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Research Article

Controlling the Integration of Emotion and Cognition

The Role of Frontal Cortex in Distinguishing Helpful From Hurtful Emotional Information

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ABSTRACT—*Emotion has been both lauded and vilified for its role in decision making. How are people able to ensure that helpful emotions guide decision making and irrelevant emotions are kept out of decision making? The orbitofrontal cortex has been identified as a neural area involved in incorporating emotion into decision making. Is this area's function specific to the integration of emotion and cognition, or does it more broadly govern whether emotional information should be integrated into cognition? The present research examined the role of orbitofrontal cortex when it was appropriate to control (i.e., prevent) the influence of emotion in decision making (Experiment 1) and to incorporate the influence of emotion in decision making (Experiment 2). Together, the two studies suggest that activity in lateral orbitofrontal cortex is associated with evaluating the contextual relevance of emotional information for decision making.*

The utility of emotional information for decision making presents something of a puzzle. Functional accounts of emotion (see Keltner & Gross, 1999) and theories such as the somatic marker hypothesis (i.e., Bechara, Damasio, & Damasio, 2000) suggest that emotion is particularly helpful for decision making. However, these theories contradict the notion that people should "think with a clear head" and ignore emotions when making decisions. This latter notion itself has theoretical and empirical support. The affect infusion model (Forgas, 1995), the emotion-as-information perspective (Schwarz, 1990), economic models of decision making (see Loewenstein, 2001), and their supporting empirical evidence suggest that emotions may bias judgments and decision making. For example, although negative moods may promote elaborative processing and lead to overestimations of risk, positive moods may promote automatic processing and, in some cases, lower perceptions of risk (e.g., Isen & Means, 1983; Johnson & Tversky, 1983). Therefore, in cases in which the emotion is incidental (i.e., contextually irrelevant) rather than integral (i.e., contextually relevant) to the decision making (Bodenhausen, 1993), emotion may exert inappropriate influence. For example, a bad day at work may generate a bad mood that colors decisions about an unrelated family event.

What neural systems support the need to flexibly incorporate useful emotion and control (i.e., inhibit) irrelevant emotion? If controlling the influence of emotion on decision making engages a system governing control over the integration of emotion and decision making, then the neural areas involved in controlling the influence of emotion on decision making would be very similar to the areas involved in incorporating emotion into decision making. In other words, a common neural system would govern both attempts to incorporate and attempts to prevent emotional influence on decision making, depending on the relevance of the emotional state for decision making.

Previous research suggests that using emotional information to guide decision making is most consistently associated with activity within the orbitofrontal cortex (Brodmann's Area, or BA, 11; Elliott, Dolan, & Frith, 2000) and is impaired when the orbitofrontal cortex is damaged (BA11/12; Bechara et al., 2000). Furthermore, it has been theorized that the lateral orbitofrontal cortex/inferior frontal gyrus (BA 47) is important for evaluating the implications of negative events for future consequences (Kringelbach & Rolls, 2004) and suppressing previously rewarded responses (Elliott et al., 2000). These studies suggest that

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this area may play a role in both incorporating negative emotional stimuli when they are relevant and inhibiting negative emotional stimuli when they are irrelevant for future decision making.

The present set of experiments examined the neural underpinnings of controlling emotional influence on decision making when emotional information is explicitly irrelevant (Experiment 1) and incorporating emotional information when it is explicitly relevant (Experiment 2). Together, these studies address whether there is common neural activity associated with evaluating the relevance and the irrelevance of emotional information for decision making or whether one of two independent systems is engaged depending on whether emotional information is being inhibited or incorporated in decision making.

EXPERIMENT 1

Experiment 1 examined the neural systems involved in inhibiting the influence of negative emotion on risk taking. Participants played a betting game and were primed with negative or neutral pictures that they were told to ignore. The influence of negative emotional information on decision making was quantified by examining the relation between neural activity and the extent to which participants did not show mood-consistent betting. If participants were successful in controlling the influence of negative emotional information on their betting, then they would bet similar amounts in the negative- and neutral-prime conditions. However, those participants who failed to inhibit the influence of negative emotion on their betting would exhibit mood-consistent betting, as shown in previous research (i.e., less money risked in the negative-prime condition than the neutral-prime condition).

