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# Individual differences in trait rumination and the neural systems supporting cognitive reappraisal

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Cognitive reappraisal can alter emotional responses by changing one's interpretation of a situation's meaning. Functional neuroimaging has revealed that using cognitive reappraisal to increase or decrease affective responses involves left prefrontal activation and goal-appropriate increases or decreases in amygdala activation (Ochsner, Bunge, Gross, & Gabrieli, 2002; Ochsner, Ray, et al., 2004). The present study was designed to examine whether patterns of brain activation during reappraisal vary in relation to individual differences in trait rumination, which is the tendency to focus on negative aspects of one's self or negative interpretations of one's life. Individual differences in rumination correlated with increases in amygdala response when participants were increasing negative affect and with greater decreases in prefrontal regions implicated in self-focused thought when participants were decreasing negative affect. Thus, the propensity to ruminate may reflect altered recruitment of mechanisms that potentiate negative affect. These findings clarify relations between rumination and emotion regulation processes and may have important implications for mood and anxiety disorders.

Although we all face challenging circumstances from time to time, the way one thinks about these situations can increase or decrease the suffering one experiences. For instance, a serious physical illness can be interpreted as a debilitating setback, or it can be viewed as an opportunity to slow down, to take care of one's self, and to reevaluate one's goals while recovering for the journey ahead.

According to appraisal theory, it is how one thinks about or appraises the meaning of one's experiences that gives rise to the emotions one has (Frijda, 1986; Lazarus, 1991). This observation has generated a great deal of interest in humans' capacity to alter their thinking about potentially significant or emotionally evocative events. This capacity is known as cognitive reappraisal, and it involves reinterpreting a stimulus's meaning in a way that changes, among other things, the trajectory of the emotional response (Gross, 2001).

Psychophysiological and behavioral studies of cognitive reappraisal have begun to elucidate the way in which reappraisal changes the trajectory of emotional responses. For example, cognitive reappraisal of negative images, relative to uninstructed watch conditions, leads to decreased self-reports of negative affect and to smaller increases in blood pressure (Jackson, Malmstadt, Larson, & Davidson, 2000; Ray, Ochsner, & Gross, 2005; Richards & Gross, 2000). More generally, cognitive reappraisal has been shown to have salutary effects on experience, physiological responding, and behavior, without some of the costs associated with other regulatory strategies, such as expressive suppression (Gross, 1998, 2002).

Imaging studies have begun to elucidate the neural bases of reappraisal. Several studies (for reviews, see Ochsner, in press; Ochsner & Gross, 2005) have shown activation of dorsolateral prefrontal cortex (DLPFC) and anterior cingulate cortex (ACC) regions implicated in verbal working memory and response selection (D'Esposito, Postle, & Rypma, 2000; Miller & Cohen, 2001) when participants use reappraisal to down-regulate sadness (Lévesque et al., 2003), sexual arousal (Beauregard, Lévesque, & Bourgouin, 2001), and negative affect (Ochsner, Bunge, Gross, & Gabrieli, 2002; Ochsner, Ray, et al., 2004), and also when reappraisal is used to increase negative affect (Ochsner, Ray, et al., 2004). In the context of reappraisal, it is thought that DLPFC is involved in generating and maintaining alternative ways of thinking about emotional stimuli and that the ACC is involved in monitoring alternative interpretations. Successful reappraisal has been associated with modulation of the amygdala (Ochsner

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et al., 2002; Ochsner, Ray, et al., 2004; Schaefer et al., 2002), which is thought to encode emotionally salient and arousing stimuli (Anderson, Christoff, Panitz, De Rosa, & Gabrieli, 2003; Anderson & Phelps, 2001; Hamann, Monarch, & Goldstein, 2000; LeDoux, 2000; Whalen et al., 1998).

People differ, however, in the extent to which they use reappraisal to cognitively turn a sow's ear into a silk purse, or vice versa (Gross & John, 2003). Such differences in reappraisal seem fraught with consequence, but they have not yet been considered in neuroimaging studies. In part, this omission is the natural result of the relatively modest sample sizes associated with neuroimaging studies. However, the omission also results from uncertainty about how best to conceptualize such differences in reappraisal. One factor that may be important is the tendency to focus on and turn over in one's mind thoughts or feelings about one's self or about an event long after the event is over. This cognitive process, known as rumination (Martin & Tesser, 1996), may draw upon some of the same cognitive operations that in the context of reappraisal are used to consider and maintain alternative interpretations of events.

