IN PRESS: *PSYCHOLOGICAL SCIENCE*

Controlling the Integration of Emotion and Cognition:
The Role of Frontal Cortex in Distinguishing Helpful from Hurtful Emotional Information

Jennifer S. Beer[1]

Robert T. Knight[2]

Mark D'Esposito[2]

[1]Department of Psychology and Center for Mind and Brain

University of California, Davis

[2]Department of Psychology and Helen Wills Neuroscience Institute

University of California, Berkeley

Word Count: 3443

Draft Date: 7/22/05

Address correspondence to:
Jennifer S. Beer, PhD
Center for Mind and Brain
One Shields Avenue
Davis, CA 95616
Phone: 530-297-4472
Fax: 530-792-1489
Email: jsbeer@ucdavis.edu

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 while 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* 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 notion is not without theoretical or empirical support. A host of theory and research suggest that emotions may bias judgments and decision-making such as the Affect Infusion Model (Forgas, 1995), Emotion as Information perspective (Schwarz, 1990) and economic models of decision-making (see Loewenstein, 2001). For example, while negative moods may promote more 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 where 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 over decision-making. 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 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 attempts to incorporate and 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 (BA 11) (Elliott, Dolan & Frith, 2000) and impaired in relation to orbitofrontal damage (BA11/12) (Bechara, Damasio, & Damasio, 2000). Furthermore, the lateral orbitofrontal cortex/inferior frontal gyrus (BA 47) has been theorized to be important for evaluating the implications of negative events for future consequences (Kringelbach & Rolls, 2004) and suppressing previously rewarded responses (Elliott, Dolan & Frith, 2000). These studies suggest that this area may be useful for both incorporating negative emotional stimuli when it is relevant and inhibiting negative emotional stimuli when it is irrelevant for future decision-making.

The present set of experiments examined the neural underpinnings of controlling emotional influence on decision-making when emotional information was explicitly irrelevant (Experiment 1) and incorporating emotional information when it was explicitly relevant (Experiment 2). Together these studies address whether there is common neural activity associated with evaluating the relevance of emotional information for decision-making or whether independent systems are engaged depending on whether emotional information is being inhibited or incorporated into 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 which they were told to ignore. The influence of negative emotion information on decision-making was quantified by examining neural activity in relation to 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 it was expected that they would bet similar amounts across the negative and neutral prime conditions. However, those participants who failed to inhibit the influence of negative emotion on their betting should exhibit mood-consistent betting as shown in previous research (i.e, less money risked in the negative prime condition compared to the neutral prime condition).

METHODS

Participants

15 participants (9 female, M 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/hour for their participation. All participants were screened for medications or psychological and/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 for two seconds (International Affective Picture Set; IAPS, Lang, Bradley, & Cuthbert, 1995). The pictures were followed by a screen with a fixation point for two seconds. The fixation point was followed by a screen with a specific bet from a roulette game. For each betting screen, participants were presented with the odds and pay off associated with that particular bet (e.g., "even", 1 to 1 pay off, 18/38 odds) for 4 seconds. Just as in a real roulette game, bets ranged from low risk and low pay off (i.e., 18/38, 1 to 1) to high risk and high pay off (i.e., 1/38, 35 to 1) and were counterbalanced across picture condition and runs. During this 4 second period, participants were required to select from four possible dollar amounts using a button box (1=$5, 2=$10, 3=$15, 4=$20). Participants were instructed that these were hypothetical gambles and their study compensation did not depend on their gambling behavior. No outcome information was provided after each trial to avoid confounds between feedback and the emotion prime. Within the run, blocks consisted of four trials of the picture-fixation-betting sequences and each of the 6 blocks (3 negative, 3 neutral) were separated from each other by twenty seconds of a screen with a fixation point.

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. The timing was exactly the same as the first set of runs, but this time participants made a decision about the emotional content of the picture rather than making a bet. As before, participants were presented with IAPS pictures (Lang, Bradley, & Cuthbert, 1995) for two seconds and then a screen with a fixation point for two seconds. The fixation point was followed by screens with a rating scale from 1 to 4 and asked participants to judge the context of each picture for neutral (1) to negative (4) content. Within the run, blocks consisted of four trials of the picture-fixation-rating sequences (the same as the betting blocks) and each of the 6 blocks (3 negative, 3 neutral) were separated from each other by twenty seconds of a screen with a fixation point.