Method

Participants

Fifteen participants (9 female; mean age = 27.1 years, $SD = 4.5$ years) were recruited in compliance with the human-subjects regulations of the University of California, Berkeley, and were compensated \$15/hr for their participation. All participants were screened for medications and psychological or neurological conditions that might influence the measurement of cerebral blood flow.

Behavioral Paradigm

Participants completed four runs of betting and four runs of rating (eight runs total). In the betting runs, participants were instructed to ignore pictures as they flashed on the screen and to respond solely to screens asking them to place a bet. In each trial, participants were presented with a negative or neutral picture prime taken from the International Affective Picture System (IAPS; Lang, Bradley, & Cuthbert, 1995). The picture was presented for 2 s and followed by a fixation point for 2 s. The next screen presented a specific bet from a roulette game, along with the odds and payoff associated with that bet (e.g., "even," 18/38 odds, 1-to-1 payoff). Just as in a real roulette game, the bets ranged from low risk and low payoff (i.e., 18/38 odds, 1-to-1 payoff) to high risk and high payoff (i.e., 1/38 odds, 35-to-1 payoff). The specific bets were counterbalanced across picture conditions and runs. During the 4-s period that the bet was displayed, participants were required to use a button box to select from four possible dollar amounts (1 = \$5, 2 = \$10, 3 = \$15, 4 = \$20). They were instructed that these amounts were hypothetical gambles and that their study compensation did not depend on their gambling behavior. To avoid confounds between feedback and the emotion prime, we did not provide outcome information after each trial. Each block consisted of four trials of the picture-fixation-betting sequence, and a run consisted of six blocks (three with negative primes and three with neutral primes). Blocks were separated by a screen with a fixation point, presented for 20 s.

In the rating runs, participants were instructed to pay attention to pictures as they flashed on the screen and to rate the negative content of the pictures, rather than to place a bet. As in the betting runs, on each trial participants were presented with an IAPS picture (Lang et al., 1995) for 2 s and then a screen with a fixation point for 2 s. The fixation point was followed by a screen that asked participants to judge the content of the picture on a scale from 1, *neutral*, to 4, *negative*. Each block consisted of four trials of the picture-fixation-rating sequence, and a run consisted of six blocks (three with negative pictures and three with neutral pictures). Blocks were separated by a screen with a fixation point, presented for 20 s.

For all runs, stimuli were projected onto a screen mounted on a custom head coil that limited head motion using foam padding. Stimulus presentation and response collection were controlled by the program E-prime running on a Windows 98 computer.

Imaging Data Acquisition

All images were acquired with a 4-T Varian INOVA magnetic resonance scanner and a transmission electron microscopy send-and-receive radio-frequency head coil. Functional images were acquired during the eight runs using a two-shot gradient-echo echo-planar image sequence with a repetition time of 2 s (echo time of 28 ms, and flip angle of 20°). Whole-brain volumes consisted of twenty 3.5-mm axial slices with a 0.5-mm interslice gap. Each slice was acquired at a 20° oblique tilt with a 22.4-cm^2 field of view with a 64×64 matrix size, resulting in an in-plane resolution of 3×3 mm. These parameters were determined to optimize coverage, although a degree of dropout in the ventromedial prefrontal cortex (e.g., parts of BA 11) remained unrecoverable. High-resolution (0.875×0.875 mm) in-plane T1-weighted anatomical images were also acquired using a gradient-echo multislice sequence for anatomical localization. Finally, MP-Flash 3-D T1-weighted scans were acquired so that functional data could be normalized to the Montreal Neurological Institute atlas space.

Imaging Data Analysis

All statistical analyses were conducted using SPM2 (Wellcome Department of Cognitive Neurology, London, England). Functional images acquired from the scanner were reconstructed from *k*-space using a linear time-interpolation algorithm to double the effective sampling rate. Image volumes were corrected for slice-timing skew using temporal sinc-interpolation and corrected for movement using rigid-body transformation parameters. Images were then smoothed with an 8-mm full-width/half-maximum Gaussian kernel. A high-pass filter with a cutoff period of 80 s was applied to remove drifts within sessions.