In common usage and in the experimental literature, *rumination* refers to the tendency to focus on negative aspects of one's self or negative interpretations of one's life, thereby using thinking to amplify or up-regulate negative emotion. For example, rumination on sad or angry thoughts and feelings about one's self or others maintains or increases the sad or angry feelings (Bushman, 2002; Morrow & Nolen-Hoeksema, 1990; Nolen-Hoeksema & Morrow, 1993; Ray, Wilhelm, & Gross, 2005; Rusting & Nolen-Hoeksema, 1998; Trask & Sigmon, 1999; Vickers & Vogeltanz-Holm, 2003), and in the long run has been linked with poor mental health outcomes (e.g., depression; Nolen-Hoeksema & Morrow, 1991). Individual-difference studies have demonstrated a strong relationship between rumination on negative thoughts and feelings about one's self and increased negative mood (Segerstrom, Tsao, Alden, & Craske, 2000; Ward, Lyubomirsky, Sousa, & Nolen-Hoeksema, 2003), higher levels of depression and longer lasting depressive symptoms (Nolen-Hoeksema & Morrow, 1991; Nolen-Hoeksema, Morrow, & Fredrickson, 1993), greater numbers of depressive episodes (Nolen-Hoeksema, 2000; Spasojevic & Alloy, 2001), and more intrusive thoughts (Watkins & Brown, 2002). However, little is known about the neural mechanisms underlying rumination.

The goal of the present study was to investigate the way in which individual differences in rumination influence the recruitment of brain regions involved in cognitive reappraisal. To achieve this goal, we used validated measures of trait rumination to predict brain activation while participants performed a task that required them to cognitively increase or decrease their negative affect using reappraisal. In this task, participants viewed negative or neutral photographs drawn from the international affective picture system (IAPS; see Lang, Greenwald, Bradley, & Hamm, 1993). The results having to do with the neural bases of specific types of reappraisal in this task have been reported elsewhere (Ochsner, Ray, et al., 2004; Ochsner et al., 2005). In the present analysis of this data set, we examined the relationship between rumination and reappraisal in four conditions that involved the use of reappraisal to actively increase or decrease negative affect and a baseline condition in which participants viewed images without the instruction to reappraise.[1]

In the first two conditions, participants were asked to cognitively increase their negative affective responses to either neutral or negative photographs. These conditions were thought to provide an experimental analogue of one type of affect-increasing cognitive operation in which ruminators, who regularly amplify their negative emotions, might excel. In the third condition, participants viewed negative and neutral photographs and let themselves respond naturally. This condition was thought to reflect uninstructed free-viewing conditions more typical of everyday life and allowed an opportunity to observe the way in which individual differences in rumination shape stimulus appraisals when participants are not given the explicit goal to change their affective response. In the fourth condition, participants used reappraisal to decrease negative affect to negative images. This condition reflects the use of thinking to alter feeling in a way not typically associated with rumination (i.e., turning negative affect down rather than up) and provides a measure of the extent to which rumination may influence the capacity to utilize reappraisal to make one's self feel better. Across all of these conditions, we hypothesized that the relationship between rumination and the neural substrates of reappraisal could manifest itself in two ways.

