

# Neural Activity to a Partner's Facial Expression Predicts Self-Regulation After Conflict

Christine I. Hooker, Anett Gyurak, Sara C. Verosky, Asako Miyakawa, and Özlem Ayduk

**Background:** Failure to self-regulate after an interpersonal conflict can result in persistent negative mood and maladaptive behaviors. Research indicates that lateral prefrontal cortex (LPFC) activity is related to emotion regulation in response to laboratory-based affective challenges, such as viewing emotional pictures. This suggests that compromised LPFC function may be a risk factor for mood and behavior problems after an interpersonal conflict. However, it remains unclear whether LPFC activity to a laboratory-based affective challenge predicts self-regulation in real life.

**Methods:** We investigated whether LPFC activity to a laboratory-based affective challenge (negative facial expressions of a partner) predicts self-regulation after a real-life affective challenge (interpersonal conflict). During a functional magnetic resonance imaging scan, healthy, adult participants in committed relationships ( $n = 27$ ) viewed positive, negative, and neutral facial expressions of their partners. In a three-week online daily diary, participants reported conflict occurrence, level of negative mood, rumination, and substance use.

**Results:** LPFC activity in response to the laboratory-based affective challenge predicted self-regulation after an interpersonal conflict in daily life. When there was no interpersonal conflict, LPFC activity was not related to mood or behavior the next day. However, when an interpersonal conflict did occur, ventral LPFC (VLPFC) activity predicted mood and behavior the next day, such that lower VLPFC activity was related to higher levels of negative mood, rumination, and substance use.

**Conclusions:** Low LPFC function may be a vulnerability and high LPFC function may be a protective factor for the development of mood and behavior problems after an interpersonal stressor.

**Key Words:** Borderline personality disorder, diathesis-stress model of mental illness, emotion, emotion regulation, expressed emotion, facial affect, interpersonal relationships, major depressive disorder, social neuroscience

Interpersonal conflicts are emotionally challenging, not only because conflicts provoke negative affect in the moment but also because, once provoked, negative affect must be managed effectively to motivate adaptive behavior in the conflict's aftermath (1). Failure to regulate mood and behavior after experiencing a negative event, such as interpersonal conflict, can result in persistent negative mood and potentially self-destructive responses. These maladaptive responses, such as rumination or substance use, can trigger a downward spiral that ultimately impairs functioning (2–6).

Self-regulation, including regulation of emotion and behavior, is achieved through a variety of strategies that use cognitive skills, such as interpretation, attention, and inhibition, to modulate one's experience and reaction (7). It is well established that these cognitive skills are mediated by a network of neural regions in which the lateral prefrontal cortex (LPFC) is a key component (8). Recent research shows that the LPFC, particularly the ventral portion (ventrolateral prefrontal cortex [VLPFC]), facilitates emotion regulation by influencing the temporal course and intensity of emotional experience through strategies that rely on cognitive skills—specifically, evaluation, affect labeling, attentional control, and reappraisal (9–13). When implementing these strategies to control emotion, people with greater LPFC

activity in response to stimuli provoking negative affect, such as gruesome images and physical pain (10–12,14), report less distress resulting from those stimuli. Greater LPFC activity to emotional stimuli is also related to better impulse control (15). These data support the idea that the LPFC implements control-related mechanisms to downregulate negative affect and inhibit maladaptive behaviors.

Furthermore, dysfunction in the LPFC has been observed in multiple psychiatric disorders, such as unipolar and bipolar mood disorders (16–18), borderline personality disorder (19,20), and substance abuse (5), which are characterized by the inability to regulate negative affect and maladaptive behaviors. Symptoms of these disorders can be precipitated or exacerbated by an interpersonal conflict with a partner (21). Thus, it has been proposed that LPFC dysfunction may be a biological vulnerability, or diathesis, that interacts with a stressor, such as an interpersonal conflict, to produce problematic mood and behavioral symptoms (16,21).

Prior research investigating the role of LPFC in regulating emotional response has used laboratory-based affective challenges, such as negative pictures, as an approximation of real-life affective challenges. However, no research thus far has addressed whether LPFC activation to a laboratory-based affective challenge predicts self-regulation in response to a real-life affective challenge. Furthermore, the exact mechanism regarding how an LPFC diathesis interacts with a stressful event, such as interpersonal conflict, is unclear. People in a negative mood state or who have a dispositional propensity to feel negative mood (as measured by high levels of neuroticism) may be more sensitive to negative interpersonal cues (22,23), making it difficult to determine whether maladaptive response to interpersonal conflict is the result of increased sensitivity to negative information or failure to recruit effective self-regulation strategies (7).

To investigate the basic mechanism of this diathesis-stress model, we addressed these questions with healthy participants involved in committed, dating relationships. We used functional magnetic resonance imaging (fMRI) along with behavioral tasks

From the Psychology Department (CIH), Harvard University, Cambridge, Massachusetts; and Psychology Department (AG, OA) and Helen Wills Neuroscience Institute (SCV, AM), University of California, Berkeley, Berkeley, California.

Address correspondence to Christine Hooker, Ph.D., William James Hall 820, Psychology Department, Harvard University, 33 Kirkland Street, Cambridge, MA 02138; E-mail: [chooker@wjh.harvard.edu](mailto:chooker@wjh.harvard.edu).

Received Feb 27, 2009; revised Sep 1, 2009; accepted Oct 5, 2009.

and a daily diary study to test whether LPFC neural response to a laboratory-based affective challenge would predict regulation of mood and behavior in response to a real-life affective challenge—an interpersonal conflict with a partner. Negative facial expressions from the partner served as the laboratory-based affective challenge, a stimulus designed to elicit control-related LPFC activity. Participants also completed a structured diary questionnaire to assess daily conflicts, mood, and maladaptive behaviors over a 3-week period. We tracked the change in mood and maladaptive behaviors from the day of the conflict to the day after. We then tested whether the LPFC activity from the laboratory-based affective challenge predicted the change in mood and maladaptive behaviors. We predicted that although everyone would experience an increase in negative mood on the day of interpersonal conflict, recovery from this negative event by the following day would depend on LPFC function. These methods address concerns of the previous literature by accounting for immediate response to conflict and directly addressing the role of subsequent regulatory ability. To validate that LPFC activity in response to the laboratory-based affective challenge relied on cognitive skills, we correlated LPFC neural activity with performance on traditional measures of cognitive control capacity.