A fixed-effects analysis was used to model block responses for each participant. Responses in each block type (i.e., each emotion-decision combination: negative-bet, neutral-bet, negative-rating, neutral-rating) were modeled using a boxcar regressor convolved with the canonical hemodynamic response function. A general linear model analysis then was used to create for each participant contrast images summarizing differences between block types, and these images were used to create group average SPM{t} maps that were thresholded at $p < .05$ corrected for multiple comparisons with family-wise error (FWE), with an extent threshold of 10 voxels. This contrast was conducted on those areas previously found to be associated with emotional control (Ochsner & Gross, in press; Phan et al., 2005) and emotional influence on decision making (anterior cingulate, medial and lateral prefrontal cortex, and orbitofrontal cortex, as delineated by the Automated Anatomical Labelling map; Tzourio-Mazoyer et al., 2002).

In order to examine whether significant activity from this contrast varied as a function of successful inhibition of emotional influence on betting, we entered each participant's average response discrepancy between negative-prime and neutral-prime betting as a regressor for the map contrasting these two conditions. Region-of-interest analyses were conducted by examining significant activity within 12-mm spheres around any significant peaks from the first contrast. The 6-mm radius was chosen by taking into account the half-width of the 8-mm smoothing kernel and rounding up to the nearest voxel ($3 \times 3 \times 3$ mm). For the behavioral regressor analysis, we expected that the effect size would be small and therefore difficult to detect in such a small sample; consequently, for the first stage of the second analysis, we used a less conservative threshold of $p < .05$, uncorrected for multiple comparisons, with an extent threshold of 20 voxels. Maxima are reported in ICMB152 (International Consortium for Brain Mapping) coordinates, as in SPM2.

Results

Behavioral Results

Gambling behavior was consistent with mood-congruent decision making (Forgas, 1995; Schwarz, 1990). Participants tended to risk less money on average in the negative condition (values refer to the numbered responses, 1–4; $M = 2.2$, $SD = 0.36$) than the neutral condition ($M = 2.4$, $SD = 0.31$), $t(14) = 3.7$, $p_{rep} = .99$, $\eta^2 = .35$. This suggests that participants on average were unable to completely ignore the negative pictures. However, there were large individual differences in the effects of emotion on betting; the differences between the negative and neutral conditions ranged from 0.02 (almost no difference) to −0.37 (betting a full standard deviation lower in the negative condition). No differences were found for reaction time (negative condition: $M = 2{,}267.7$ ms, $SD = 653$ ms; neutral condition: $M = 2{,}000.8$ ms, $SD = 613$ ms; n.s.).

Imaging Results

Activity related to inhibiting emotional influence on decision making was examined in two ways. First, we contrasted the contrast between the negative-bet condition (A) and the neutral-bet condition (B) with the contrast between the negative-rating condition (C) and the neutral-rating condition (D; i.e., A > B vs. C > D). This contrast was chosen to isolate effects related to the interaction of emotion with decision making by subtracting out decision making (B) and the difference between a negative and neutral emotional reaction (C−D). This contrast revealed activation in left inferior frontal gyrus (i.e., BA 47), with a peak at (−26, 22, −16); FWE, $p < .05$ (see Fig. 1a). No significant activations were found for any other area examined.

Second, for each person, the behavioral difference between betting in the negative versus neutral conditions was entered as a regressor for the first contrast. A 12-mm sphere around the peak of the first contrast was examined for activation (see Imaging Data Analysis). More successful inhibition of emotional influence over betting was associated with increased activity in left inferior frontal gyrus (i.e., BA 47), with a peak at (−34, 26, –14), $p = .01$ (see Fig. 1b). In other words, activity in the left inferior frontal gyrus was particularly increased in those subjects whose betting behavior did not change as a function of the emotional prime (i.e., they were more successful at controlling the influence of emotion on decision making; see Fig. 1c).