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 was controlled by the program E-prime running on a Windows 98 Computer.

MRI Data Acquisition

All images were acquired with a 4-T Varian INOVA MR scanner and a TEM-send and receive RF head coil. Functional images were acquired during eight runs using a two-shot gradient-echo echo-planar image (EPI) sequence with a repetition time (TR) 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 .5-mm interslice gap. Each slice was acquired at a 20 degree oblique tilt with a 22.4 cm^2 field of view with a 64 x 64 matrix size, resulting in an in-plane resolution of 3 x 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 x 0.875 mm) in-plane T1-weighted anatomical images were also acquired using a gradient-echo multislice (GEMS) sequence for anatomical localization. Finally, MP-Flash 3D T1-weighted scans were acquired so that functional data could be normalized to the Montreal Neurological Institute (MNI) atlas space.

MRI Data Analysis

All statistical analyses were conducted using SPM2 (Wellcome Department of Cognitive Neurology). 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 FWHM Gaussian kernel. To remove drifts within sessions, a high-pass filter with a cutoff period of 80 seconds was applied.

A fixed-effects analysis was used to model block responses for each participant. Responses related to the emotion-decision combinations (i.e., negative-bet, neutral-bet, negative-rate, neutral-rate) were modeled using a boxcar regressor convolved with the canonical hemodynamic response function. A general linear model analysis then was used to create contrast images for each participant summarizing differences between block types, and these images were used to create group average SPM{t} maps that were thresholded at $p < 0.05$

corrected for multiple comparisons with FWE, with an extent threshold of 10 voxels in 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 (AAL) map, Tzourio-Mazoyer et al, 2002).

In order to examine whether significant activity from the contrast above varied as a function of successful inhibition of emotional influence on betting, each participants' average response discrepancy between negative-prime and neutral-prime betting was entered as regressor for the map contrasting these negative-prime and neutral-prime 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 of the sphere was chosen taking into account the half width of the 8mm smoothing kernel and rounding up to the nearest voxel (3 x 3 x 3mm). For the behavioral regressor analysis, it was expected that the likely small effect size would make it difficult to detect in such a small sample, therefore a less conservative threshold of $p < .05$, uncorrected for multiple comparisons, with an extent threshold of 20 voxels was used for the first stage of the second analysis. Maxima are reported in ICMB152 coordinates as in SPM2.

RESULTS

Behavioral Results

Consistent with the literature on mood-congruent decision-making (Forgas, 1995; Schwarz, 1990), participants tended to risk less money on average in the negative versus neutral conditions (Negative, M = 2.2, SD = .36; Neutral, M = 2.4, SD = .31; $t(14) = 3.7$, *p*-rep = .99, eta squared = .35) suggesting that participants on average were unable to completely ignore the negative pictures. However, there were large individual differences in emotional effects on betting; the differences between the negative and neutral betting conditions ranged from .02 (almost no difference) to -.37 (betting a full standard deviation lower in the negative condition). No differences were found for reaction time (Negative, M = 2267.7 ms, SD = 653 ms; Neutral, M = 2000.8, SD = 613 ms; ns).

Imaging Results

Activity related to inhibiting emotional influence on decision-making was examined in two ways. First, the contrast between the (A) negative-bet and (B) neutral-bet condition was contrasted with the contrast between the (C) negative-rate and (D) neutral rate condition (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; peak = -26 22 -16; FWE, $p < .05$; see Figure 1A). No significant activations were found for any other hypothesized area.

Second, the behavioral difference between betting in the negative vs neutral condition for each subject was entered as a regressor for the contrast above. Using the peak from the above contrast, activation within a 12-mm sphere was examined (see MRI Data Analysis above). Similar to the first analysis, this analysis showed that better inhibition of emotional influence over betting was associated with increased activity in left inferior frontal gyrus (i.e., BA 47; peak = -34 26 -14, $p = .01$, see Figure 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 Figure 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 for controlling emotional influence when it is contextually inappropriate (as in Experiment 1) but also particularly active for using emotional information when it is contextually appropriate. Experiment 2 addresses the question of 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 is 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-prime betting and neutral-prime betting.