## Methods and Materials

### Participants

Couples in dating relationships for at least 3 months were recruited. Twenty-seven (13 male/14 female) English speaking, right-handed adults participated in the study (mean age = 21 years [SD = 2.4]; mean relationship length 22.4 [20.01] months). Participants included 11 couples and 5 individuals whose partners did not undergo fMRI scanning.<sup>1</sup> They reported no neurological or psychiatric illness and were not taking psychotropic medication.

### Procedure

At the initial laboratory session, each participant completed questionnaires assessing relationship closeness (24), relationship commitment, and trait neuroticism (25), as well as three standard measures of cognitive control capacity: 1) a behavioral go/no-go task to assess response inhibition (26); 2) a self-report questionnaire of voluntary attentional control (27); and 3) a self-report questionnaire of behavioral impulsivity (28). They also had facial expression photographs taken; were screened for the fMRI study; were scheduled for a scan, if eligible; and received instructions on the structured daily-diary questionnaires.

The behavioral and self-report measures are standard instruments (Supplement 1) and were used here to better understand our primary fMRI and daily diary results.

### fMRI Task

Subjects viewed pictures of their partner, themselves, and an opposite-sex stranger in three facial expression conditions: negative, positive, and neutral. Data from the partner and opposite-sex stranger are reported here.<sup>2</sup>

<sup>1</sup>Although heterosexuality was not specified in recruitment, all couples in the sample were heterosexual.

<sup>2</sup>Postscan ratings of the photo stimuli showed that participants were significantly more embarrassed when viewing pictures of themselves as compared with pictures of their partner or the stranger. Because feelings of embarrassment presented a potentially confounding factor, the self trials were dropped from further analysis.

**Facial Expression Stimuli.** Photographs were taken of each participant posing interpersonally meaningful facial expressions, including four negative expressions (anger, disappointment, contempt, and disgust), four positive expressions (happy, flirty, caring, and pleasantly surprised), and a neutral expression. Expressions were coached by showing the participant model expressions from standardized facial affect stimulus sets (29,30). One female participant served as the stranger for male participants and one male participant served as the stranger for female participants.<sup>3</sup>

During the fMRI scan, participants rated how each picture made them feel on a scale ranging from 1 (very negative) to 4 (very positive). Purposefully, there were no explicit instructions to regulate emotional reactions, thus allowing for individual differences in the amount of control applied in response to the affective challenge.

The partner's negative facial expression condition was the laboratory-based affective challenge. Neural activity in response to partner negative versus partner neutral expressions was expected to be the strongest predictor of self-regulation after conflict. Additional conditions of positive valence and an opposite-sex stranger were included to identify whether the predictive value of the laboratory-based affective challenge was specific to negatively valenced or personally meaningful stimuli.

### fMRI Task

Photographs were presented in blocks of 12 pictures from each condition (3 pictures from each specific emotion). Each picture was presented for 2 sec. Each 24-sec condition block was followed by 12 sec of rest. Each condition block was repeated nine times in a fixed random order across three runs. There were six conditions of interest: partner negative, partner positive, partner neutral, stranger negative, stranger positive, and stranger neutral.

### fMRI Image Acquisition, Processing, and Analysis

Images were acquired on a 4 T Varian INOVA scanner (Varian, Palo Alto, California). See Supplement 1 for acquisition and processing details.

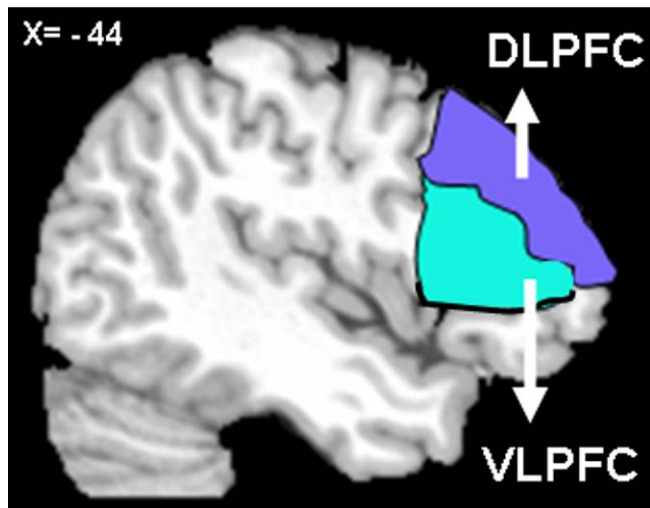
For each contrast of interest, significant activation  $t(26) = 3.4$ ,  $p < .001$  (uncorrected) at the group level was corrected for multiple comparisons within the LPFC (Figure 1). Individual participant's level of neural activity from each significant LPFC cluster was extracted and used as a predictor in the hierarchical linear modeling analysis with the daily diary data.

### Reports of Mood and Behavior in the Daily Diary

The online daily diary consisted of structured questionnaires completed at the end of each day (between 5:00 PM and 3:00 AM) for 21 days. Participants were asked to complete the diary separately from their partner and refrain from discussing their responses until the study ended. Electronic questionnaire submissions were time stamped and could not be modified. Each day, participants reported whether or not they had a conflict with their partner (yes/no) and rated on a 5-point scale (1 = not at all; 5 = extremely) the extent to which the conflict was resolved and the extent to which they felt positive and negative mood and engaged in rumination and substance use.

The specific items were as follows: positive mood: loved, accepted, happy, calm, supported, satisfied, confident; negative

<sup>3</sup>The stranger photographs were selected by research staff based on the quality of the photograph, such as how well the target emotions were depicted.



