACC in a conflict-specific manner. For this, the dACC would need to access information about the nature of the conflict, perhaps by virtue of distinct spatial or temporal patterns of afferent signals, so that it may recruit the appropriate conflict resolution mechanism in turn. On the other hand, whether the target of the dACC conflict signal is the LPFC or the rACC may be determined solely by the nature of the task-relevant processing context (i.e., cognitive vs. emotional) rather than by the nature of the conflicting task-irrelevant information. Because in the current experiment we varied both the task-relevant and irrelevant processing domains simultaneously, we cannot rule out this possibility.

In addition to the hypothesis-driven data analyses discussed above, we also conducted a set of exploratory whole-brain

analyses. However, the results we obtained from these analyses are difficult to interpret, because we neither detected regions that showed main effects of conflict monitoring (akin to the dACC results) or conflict resolution, nor regions that showed task-specific effects of conflict monitoring or conflict resolution (akin to the rACC and LPFC). In other words, none of the regions reported in the exploratory analyses displayed a common or dissociable function between nonemotional and emotional task conditions, which precludes us from engaging in any meaningful interpretation of the potential function of these regions in our task.

We note also that the emotional conflict paradigm was designed to be a direct extrapolation of the conflict tasks used in the selective attention literature (Etkin et al. 2006). An advantage of conflict tasks is that they induce strong interference effects in reference to a well-defined and perceptually comparable control condition (i.e., congruent or neutral stimuli). Conflict tasks thus provide a reliable behavioral metric of the efficiency of attentional selection that is regarded as the gold standard in attention research (MacLeod 1991). Development of an equivalent paradigm for gauging emotional distracter processing in healthy subjects is particularly important because the traditional “emotional Stroop” task does not induce a direct incompatibility between distracter and target processing (Algom et al. 2004), and rarely produces reliable effects in healthy volunteers (Williams et al. 1996). It should be noted, however, that conflict tasks represent experimentally reduced examples of attentional selection in the face of distraction, and are thus somewhat removed from the type of distraction typically encountered in everyday life. For instance, it is thought that it is the intrusion of emotional processing into unrelated “cognitive” processing that characterizes patients suffering from anxiety-related disorders (Mathews and MacLeod 1985; Williams et al. 1996). By contrast, our emotional conflict task assesses the interference of emotional distracters with target processing which in itself is of an emotional nature (e.g., categorizing affective facial expressions). In other words, our paradigm assesses conflict and conflict resolution effects within the emotional system, rather than the interference of task-irrelevant emotional processing with ongoing nonemotional task-relevant processing. It will be important for future studies to assess trial-to-trial adaptation effects in tasks in which emotional stimuli induce significant interference with unrelated task-relevant processing, to see whether this type of emotional distraction is regulated in the same way as the emotional conflict in our current task. However, given that studies which employed pure distraction paradigms (i.e., the emotional Stroop task) have found activation in the rACC during the processing of task-irrelevant emotional stimuli (Bush et al. 1998; Whalen et al. 1998; Bishop et al. 2004; Mohanty et al. 2007), it appears likely that the same mechanisms are in play for other emotional distraction contexts.

To summarize, the current study dissociated 2 neural mechanisms that mediate the resolution of conflict from nonemotional versus emotional distracters. In line with previous research, activity in the LPFC was associated with the resolution of nonemotional conflict (MacDonald et al. 2000; Kerns et al. 2004; Egner and Hirsch 2005a, 2005b), and predictive of concurrent activity increases in visual regions that represent task-relevant stimulus information (Egner and Hirsch 2005b), but it was not involved in resolving emotional conflict. By contrast, emotional conflict resolution was uniquely associated with recruitment of

the rACC, whose increased activity was predictive of concurrent reductions in amygdalar activity (Etkin et al. 2006). Of interest, conflict-monitoring processes were associated with activity in the dACC, irrespective of the source of conflict. In conclusion, we show that the neuroanatomical networks recruited to overcome distraction vary systematically with the nature of the distracting stimulus information (see also Egner et al. 2007), even though they may share a common mechanism for detecting distraction. Furthermore, this work further specifies a specialized cortico-limbic mechanism for safe-guarding goal-directed cognition from interference by emotional processing.

Notes

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