Our first hypothesis had two parts: (1a) that individual differences in trait rumination should be associated with the magnitude of activation in regions identified as playing an essential role in the use of reappraisal to increase or decrease negative affect (Ochsner & Gross, 2004; Ochsner, Ray, et al., 2004) and (1b) that individual differences in trait rumination should be associated with regions involved in appraising aversive events in general. Previous analyses of this data set have shown activation of dorsolateral prefrontal systems and increases in amygdala activation when cognitive reappraisal is used to increase negative affect (Ochsner, Ray, et al., 2004), and previous research has revealed that the maintenance of negative information in working memory can sustain amygdala activity after an aversive stimulus has disappeared (Schaefer et al., 2002). This pattern of sustained amygdala activity in response to negative information has also been demonstrated in depressed individuals and was modestly associated with the tendency to ruminate (Siegle, Steinhauer, Thase, Stenger, & Carter, 2002). In keeping with these findings, to the extent that trait rumination reflects a general enhanced facility to maintain representations of emotionally evocative thoughts concerning the self and to use these representations to amplify emotional responding, we expected trait rumination (1) to influence activation of prefrontal regions supporting cognitive reappraisal and (2) to heighten activation of the amygdala, which supports encoding of the aversive properties of stimuli. In addition, because trait rumination specifically reflects the tendency to reflect upon negative aspects of the self and events that increase negative affect, we expected rumination to functionally facilitate neural systems supporting reappraisal while participants were increasing negative affect and to functionally inhibit them while participants were using cognitive reappraisal to decrease negative affect.

Our second hypothesis stems from the fact that the targets of ruminative thoughts are most often one's self and one's negative feelings. Rumination's self-relevant cognitions may include thoughts about one's dispositions (e.g., "I am a failure"), thoughts about the actions and intentions of other people toward the self (e.g., "Why did he criticize me?"), and awareness of and attention to one's negative feelings (e.g., "Why do I always feel this way?"). Functional imaging studies have related each of these types of self-relevant cognition to activation of the medial prefrontal cortex (MPFC). The MPFC and related paracingulate regions are recruited when evaluating the self-descriptiveness of traits (Craik et al., 1999; Fossati et al., 2003; Johnson et al., 2002; Kelley et al., 2002; Kircher et al., 2002; Lieberman, Jarcho, & Satpute, 2004), judging the intentions or mental states of others (Gallagher & Frith, 2003; Ochsner, Knierim, et al., 2004), and making judgments about one's own feelings (Gusnard & Raichle, 2001; Lane, Fink, Chau, & Dolan, 1997; Ochsner, Knierim, et al., 2004; Phan et al., 2003). On the basis of these data, we hypothesized that individual differences in trait rumination should be associated with changes in activation in the medial prefrontal areas involved in self-referential processing and attention to one's emotions.

## METHOD

### Participants

Twenty-four right-handed females (mean age: 20.6 years) participated in compliance with Stanford University's human subjects guidelines and were reimbursed $60 for completion of the study. Only female participants were included in order to eliminate gender differences in variability of responses to negative images (e.g., Cahill et al., 2001; Canli, Desmond, Zhao, & Gabrieli, 2002; Kring & Gordon, 1998).

### Trait Rumination Measures

When conducting correlational analyses with the comparatively small sample sizes typical of imaging experiments, it is especially important that the individual-difference measures that are used provide a reliable and valid index of the psychological construct of interest. To ensure that rumination was measured broadly, three different measures of trait rumination were used to assess the tendency to ruminate about one's negative feelings and self-concept. This also allowed for measurement of a ruminative process that was neither depression- nor anger-specific, but reflected the underlying processes involved in both.

The first measure was the ruminative responses scale (RRS), which assesses depressive rumination style ($\alpha = .87$) with items such as "Why do I always react this way?" (Nolen-Hoeksema & Morrow, 1991). Two factors for the scale have been identified that measure the specific tendencies to "ponder" and "brood." The "brood" factor was identified as the more harmful rumination factor and was used for this study (Treynor, Gonzales, & Nolen-Hoeksema, 2003). The second measure was the rumination subscale of the rumination and reflection questionnaire (RRQ), which measures rumination on negative aspects of the self ($\alpha = .84$) with items such as "It's hard for me to shut off thoughts about myself" (Trapnell & Campbell, 1999). The final measure was the anger rumination scale (ARS), which measures rumination on angry thoughts, events, and memories ($\alpha = .92$) with items such as "I analyze events that make me angry" (Sukhodolsky, Golub, & Cromwell, 2001). These measures correlate with one another moderately ($r = .65$ to .71) in this sample, suggesting that together they provide an index of common ruminative tendencies.