**Figure 1.** The anatomical mask used to identify lateral prefrontal cortex (LPFC) activity. Significant activity in the whole-brain, random-effects analysis that was within this LPFC region of interest was identified (listed in Table 2) and then individual contrast values were extracted. The LPFC anatomical mask included the ventral portion (VLPFC) shown in light blue and dorsal portion (DLPFC) shown in dark blue. The VLPFC included the inferior frontal gyrus-triangularis (BA 45 and portions of BA 44). The DLPFC included the middle frontal gyrus (portions of BA 46, BA 9, and BA 10). The LPFC mask was created by using the Automated Anatomical Labeling maps in the program MRlcro (<http://www.sph.sc.edu/comd/rorden/template.html>) as a guide for identifying the inferior frontal and middle frontal gyri and the BAs, Brodmann area.

mood: insecure, self-critical, resentful, guilty, ashamed, anxious, angry, lonely, rejected, depressed, suspicious; rumination: “I replayed an argument I had with my partner in the past over and over in my head”; substance use: “I drank alcohol or used drugs more than I should have”; and conflict resolution: “The conflict has been resolved to my satisfaction.”

**Analysis of Neural Activity and Daily Diary Data**

The diary data involved a hierarchical structure where participants were nested within couples and days of assessment were nested within participants. For each couple, this structure represented a two-level model and required the simultaneous analysis of within-person and between-person levels that are hierarchically organized.

Mixed procedure in SAS statistical package (SAS Institute, Cary, North Carolina) (31) was used to estimate within-subjects

associations between occurrence of a conflict on any given diary day and mood and behavior the next day. We identified longitudinal changes in mood and behavior from conflict days to the following day. To examine whether the effect of conflict on next day’s mood and behavior was dependent on between-subjects differences in LPFC activity, we tested the statistical interaction between conflict occurrence and LPFC activity by using contrast values extracted from significant LPFC clusters. Our hypothesis was that on days preceded by conflict, low LPFC activity would be related to higher levels of overall negative mood, rumination, and substance use. Following days when no conflict occurred, we did not expect LPFC activity to be significantly related to mood and behavior the next day (Supplement 1).

All analyses controlled for neuroticism to ensure that individual differences in the neural response to negative facial expressions (22) or the propensity to experience negative mood (32) did not influence the results. Big Five Inventory (25) mean neuroticism (7-point scale [2]) was 3.9 (1.2) with range 1.9 to 6.1.

**Results**

**Behavioral Results from fMRI Scan**

Participants reported more negative feelings in response to negative versus neutral expressions and more positive feelings in response to positive versus neutral expressions in both the partner and stranger conditions (Table 1). These findings indicate that the facial expression stimuli produced the expected affective response.

**fMRI Results**

Results from the group analysis show that the LPFC was significantly more active to negative and positive expressions compared with neutral expressions from the partner and the stranger (Table 2). Activation in each contrast was in the VLPFC, with peak activation in the inferior frontal gyrus—triangularis region (Brodmann area [BA] 45).

**Behavioral Results from the Daily Diary**

Eighty-five percent of the group (23 participants) reported at least one conflict with their partner during the diary period. Across all participants, the number of conflict days ranged from 0 to 8; the average number of conflict days was  $X = 2.11$  (2.22), representing approximately 10% of the 21 diary days. Couples agreed about whether a conflict had occurred on 91% of the days.

Positive mood items ( $\alpha = .91$ ) and negative mood items ( $\alpha = .90$ ) had adequate internal consistency. Across the 21 diary days,

**Table 1.** Behavioral Ratings in Response to the Question “How Does This Picture Make You Feel?”

Partner Conditions	Rating	Stranger Conditions	Rating
Partner Negative	1.8 (.27)	Stranger Negative	1.7 (.24)
Partner Positive	3.5 (.27)	Stranger Positive	3.2 (.46)
Partner Neutral	2.6 (.47)	Stranger Neutral	2.4 (.38)
Paired <i>t</i> Tests of Ratings for Different Conditions			
Partner Negative vs. Partner Neutral	$t = 10.6^b$	Stranger Negative vs. Stranger Neutral	$t = 9.8^b$
Partner Positive vs. Partner Neutral	$t = 7.5^b$	Stranger Positive vs. Stranger Neutral	$t = 7.4^b$
Partner Negative vs. Stranger Negative	ns	Partner Positive vs. Stranger Positive	$t = 3.1^a$

Rating scale: 1 = very negative, 2 = slightly negative, 3 = slightly positive, 4 = very positive. Ratings listed as group mean (standard deviation). Paired *t* tests show differences between conditions.

ns, nonsignificant.

<sup>a</sup> $p < .01$ .

<sup>b</sup> $p < .001$ .

**Table 2.** Peak Coordinates and Volume of the Significant LPFC Activations for Each fMRI Contrast in the Whole-Brain, Random-Effects (Group-Level) Analysis

Condition Contrast	R/L	Region	BA	Volume <sup>a</sup> in Voxels	MNI Coordinates x, y, z	t Value <sup>c</sup>
Partner Negative > Partner Neutral	L	VLPFC	45	12	-44, 28, 16	3.81
Partner Positive > Partner Neutral	L	VLPFC	45	357 <sup>b</sup>	-40, 30, 2	5.37
Partner Positive > Partner Neutral	R	VLPFC	45	77	54, 36, 2	4.63
Stranger Negative > Stranger Neutral	L	VLPFC	45	3	-44, 28, 26	3.54
Stranger Positive > Stranger Neutral	L	VLPFC	45	56	-42, 24, 22	4.22
Stranger Positive > Stranger Neutral	R	VLPFC	44, 45	5	44, 22, 26	3.6
Stranger Positive > Stranger Neutral	R	VLPFC	45	14	54, 26, 24	3.36
Partner Negative > Stranger Negative	R	VLPFC	45	11	44, 38, 4	3.84
Partner Positive > Stranger Positive	L	VLPFC	45	8	-44, 32, 0	3.73

Statistical threshold is [ $t(26) = 3.4, p < .001$  (uncorrected)]. Activity was identified as within the LPFC by an anatomical mask that included the dorsal and ventral portions of the LPFC (Figure 1), labeled here as DLPFC and VLPFC, respectively. Significant activation was corrected for multiple comparisons within the LPFC region. See Table S1 in Supplement 1 for significant activity across the whole brain.