EXPERIMENT 2

Experiment 1 found that left inferior frontal gyrus activity was associated with controlling the influence of negative emotional information on decision making. However, Experiment 1 confounded control of emotional influence with contextual relevance. That is, participants were instructed to ignore the emotional information, so it was contextually appropriate for them do so. It has been theorized that BA 47 may be associated with computing the contextual relevance of negative emotional stimuli for future decision making (Kringelbach & Rolls, 2004). If this is the case, then this area might be particularly active not only for controlling emotional influence when it is contextually inappropriate (as in Experiment 1), but also for using emotional

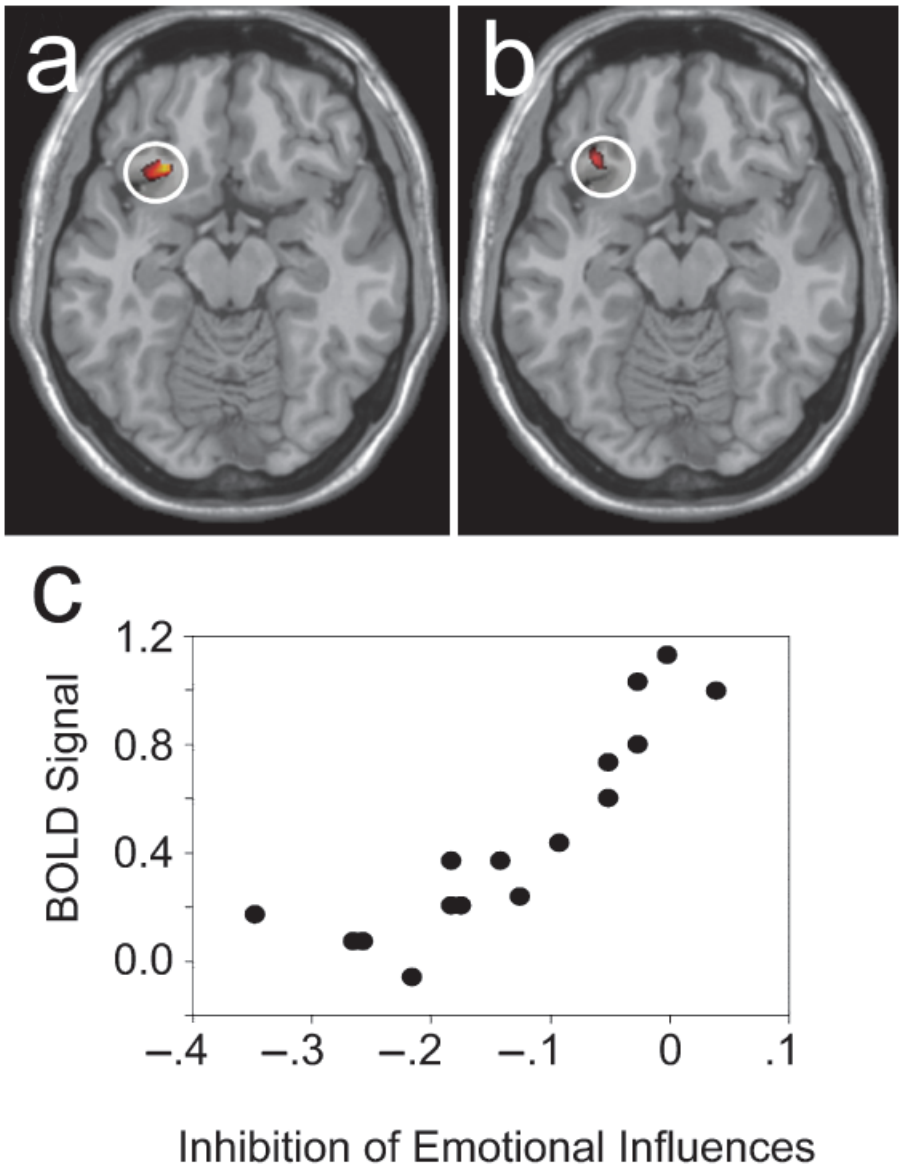


Fig. 1. Results from Experiment 1. The upper panels illustrate the activation in left inferior Brodmann's Area 47 associated with controlling the influence of negative emotional information on betting: results from (a) the main contrast and (b) the behavioral regressor analysis (axial slice at $z = -14$). The graph in (c) presents the data plot of the behavioral regressor analysis. BOLD = blood oxygenation level dependent.