METHODS

Participants

14 participants (11 female, M 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/hour for their participation. All participants were screened for medications or psychological and/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, participants were presented with pictures (negative or neutral primes) for two seconds followed by a screen with a fixation point. The duration of the fixation point screens were jittered so that activity in relation to the picture prime and the subsequent betting screen could be analyzed independently (Donaldson, Petersen, Ollinger, & Buckner, 2001). These fixation screens were jittered with lengths varying from 4 to 8 seconds with an average interval of 6 seconds. As in Experiment 1, a betting screen then appeared for four seconds. Participants selected from the same dollar amounts as in Experiment 1 using a four-button response box. Participants were instructed that these were hypothetical gambles and their study compensation did not depend on their gambling behavior. No outcome information was provided after each trial to avoid confounds between feedback and the emotion prime. After betting, a screen with a fixation point appeared. The duration of these screens were jittered in the same approach used for the screens in between the picture and betting. Each run consisted of 24 trials: 8 neutral-prime trials and 8 negative trials. Betting conditions were counterbalanced for risk 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 was controlled by the program E-prime running on a Windows 98 Computer.

MRI Data Acquisition

Images were acquired in the same manner as described in Experiment 1.

MRI Data Analysis.

All statistical analyses were conducted in the same manner as Experiment 1 with the exception that a high-pass filter with a cutoff period of 200 seconds 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 for each participant summarizing differences between the negative and neutral betting conditions. and these images were used to create group average SPM{t} maps that were thresholded at $p < 0.05$ 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.

RESULTS

Behavioral Results

Consistent with the literature on mood-congruent decision-making (Forgas, 1995; Schwarz, 1990), participants on average tended to risk less money in the negative versus neutral conditions (Negative, M = 1.8, SD = .33; Neutral, M = 2.6, SD = .32; $t\ (13) = -7.7$, *p*-rep = .99, eta squared = .41). As in Experiment 1, no differences were found for reaction time between the negative and neutral conditions (Negative, M = 2296.9 ms, SD = 662; Neutral, M = 2458.6, SD = 628, ns).

Imaging Results

The contrast between negative-prime betting behavior and neutral-prime betting behavior showed significant activation using the peak from the behavioral regressor analyses but not from the contrast analysis in Experiment 1. Consistent with the hypothesis that this area is involved in incorporating emotion into cognition when emotion is contextually relevant, increased activity in inferior frontal gyrus (i.e., BA 47, peak = -36 26 -10, p = .01) was associated with incorporating emotional information into betting behavior. Figure 2 shows a sagittal view of the activation from Experiment 1 and 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, activation in this area was associated with inhibiting the influence of emotion on decision-making when participants were instructed to ignore the emotional primes. Furthermore, the activity in this area was negatively correlated with incorporating emotional information into betting decisions. In Experiment 2, activation in this area was associated with incorporating emotion into decision-making when participants were instructed to use the prime as a clue about the risk of the upcoming bet. Therefore, the inferior frontal gyrus/lateral orbitofrontal cortex may represent (part of) a neural system that allows individuals to flexibly incorporate emotion into cognition when it is relevant and to reduce emotional impact when it is not relevant.

The present research also 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 previous studies on emotional control suggest 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 it is possible that somewhat different systems are employed when individuals are attempting to prevent or reduce an emotional state in comparison to times when individuals are attempting to prevent or reduce the impact of an emotional state on decision-making. However, one study of emotional control has found activity in the contralateral portion of inferior frontal gyrus/lateral orbitofrontal cortex (i.e., BA 47) found in the present research (e.g., Ochsner, et al., 2004). Although the activations 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 found less frequently across studies of emotional control is the lack of behavioral assurance that control has actually occurred. Many of the previous studies rely on participants' self-reports of reduced emotional states which may be subject to experimental demand (Ochsner & Gross, in press). The present research is an example of a paradigm in which emotional control can be behaviorally measured (i.e., differences in betting across the prime conditions) and involves less experimental demand (i.e., participants had no idea that the pictures contained content that affected their betting in Experiment 1).