BA, Brodmann area; DLPFC, dorsolateral prefrontal cortex; fMRI, functional magnetic resonance imaging; L, left; LPFC, lateral prefrontal cortex; MNI, Montreal Neurological Institute; R, right; VLPFC, ventrolateral prefrontal cortex.

<sup>a</sup>Voxel size is  $2 \times 2 \times 2$  mm.

<sup>b</sup>Volume of the cluster within the LPFC. The entire cluster extended to the lateral orbital frontal cortex.

<sup>c</sup>All values significant at  $p < .001$  with small volume correction for multiple comparisons in the LPFC.

average positive mood ( $X = 3.35$  [.76]) and negative mood ( $X = 1.51$  [.55]) at the daily level were negatively related to one another ( $b = -.40, p = .0001$ ). Therefore, positive mood items were reverse scored to create a single overall negative mood index where higher scores indicated greater negative mood and lower positive mood ( $X = 1.95$  [.53]). Across the 21 diary days, the average level of rumination was  $X = 1.2$  (.66), substance use was  $X = 1.1$  (.56), and conflict resolution was  $X = 2.56$  (1.38). All items were on a 5-point scale.

### Relationship Between Neural Activity and Daily Diary Data

Individual contrast values from each LPFC cluster listed in Table 2 were extracted and entered as a predictor in the hierarchical linear model (HLM).<sup>4</sup> Lateral prefrontal cortex activity from two contrasts (partner negative vs. partner neutral and partner positive vs. partner neutral) significantly interacted with interpersonal conflict to predict change in mood and/or behavior. These data are detailed below. None of the other contrasts showed a significant interaction with conflict.

#### Left VLPFC Activity: Partner Negative Versus Partner Neutral Expressions

In the analysis of day-to-day changes in mood and behavior, left VLPFC activity to partner negative versus partner neutral significantly interacted with occurrence of conflicts in predicting change in overall negative mood [ $F(1,15) = 6.31, b = -.12, p = .02$ ], rumination [ $F(1,15) = 6.54, b = -.25, p = .02$ ], and substance use [ $F(1,15) = 8.45, b = -.16, p = .01$ ]. To further understand these interactions, we examined the relationship between left VLPFC activity and mood and behavior for days in which no conflict occurred the previous day and then separately for days in which a conflict had occurred the previous day by conducting simple slopes analysis (33). On days when no interpersonal conflict was reported the previous day, left VLPFC

<sup>4</sup>Across the diary period, neuroticism was significantly related to mean level of negative mood [ $r(25) = .41, p = .03$ ] and shows a trend level relationship to rumination [ $r(25) = .36, p = .06$ ] and substance use [ $r(25) = .35, p = .07$ ]. These results indicate that it is appropriate to control for neuroticism (as we did) in our analyses. Neuroticism was not related to VLPFC activity.

activation had no relationship to any of the outcome variables: overall negative mood [ $b = -.02, t(15) = -.88, p = .39$ ]; rumination [ $b = -.01, t(15) = -.34, p = .74$ ]; substance use [ $b = -.002, t(15) = .09, p = .93$ ].

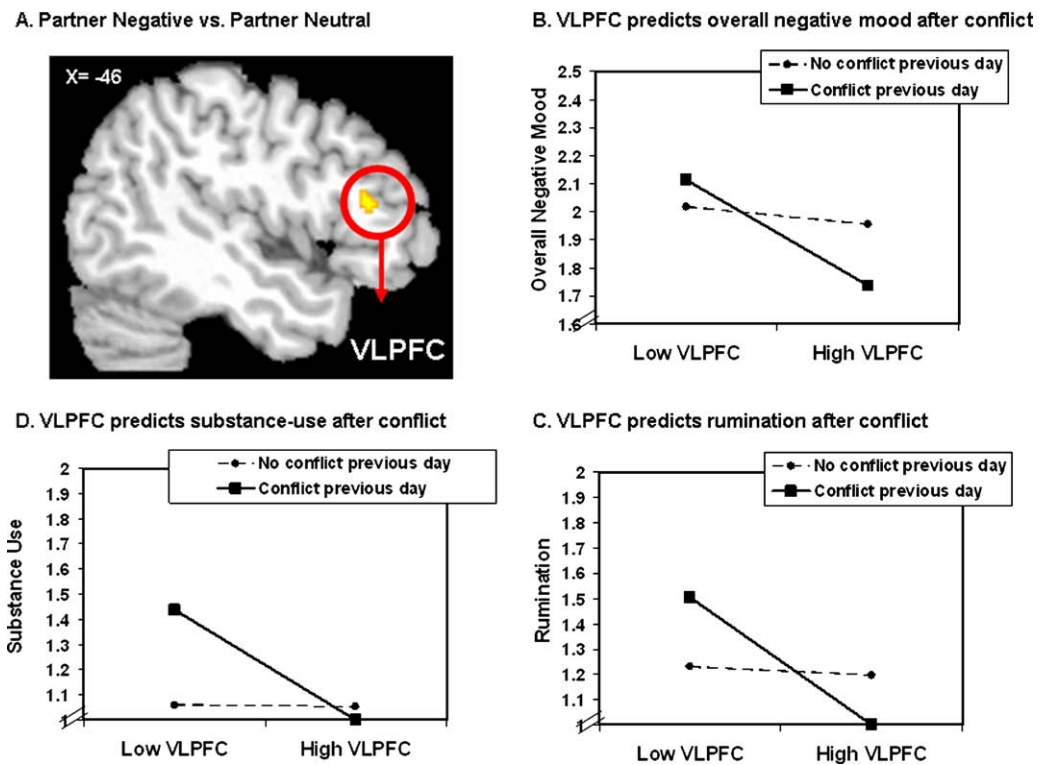
However, on days following interpersonal conflicts, left VLPFC activity was significantly associated with overall negative mood [ $b = -.12, t(15) = -2.66, p = .02$ ], rumination [ $b = -.22, t(15) = -2.72, p = .02$ ], and substance use [ $b = -.16, t(15) = -2.92, p = .01$ ], such that participants with lower VLPFC had higher overall negative mood, more rumination, and more substance use on days following interpersonal conflict. (Figure 2).