### Behavioral Task

As we have described elsewhere (Ochsner, Ray, et al., 2004), the 24 female participants viewed 27 images in each of six different conditions defined by the crossing of two factors, type of instruction (increase, decrease, look) and type of photo (negative, neutral), for a total of 162 trials. As we described in the introduction above, four of these conditions were considered in the present analysis. On increase trials with negative and neutral images, the participants were instructed how to employ cognitive reappraisal to increase negative affect. On look trials with negative images, they were instructed to view the images and respond naturally without utilizing reappraisal. Look trials in response to neutral images were used as a baseline to create two of the four contrasts (increase neutral and look negative) but were not considered on their own. On decrease trials with negative images, the participants were instructed how to use cognitive reappraisal to decrease negative affect. Decrease trials in response to neutral images were not considered here.

The participants were randomly assigned to one of two groups that used either a self- or situation-focused strategy to reappraise. These strategies were found in piloting to be two of the most common types of reappraisal employed by participants. The self-focus participants were instructed to think about the personal relevance of each image. For example, when using cognitive reappraisal to increase negative affect, they were asked to think about the images in a way that increased their sense of subjective closeness to the pictured events by either thinking of themselves or a close other as taking the place of the central figure in the photo or by imagining themselves present, witnessing the actions unfolding. When using cognitive reappraisal to decrease negative affect, the self-focus participants were instructed to think about the pictures in a way that created a sense of objective distance, viewing pictured events from a detached, third-person perspective. The participants assigned to the situation-focus group were instructed to use cognitive reappraisal to reinterpret the emotions, actions, and outcomes of individuals as depicted in their situational context in the image. To increase negative affect using this strategy, the participants in this group were directed to think about the events in the image getting worse. To decrease negative affect, they were asked to think about pictured events getting better.

Each trial comprised four parts (Figure 1B). First, a cue word in all capital letters (INCREASE, DECREASE, or LOOK) appeared for 2 sec. Second, an aversive or neutral image appeared for 10 sec. While the image remained on the screen, the participants performed the cognitive operations specified by the instructional cue. Third, a rating scale appeared immediately after presentation of the photo. This scale allowed the participants to rate the current strength of their negative affect after both the uninstructed trials and instructed reappraisal trials; their ratings served as a behavioral index of the success of reappraisal. The scale consisted of a horizontal rectangular bar with the anchors 0 and 7 to indicate relative strength of negative affect. At the beginning of the 4-sec rating period, the bar grew