information when it is contextually appropriate. We conducted Experiment 2 to examine whether this area is also associated with incorporating emotional information when it is relevant. Participants completed the same task as Experiment 1, but were instructed to attend to the pictures because they held a clue about the risk of the upcoming bet. Specifically, participants were instructed that negative pictures indicated that the upcoming bet was particularly risky. If the area in inferior prefrontal cortex that was implicated in Experiment 1 is also associated with following contextual rules about integrating emotion into decision making, then this area should show significant activity in relation to significant behavioral differences between negative-primed betting and neutral-primed betting when the emotional cue is relevant for betting.

Method

Participants

Fourteen participants (11 female; mean age = 20.8 years, *SD* = 1.2 years) were recruited in compliance with the human-subjects regulations of the University of California, Berkeley, and were compensated $15/hr for their participation. All partici-

pants were screened for medications and psychological or neurological conditions that might influence the measurement of cerebral blood flow.

Behavioral Paradigm

Participants completed five runs of event-related trials. As in Experiment 1, each picture (negative or neutral prime) was presented for 2 s and followed by a screen with a fixation point. The durations of the fixation-point screens were jittered so that we could analyze activity relating to the subsequent betting independently of the activity related to the picture prime (Donaldson, Petersen, Ollinger, & Buckner, 2001). The durations varied from 4 to 8 s, with an average of 6 s. As in Experiment 1, the fixation point was followed by a betting screen that was displayed for 4 s. Participants used a four-button response box to select from the same dollar amounts as in Experiment 1. They were instructed that these amounts were hypothetical gambles and that their study compensation did not depend on their gambling behavior. To avoid confounds between feedback and the emotion prime, we did not provide outcome information after each trial. After each bet was made, a screen with a fixation point appeared. The durations of these screens were jittered in the same way as the durations of the screens that preceded the betting screens. Each run consisted of 16 trials: 8 neutral-prime trials and 8 negative-prime trials. The risk of the bets was counterbalanced across negative-prime and neutral-prime trials.

All stimuli were projected onto a screen mounted on a custom head coil that limited head motion using foam padding. Stimulus presentation and response collection were controlled by the program E-prime running on a Windows 98 computer.

Imaging Data Acquisition and Data Analysis

Images were acquired in the same manner as described for Experiment 1. All statistical analyses were conducted in the same manner as in Experiment 1 with the exception that a high-pass filter with a cutoff period of 200 s was more appropriate for this data set.

A fixed-effects analysis was used to model event-related responses for each participant. Responses related to neutral-primed betting behavior and negative-primed betting behavior were modeled with a canonical hemodynamic response function. A general linear model analysis then was used to create contrast images summarizing differences between the negative and neutral conditions for each participant. These images were used to create group average SPM{t} maps that were thresholded at $p < .05$ with an extent threshold of 20 voxels. A region-of-interest analysis for the left inferior orbitofrontal cortex (BA 47) was conducted by examining significant activity ($p < .05$, uncorrected for the small sphere) within a 12-mm sphere of the peaks of significant activation from Experiment 1: (−26, 22, −16) and (−34, 26, −14). Maxima are reported in ICMB152 coordinates, as in SPM2.

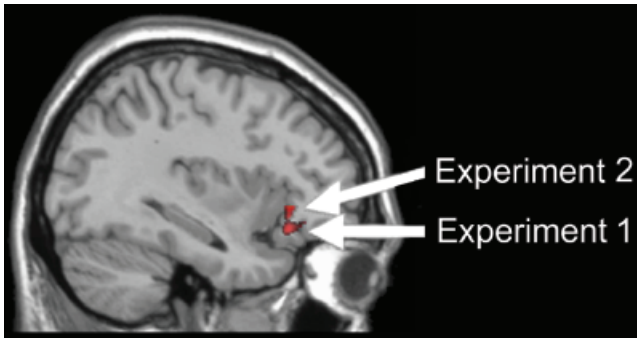


Fig. 2. Activation in left inferior Brodmann's Area 47 (sagittal slice at $x = -34$) associated with inhibiting emotional influence on decision making (Experiment 1) and with incorporating emotional influence into decision making (Experiment 2).