To further investigate the relationship between left VLPFC activity and change in overall negative mood, additional analyses were conducted on negative mood and positive mood separately. Left VLPFC activity to partner negative versus partner neutral significantly interacted with occurrence of conflicts in predicting negative mood only [ $F(1,15) = 5.00, b = -.14, p = .04$ ] and positive mood only [ $F(1,15) = 6.08, b = .17, p = .03$ ]. In the absence of conflict, there was no relationship between left VLPFC and negative mood [ $b = -.01, t(15) = -.41, p = .69$ ] or positive mood [ $b = .01, t(15) = .45, p = .66$ ] the next day. However, on days following conflict, left VLPFC activity predicted negative mood [ $b = -.12, t(15) = -2.08, p = .05$ ] and positive mood [ $b = .19, t(15) = 2.61, p = .02$ ], such that lower left VLPFC activity was related to more negative mood and less positive mood. Thus, both positive and negative mood contributed to the mood effect.

#### Left VLPFC Activity: Partner Positive Versus Partner Neutral

Left VLPFC activity to partner positive versus partner neutral expressions significantly interacted with the occurrence of interpersonal conflicts in predicting change in overall negative mood [ $F(1,15) = 5.02, b = -.10, p = .04$ ] but not rumination [ $F(1,15) = 2.39, b = -.13, p = .14$ ] or substance use [ $F(1,15) = 3.54, b = -.13, p = .08$ ].

Analysis of the interaction between left VLPFC activity and conflict showed that when there was no conflict the previous day, left VLPFC activity had no relationship to overall negative mood [ $b = -.004, t(15) = -.16, p = .87$ ]. However, left VLPFC

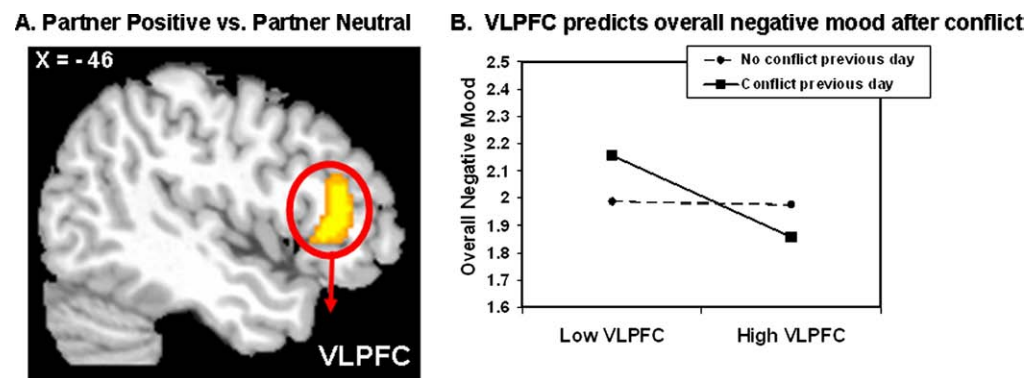


**Figure 2.** (A) Whole-brain, random-effects analysis across the group of subjects ( $n = 27$ ) shows significant left VLPFC activity for partner negative versus partner neutral expressions contrast. (B) Individual level of VLPFC activity, extracted from this group activation, significantly interacted with interpersonal conflict to predict overall negative mood. Higher scores correspond to more negative mood (graphed on the Y axis). As shown in the figure, when there was no conflict the previous day, VLPFC activity was not related to overall negative mood. However, when a conflict occurred the previous day, lower VLPFC activity was related to more overall negative mood. The same pattern of results can be seen with (C) rumination and (D) substance use. VLPFC, ventrolateral prefrontal cortex.

activity predicted overall negative mood on days following an interpersonal conflict [ $t(15) = 2.40, b = -.10, p = .03$ ], such that people with lower VLPFC activity had more overall negative mood (Figure 3).

Additional analyses on negative mood and positive mood separately suggest that the relationship between left VLPFC activity to partner positive versus partner neutral and change in overall negative mood after conflict is driven, primarily, by the change in positive mood. Left VLPFC activity did not interact with

occurrence of conflicts in predicting negative mood only [ $F(1,15) = .25, b = -.03, p = .62$ ], but it did predict positive mood only [ $F(1,15) = 6.5, b = .14, p = .02$ ]. In the absence of conflict, there was no relationship between left VLPFC and positive mood [ $b = -.01, t(15) = -.23, p = .82$ ] the next day. However, on days following conflict, left VLPFC activity predicted positive mood at the trend level [ $b = .12, t(15) = 1.84, p = .09$ ], such that lower left VLPFC activity was related to less positive mood (see Supplement 1 for detailed results).



**Figure 3.** (A) Whole-brain, random-effects analysis across the group of subjects ( $n = 27$ ) shows significant left VLPFC activity for partner positive versus partner neutral expressions. (B) Individual level of VLPFC activity, extracted from this group activation, significantly interacted with interpersonal conflict to predict overall negative mood. On days in which there was no conflict the previous day, VLPFC activity was not related to overall negative mood. On days in which there was a conflict the previous day, VLPFC activity significantly predicted overall negative mood, such that lower VLPFC activity was related to more overall negative mood. VLPFC, ventrolateral prefrontal cortex.

## Validation of the Observed Relationship Between Neural Activity and Daily Diary

**Left VLPFC Activity and Reaction to Conflict.** Analyses were conducted to verify that VLPFC activity was related to regulation after conflict and not reactivity to conflict. We calculated the (within-person) association between conflict occurrence and the change in overall negative mood, rumination, and substance use from the day before conflict to the day of conflict. This showed a main effect of conflict, such that all participants had an increase in overall negative mood [ $F(1,15) = 13.94$ ,  $t(15) = 3.73$ ,  $b = .29$ ,  $p = .001$ ] and rumination [ $F(1,15) = 17.93$ ,  $t(15) = 4.23$ ,  $b = .66$ ,  $p = .0007$ ]. However, left VLPFC did not interact with conflict to predict this change in negative mood or rumination (interaction terms between VLPFC activity [both contrasts] and conflict,  $F_s < 1$ ), showing that the increase in negative mood and rumination on the day of the conflict was not dependent on LPFC activity. There was no main effect of conflict for substance use on conflict days ( $F < 1$ ), so no further analysis on substance use was conducted. These findings demonstrate that LPFC is not related to initial reactivity to interpersonal conflict (i.e., everyone had an equal increase in negative mood on conflict days).