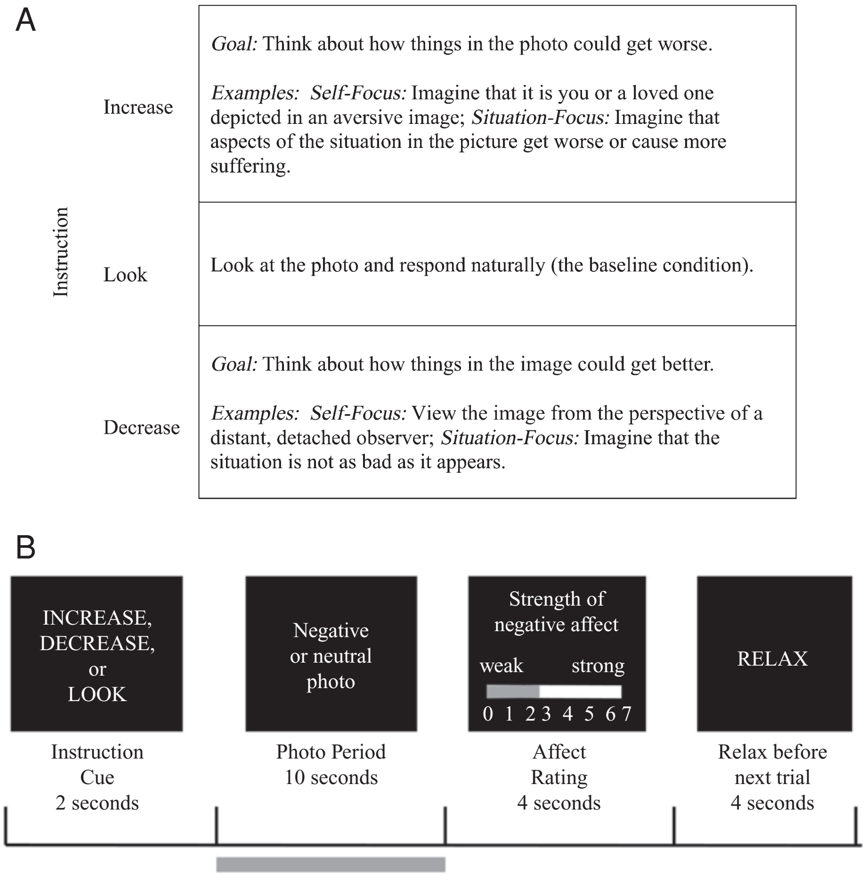


**Figure 1. (A) Table with the trial instruction cues and the instructions that participants were given during training. For both the increase and decrease instructions, the self-focus instruction is listed first and followed by the instruction given to the situation-focus participants. (B) Timeline of the trial structure. Trials started with an instructional cue, followed by a photo period during which participants followed the instructions associated with the preceding cue. After the photo disappeared from the screen, participants rated their negative affect, and finally they relaxed before the next trial began.**

from left to right and the participants pressed a key when the bar grew to a size that corresponded to the strength of their current negative feeling. This bar provided a continuous index of the participants' subjective experience of negative affect. The participants were instructed that although on some trials they might experience positive affect, we were only interested in measuring the strength of their negative affect. We elected to use a single rating of negative affect (and not to include an additional rating of positive affect) so as to keep the rating simple, keep the trial length as short as possible in order to increase the number of observations we could include per condition, and minimize the number of non-reappraisal-related cognitions the participants would engage in during the task. Fourth, the word RELAX appeared for 4 sec in the center of the screen in capital letters, indicating that the participants should relax until the next trial began. On increase trials, the participants were instructed to reappraise the situations in the pictures in such a way that they appeared worse by making either the situation involving themselves or the circumstances surrounding the picture become worse. In decrease trials, the participants reappraised images so that they thought about the situations in an objective and distant fashion or imagined the situations as improving. On look trials, the participants were instructed simply to look at the image and respond naturally. This trial type served as a baseline for comparison with the increase and decrease reappraisal trials. Highly negative and neutral images were selected from the IAPS (Lang et al., 1993) and were balanced for valence and arousal across instruction types. Images were seen in one of three quasi-random orders, so that different individuals saw each picture paired with a different instruction type. The contents of the negative pictures included various types of bodily injury (e.g., mutilations, burns, cuts, gunshot wounds), violence (e.g., a man attacking a woman with a knife), and victims of crime and starvation, whereas the contents of the neutral images included common household objects (e.g., chair, bowl) and individuals with neutral facial expressions.

**Individual-Difference Assessment and Pretraining**

Three to 5 days prior to scanning, the participants first completed the individual-difference measures and were trained on the task in the Stanford psychology department. During this session, they received instructions and guidance in the reappraisal strategy they would be assigned to use in the scanning session. The participants read a brief description of either the self- or situation-focused strategies that they were assigned to employ and then viewed a series of images for which they were asked to generate appropriate reappraisals spontaneously. The experimenter helped shape these reappraisals so that they fit the self- or situation-focused strategy that the participant was instructed to use. Experimenters also stressed that participants not reappraise stimuli using other strategies not relevant to the individual participant's group assignment. The participant then completed a block of 27 practice trials whose length was equivalent to one of the scans the participant would later complete in the scanner. At the end of this practice block, the experimenters debriefed the participants to ensure that they were able to reappraise effectively and to address any questions a participant might have. This training ensured that the participants understood the specific type of strategy they were to employ inside the scanner and that they could effectively implement that strategy to reappraise negative images. The experimenters emphasized that the participants should do their best to reappraise on each trial when asked to do so and should accurately report the strength of their negative affect whether or not they felt reappraisal had changed the way they felt.