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

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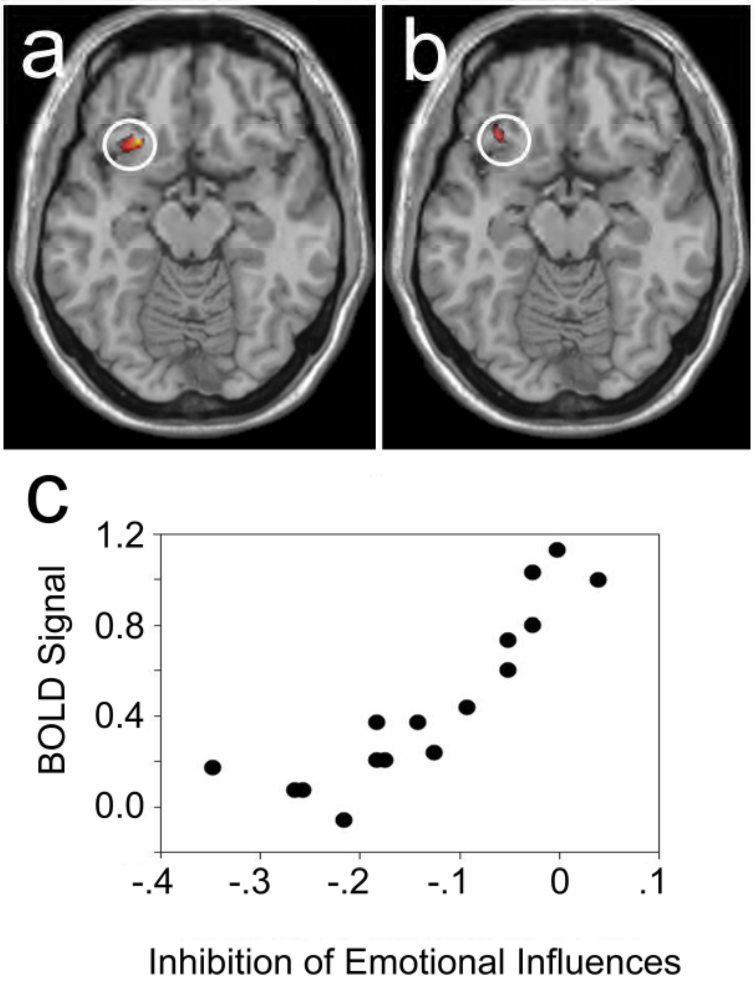
ACKNOWLEDGEMENTS

This research was supported by NIMH MH66574 to JSB and NIMH MH 066737 and NINDS NS21135 to RTK.

FIGURE CAPTIONS

Figure 1. Activation in left inferior BA 47 (z = - 14) associated with controlling the influence of negative emotional information on betting. (A) Main contrast; (B) Behavioral regressor.

Figure 2. Activation in left inferior BA 47 (x = -34) associated with controlling emotional influence on decision-making (Experiment 1) and with incorporating emotional influence on decision-making (Experiment 2).


a
b
c
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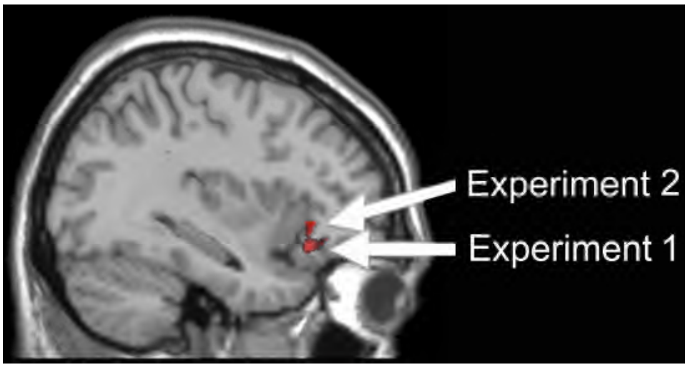
Inhibition of Emotional Influences


Experiment 2
Experiment 1