**Correlation Between Left VLPFC Activity and Cognitive Control Measures.** Bivariate correlations between VLPFC activity and behavioral cognitive control measures were conducted to verify that VLPFC was related to cognitive control capacity. Left VLPFC activity to partner negative versus partner neutral was positively correlated with response inhibition accuracy on the go/no-go task [ $r(25) = .53$ ,  $p = .005$ ] and negatively correlated with self-reported impulsivity [ $r(25) = -.38$ ,  $p = .05$ ] but not attentional control [ $r(25) = .21$ ,  $p = .29$ ]. Left VLPFC activity to partner positive versus partner neutral was positively correlated with response inhibition accuracy at the trend level [ $r(25) = .35$ ,  $p = .07$ ] and attentional control [ $r(25) = .45$ ,  $p = .02$ ] but not impulsivity [ $r(25) = -.14$ ,  $p = .49$ ].<sup>5</sup>

**Relationship Quality Indexes.** To verify that the findings are not due to preexisting differences in relationship quality between those with high and low VLPFC activity, we examined the relationship between the two VLPFC activity variables discussed above and relationship quality indexes. There was no significant relationship between VLPFC activity and number of conflicts, the degree to which daily conflicts were resolved, relationship commitment, or relationship closeness (all  $F_s < 1$ ).

## Discussion

These results show that LPFC activity in response to a laboratory-based affective challenge—negative facial expressions from a partner—predicts the ability to regulate mood and behavior after a real-life affective challenge—an interpersonal conflict with that person. Control-related VLPFC activity to the partner's negative facial expressions robustly predicted whether an interpersonal conflict resulted in a significant change in mood, rumination, and substance use. Specifically, when there was no interpersonal conflict, left VLPFC activity was not related to mood or behavior the next day. However, when an interpersonal conflict did occur, left VLPFC predicted mood and behavior the next day, such that lower VLPFC activity was related to higher levels of overall negative mood, rumination, and substance use.

<sup>5</sup>Additional HLM analyses were conducted to see whether behavioral cognitive control measures alone would predict the change in mood and behavior after conflict. None of the cognitive control measures significantly interacted with conflict to predict change in mood and behavior.

In addition, left VLPFC activity to the partner's positive expressions predicted overall negative mood after conflict, such that lower VLPFC activity was related to higher overall negative mood. These data support the hypothesis that LPFC dysfunction is a vulnerability for the development of mood and behavioral problems after interpersonal stressors (16) and further suggests that intact or superior VLPFC function may be a protective factor that promotes an adaptive profile of response (34).

The current findings address potential confounds in prior research and illustrate the contribution of control-related VLPFC processes in managing mood and behavior in the aftermath of an emotionally provocative event. This contribution is seen most clearly in the analysis of overall negative mood. Here, we statistically control for the tendency to experience negative mood (i.e., neuroticism), account for individual differences in daily negative mood, and verify that VLPFC activity is related to cognitive control skills. The results show that although all participants experienced an increase in negative mood the day of the conflict, recovery from this affective challenge by the following day was dependent on VLPFC function.

Additionally, the data indicate that the VLPFC may control mood by co-opting and implementing control-related cognitive skills to both downregulate negative mood and upregulate positive mood. High left VLPFC activity to the laboratory-based affective challenge (partner's negative expressions) was related to better response inhibition and impulse control. Prior research has similarly shown that high VLPFC while viewing negative facial expressions is related to better impulse control (15). This suggests that the laboratory-based affective challenge may have elicited control-related activity in the VLPFC. Furthermore, higher VLPFC activity to the partner's positive expressions was related to better attentional control, suggesting that different types of cognitive control mechanisms may be implemented by the VLPFC to produce the desired emotion. Consistent with this, VLPFC activity during effortful regulation is related to the successful downregulation and upregulation of affect to both negative and positive stimuli (12,35,36). The current data advance this literature by showing that VLPFC activity to the laboratory-based affective challenge predicts both the downregulation of negative mood and the upregulation of positive mood after a real-life affective challenge.

The rumination and substance use findings suggest that VLPFC function regulates internalizing and externalizing maladaptive responses, which can contribute to a downward spiral of worsening mood and behavioral problems.

Rumination, an internal focus on negative mood and thoughts (37,38), exacerbates and prolongs negative mood and predicts the onset and relapse of psychological disorders after a stressful event (4,39). Thus far, it has been unclear whether rumination after a negative event results from poor control over negative affect, as evidenced by the association of rumination and poor performance on cognitive control tasks (40), or greater sensitivity to negative affect, as evidenced by the association of rumination with higher neuroticism (41). Here, we account for neuroticism and daily rumination and show that although everyone had an increase in rumination the day of the conflict, higher control-related VLPFC activity was related to a decrease in rumination the next day.

Substance use did not uniformly increase on the day of conflict; however, lower VLPFC activity was related to more self-reported substance use the day after conflict. This is consistent with diathesis-stress models of substance abuse, which propose that stressful events trigger impulses to reduce distress

and insufficient control-related LPFC function makes those impulses difficult to resist (6,42–44).

Interestingly, people with high VLPFC activity had an improvement in mood and maladaptive behavior after conflict. Although adaptive regulation strategies were not measured, one interpretation is that people with high VLPFC activity used more effective cognitive strategies to reframe the interpersonal conflict as a positive experience. Consistent with this interpretation, prior research has shown that greater VLPFC activity in response to negative facial expressions is related to greater use of reappraisal (45), and the use of reappraisal to identify positive meaning in negative events can create an upward spiral of adaptive behavior (46–48). Our findings are also consistent with evidence showing that cognitive control skills provide protection for people at elevated risk for difficulties after a negative event (34,49,50).