Results

Behavioral Results

Gambling behavior was consistent with mood-congruent decision making (Forgas, 1995; Schwarz, 1990). Participants on average tended to risk less money in the negative condition ($M = 1.8$, $SD = 0.33$) than the neutral condition ($M = 2.6$, $SD = 0.32$), $t(13) = -7.7$, $p_{rep} = .99$, $\eta^2 = .41$. As in Experiment 1, reaction time did not differ significantly between the negative condition ($M = 2{,}296.9$ ms, $SD = 662$ ms) and the neutral condition ($M = 2{,}458.6$ ms, $SD = 628$ ms).

Imaging Results

The contrast between negative-prime betting behavior and neutral-prime betting behavior showed significant activation around the peak from the behavioral regressor analysis, but not the contrast analysis, in Experiment 1. Increased activity in inferior frontal gyrus (i.e., BA 47), with a peak at (−36, 26, −10), $p = .01$, was associated with incorporating emotional information into betting behavior. This result is consistent with the hypothesis that this area is involved in incorporating emotion into cognition when emotion is contextually relevant. Figure 2 shows a sagittal view of the activation from Experiment 1 and the activation from Experiment 2.

DISCUSSION

Together these two studies suggest that the inferior frontal gyrus/lateral orbitofrontal cortex (i.e., BA 47) is important for computing the contextual relevance of emotional information for decision making. In Experiment 1, in which participants were instructed to ignore the emotional primes, activation in this area was associated with inhibiting the influence of emotion on decision making. Furthermore, the activity in this area was negatively correlated with incorporating emotional information into betting decisions. In Experiment 2, in which participants were instructed to use the primes as a clue about the risk of the upcoming bets, activation in this area was associated with

incorporating emotion into decision making. Therefore, the inferior frontal gyrus/lateral orbitofrontal cortex may represent a neural system (or part of a neural system) that allows individuals to flexibly incorporate emotion into cognition when it is relevant and reduce the influence of emotion when it is not relevant.

The present research has implications for understanding the relation between controlling an emotional state and controlling the impact of an emotional state on decision making. Although these two processes may appear psychologically redundant, a comparison of the neural activity in Experiment 1 and in previous studies on emotional control suggests that these processes may not share a completely common neural system. Unlike previous studies of emotional control, Experiment 1 did not find significant activation in the anterior cingulate and portions of the lateral prefrontal cortex (Ochsner & Gross, in press; Phan et al., 2005). This suggests that the systems employed when individuals attempt to prevent or reduce an emotional state may be somewhat different from the systems employed when they attempt to prevent or reduce the impact of an emotional state on decision making. However, one study of emotional control (Ochsner et al., 2004) has found activity in the right inferior frontal gyrus/lateral orbitofrontal cortex (i.e., BA 47). Although the activations in that study and the present study were in different hemispheres, the possibility of neural redundancy between controlling emotion and controlling its impact on decision making warrants further examination. For example, one possible reason that BA 47 activity is not found consistently across studies of emotional control is that control may not actually occur. Many such studies rely on participants' self-reports of emotional states, and self-reports may be subject to experimental demand (Ochsner & Gross, in press). In the paradigm used in the present research, emotional control can be measured behaviorally (i.e., differences in betting across the priming conditions), and there is less experimental demand (i.e., participants told to ignore the pictures, as in Experiment 1, do not know that the content of the pictures affects their betting).

Although behavioral research has come a long way in demonstrating that emotion can influence decision making in both helpful and hurtful ways, understanding of the system governing the integration of emotion with decision making is far from complete. Understanding this system is important not only for current discussions of emotion-cognition synthesis and general control systems, but also for understanding mood disorders characterized by cognitions that are clouded by emotion.

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