One limitation of the current study is that all daily mood, rumination, and substance use assessments were self-reported and thus subject to bias. Future research could include a more objective measure of functioning. Additionally, while the use of personalized facial expressions created an ecologically valid and thus sensitive affective challenge, it also added variability across subjects, since some participants may have been better at posing the target expressions. Future research could include standardized stimuli as the affective challenge. Finally, it is not clear whether the change in mood and behavior shown here represents a clinically significant change. Future research, particularly with clinical samples, could use symptom measures and clinical criteria to identify whether LPFC function interacts with conflict to cause clinically significant change in symptoms, functioning, and overall distress.

Nonetheless, collectively, the current findings have implications for the clinical management and treatment of multiple psychiatric disorders. Recovering psychiatric patients who experience interpersonal criticism from a partner or family member are more likely to relapse (21). Furthermore, formerly depressed patients have low LPFC activity when listening to their mother's criticism (51,52). The current study with healthy participants indicates that individual level of LPFC activity to an affective challenge may provide information about that person's risk for maladaptive responses after an interpersonal stressor, which can be used to develop strategies to cope with such environmental provocations.

In summary, our findings show that control-related VLPFC activity to an interpersonally meaningful laboratory-based affective challenge is a crucial neurocognitive indicator of whether a real-life affective challenge—such as an interpersonal conflict—will result in a downward spiral of worsening mood and self-destructive behaviors or an upward spiral of improved mood and adaptive responses.

*This research was supported by National Institute of Mental Health Grants K08 MH71746 (CH) and R01 MH 0697043 (OA), as well as a National Alliance for Research on Schizophrenia and Depression (NARSAD) Young Investigator Award (CH). The author SCV is currently affiliated with the Psychology Department, Princeton University, Princeton, New Jersey.*

*We thank Mark D'Esposito and Robert T. Knight for support and guidance with functional magnetic resonance imaging data collection and analysis.*

*The authors report no biomedical financial interests or potential conflicts of interest.*

*Supplementary material cited in this article is available online.*

1. Arriaga XB, Rusbult CE (1998): Standing in my partner's shoes: Partner perspective taking and reactions to accommodative dilemmas. *Pers Soc Psychol Bull* 24:927–948.
2. Ayduk O, Downey G, Kim M (2001): Rejection sensitivity and depressive symptoms in women. *Pers Soc Psychol Bull* 27:868–877.
3. Baker TB, Piper ME, McCarthy DE, Majeskie MR, Fiore MC (2004): Addiction motivation reformulated: An affective processing model of negative reinforcement. *Psychol Rev* 111:33–51.
4. Nolen-Hoeksema S (2000): The role of rumination in depressive disorders and mixed anxiety/depressive symptoms. *J Abnorm Psychol* 109: 504–511.
5. Li CS, Sinha R (2008): Inhibitory control and emotional stress regulation: Neuroimaging evidence for frontal-limbic dysfunction in psycho-stimulant addiction. *Neurosci Biobehav Rev* 32:581–597.
6. Sinha R (2007): The role of stress in addiction relapse. *Curr Psychiatry Rep* 9:388–395.
7. Ochsner KN, Gross JJ (2005): The cognitive control of emotion. *Trends Cogn Sci* 9:242–249.
8. Miller EK, Cohen JD (2001): An integrative theory of prefrontal cortex function. *Annu Rev Neurosci* 24:167–202.
9. Dolcos F, McCarthy G (2006): Brain systems mediating cognitive interference by emotional distraction. *J Neurosci* 26:2072–2079.
10. Lieberman MD, Eisenberger NI, Crockett MJ, Tom SM, Pfeifer JH, Way BM (2007): Putting feelings into words: Affect labeling disrupts amygdala activity in response to affective stimuli. *Psychol Sci* 18:421–428.
11. Lieberman MD, Jarcho JM, Berman S, Naliboff BD, Suyenobu BY, Mandelkern M, *et al.* (2004): The neural correlates of placebo effects: A disruption account. *Neuroimage*. 22:447–455.
12. Ochsner KN, Bunge SA, Gross JJ, Gabrieli JD (2002): Rethinking feelings: An fMRI study of the cognitive regulation of emotion. *J Cogn Neurosci* 14:1215–1229.
13. Satpute AB, Lieberman MD (2006): Integrating automatic and controlled processes into neurocognitive models of social cognition. *Brain Res* 1079:86–97.
14. Salomons TV, Johnstone T, Backonja MM, Shackman AJ, Davidson RJ (2007): Individual differences in the effects of perceived controllability on pain perception: Critical role of the prefrontal cortex. *J Cogn Neurosci* 19:993–1003.
15. Brown SM, Manuck SB, Flory JD, Hariri AR (2006): Neural basis of individual differences in impulsivity: Contributions of corticolimbic circuits for behavioral arousal and control. *Emotion* 6:239–245.
16. Davidson RJ, Pizzagalli D, Nitschke JB, Putnam K (2002): Depression: Perspectives from affective neuroscience. *Annu Rev Psychol* 53:545–574.
17. Green MJ, Cahill CM, Malhi GS (2007): The cognitive and neurophysiological basis of emotion dysregulation in bipolar disorder. *J Affect Disord* 103:29–42.
18. Stanfield AC, Moorhead TW, Job DE, McKirby J, Sussmann JE, Hall J, *et al.* (2009): Structural abnormalities of ventrolateral and orbitofrontal cortex in patients with familial bipolar disorder. *Bipolar Disord* 11:135–144.
19. Koenigsberg HW, Siever LJ, Lee H, Pizzarello S, New AS, Goodman M, *et al.* (2009): Neural correlates of emotion processing in borderline personality disorder. *Psychiatry Res* 172:192–199.
20. Lis E, Greenfield B, Henry M, Guile JM, Dougherty G (2007): Neuroimaging and genetics of borderline personality disorder: A review. *J Psychiatry Neurosci* 32:162–173.
21. Hooley JM (2007): Expressed emotion and relapse of psychopathology. *Annu Rev Clin Psychol* 3:329–352.
22. Hooker CI, Verosky SC, Miyakawa A, Knight RT, D'Esposito M (2008): The influence of personality on neural mechanisms of observational fear and reward learning. *Neuropsychologia* 46:2709–2724.
23. Gotlib IH, Krasnoperova E, Yue DN, Joormann J (2004): Attentional biases for negative interpersonal stimuli in clinical depression. *J Abnorm Psychol* 113:121–135.
24. Aron A, Aron EN, Smollan D (1992): Inclusion of other in the self scale and the structure of interpersonal closeness. *J Pers Soc Psychol* 63:596–612.
25. John OP, Srivastava S (1999): The Big Five trait taxonomy: History, measurement, and theoretical perspectives. In: John OP, Pervin LA, editors. *Handbook of Personality: Theory and Research*, 2nd ed. New York: Guilford, 102–138.

26. Durston S, Thomas KM, Worden MS, Yang Y, Casey BJ (2002): The effect of preceding context on inhibition: An event-related fMRI study. *Neuroimage* 16:449–453.
27. Derryberry D, Reed MA (2002): Anxiety-related attentional biases and their regulation by attentional control. *J Abnorm Psychol* 111: 225–236.
28. Patton JH, Stanford MS, Barratt ES (1995): Factor structure of the Barratt Impulsiveness Scale. *J Clin Psychol* 51:768–774.
29. Baron-Cohen S (2004): *Mind Reading Emotions Library*. Cambridge, UK: Jessica Kingsley Publishers.
30. Matsumoto D, Ekman P (1988): Japanese and Caucasian Facial Expressions of Emotion (JACFEE). Slides. San Francisco: Intercultural and Emotion Research Laboratory, Department of Psychology, San Francisco State University.
31. Kenny DA, Kashy DA, Cook WL (2006): *Dyadic Data Analysis*. New York: Guilford Publications.
32. Costa PT Jr, McCrae RR (1980): Influence of extraversion and neuroticism on subjective well-being: Happy and unhappy people. *J Pers Soc Psychol* 38:668–678.
33. Aiken LS, West SG (1991): *Multiple Regression: Testing and Interpreting Interactions*. Thousand Oaks, CA: Sage Publications, Inc.
34. Nigg J, Nikolas M, Friderici K, Park L, Zucker RA (2007): Genotype and neuropsychological response inhibition as resilience promoters for attention-deficit/hyperactivity disorder, oppositional defiant disorder, and conduct disorder under conditions of psychosocial adversity. *Dev Psychopathol* 19:767–786.
35. Kim SH, Hamann S (2007): Neural correlates of positive and negative emotion regulation. *J Cognit Neurosci* 19:776–798.
36. Ochsner KN, Ray RD, Cooper JC, Robertson ER, Chopra S, Gabrieli JD, *et al.* (2004): For better or for worse: Neural systems supporting the cognitive down- and up-regulation of negative emotion. *Neuroimage* 23: 483–499.
37. Just N, Alloy LB (1997): The response styles theory of depression: Tests and an extension of the theory. *J Abnorm Psychol* 106:221–229.
38. Moberly NJ, Watkins ER (2008): Ruminative self-focus and negative affect: An experience sampling study. *J Abnorm Psychol* 117:314–323.
39. Lyubomirsky S, Nolen-Hoeksema S (1993): Self-perpetuating properties of dysphoric rumination. *J Pers Soc Psychol* 65:339–349.
40. Davis RN, Nolen-Hoeksema S (2000): Cognitive inflexibility among ruminators and nonruminators. *Cognit Ther Res* 24:699–711.
41. Roberts JE, Gilboa E, Gotlib IH (1998): Ruminative response style and vulnerability to episodes of dysphoria: Gender, neuroticism, and episode duration. *Cognit Ther Res* 22:401–423.
42. Garavan H, Hester R (2007): The role of cognitive control in cocaine dependence. *Neuropsychol Rev* 17:337–345.
43. Cox WM, Hogan LM, Kristian MR, Race JH (2002): Alcohol attentional bias as a predictor of alcohol abusers' treatment outcome. *Drug Alcohol Depend* 68:237–243.
44. Goldstein RZ, Volkow ND (2002): Drug addiction and its underlying neurobiological basis: Neuroimaging evidence for the involvement of the frontal cortex. *Am J Psychiatry* 159:1642–1652.
45. Drabant EM, McRae K, Manuck SB, Hariri AR, Gross JJ (2009): Individual differences in typical reappraisal use predict amygdala and prefrontal responses. *Biol Psychiatry* 65:367–373.
46. Campbell L, Simpson JA, Boldry J, Kashy DA (2005): Perceptions of conflict and support in romantic relationships: The role of attachment anxiety. *J Pers Soc Psychol* 88:510–531.
47. Gottman MJ, Krokoff LJ (1989): Marital interaction and satisfaction: A longitudinal view. *J Consult Clin Psychol* 57:47–52.
48. Fredrickson BL (2004): The broaden-and-build theory of positive emotions. *Philos Trans R Soc Lond B Biol Sci* 359:1367–1378.
49. Ayduk O, Zayas V, Downey G, Cole AB, Shoda Y, Mischel W (2008): Rejection sensitivity and executive control: Joint predictors of borderline personality features. *J Res Pers* 42:151–168.
50. Buckner JC, Mezzacappa E, Beardslee WR (2003): Characteristics of resilient youths living in poverty: The role of self-regulatory processes. *Dev Psychopathol* 15:139–162.
51. Hooley JM, Gruber SA, Scott LA, Hiller JB, Yurgelun-Todd DA (2005): Activation in dorsolateral prefrontal cortex in response to maternal criticism and praise in recovered depressed and healthy control participants. *Biol Psychiatry* 57:809–812.
52. Hooley JM, Gruber SA, Parker HA, Guillaumot J, Rogowska J, Yurgelun-Todd DA (2009): Cortico-limbic response to personally challenging emotional stimuli after complete recovery from depression. *Psychiatry Res* 172:83–91.