### MRI Data Acquisition

Whole-brain images were collected on a 3T GE Signa LX Horizon Echospeed scanner. Twenty-five axial slices (4 mm thick, 1-mm gap) with a T2*-sensitive gradient echo spiral-in/out pulse sequence (30 msec TE, 2,000 msec TR, 2 interleaves, 60º flip angle, 24-cm field of view, 64 × 64 data acquisition matrix; see Glover & Law, 2001) followed a high-order shim using the scanner's software (developed in the Lucas Center for GE; see Glover, 1999). T2-weighted flow-compensated spin-echo scans were acquired for anatomical localization using the same slice prescription (2,000 msec TR; 85 msec TE). The spiral-in/out sequence has been found particularly valuable in reducing susceptibility dropout in frontal and medial temporal brain regions (Glover & Law, 2001; Preston, Thomason, Cooper, Ochsner, & Glover, 2004). Stimulus presentation and data acquisition were controlled using PsyScope software (Cohen, MacWhinney, Flatt, & Provost, 1993) running on a Macintosh G3 computer. An LCD projector displayed stimuli on a screen mounted on a custom head coil fitted with a bite bar to limit head motion. Responses were made with the index finger of the right hand using one button on a four-button response box.

### Data Analysis

Functional images were slice-time and motion corrected using SPM99 (Wellcome Department of Imaging Neuroscience, University College London). Anatomical images were coregistered to the mean functional image and normalized to a standard template brain; the functional images were then normalized using those parameters and interpolated to 2 × 2 × 2 mm voxels. Functional images were smoothed with a Gaussian filter (6-mm full width at half maximum). A high-pass filter with a cutoff period of 120 sec was applied to remove drifts within sessions.

Fixed effects for each participant were modeled using a mixed design. The 2-sec instruction period and 4-sec rating period were modeled with a canonical hemodynamic response function at the onset of each period; the 10-sec regulation period and 4-sec relaxation period were modeled as a boxcar regressor convolved with the canonical hemodynamic response. A general linear model analysis was used in SPM99 to create contrast images for each participant summarizing differences between trial types.

The results of the main effect contrasts for these data have been reported elsewhere (Ochsner, Ray, et al., 2004; Ochsner et al., 2005). In the present analysis, we sought to determine whether individual differences in rumination modulate activity in areas recruited by cognitive reappraisal. To do so, scores from all three rumination measures for each individual were entered separately into a whole-brain multiple regression analysis using the four contrast images of interest to create SPM$\{t\}$ maps for the group. These analyses were thresholded at $p < .001$ with an extent threshold of 10 voxels. Motivated by a priori hypotheses concerning the role of the amygdala in cognitive reappraisal and its predicted association with rumination, we performed small-volume corrected region of interest (ROI) analyses for structurally defined amygdala volumes derived from coordinates specified in the Talairach atlas. ROIs were transformed into MNI space and smoothed with the same kernel as the functional data. Maxima are reported in MNI coordinates. Fisher's $z$ tests revealed no differences between the self-focus and situation-focus instruction groups, so analyses were collapsed across groups.

## RESULTS

### Behavioral Results

Multiple regressions of trait individual differences in rumination on self-reported negative affect did not predict negative affect when simply viewing pictures, when using reappraisal to increase negative affect, or when employing reappraisal to decrease negative affect. This held true for the whole-group analyses collapsing across instruction types and did not covary with instruction type. In addition, there were no differences between the instruction groups in any of their rumination scores.

### Imaging Results

Multiple regression of trait rumination measures on imaging data was used to test our two hypotheses that individual differences in trait rumination (1a) would be associated with the magnitude of activation in regions known to be involved in reappraisal, including prefrontal cortex and/or the amygdala, when using reappraisal to increase or decrease negative affect; (1b) would be associated with increases in amygdala responses during uninstructed periods; and (2) would be associated with activations in systems involved in self-reflective thought and awareness of one's emotions, although the systems were not specifically implicated in reappraisal. These hypotheses were tested by looking at activated regions associated with trait measures of rumination in the following experimental conditions: when using reappraisal to increase negative affect in response to an already negative stimulus, when using reappraisal to increase or manufacture negative affect in response to a neutral stimulus, when responding naturally to negative stimuli without a regulatory goal, and when using reappraisal to decrease negative affect.

**Relationship between trait rumination and reappraisal to increase negative affect**. To the extent that rumination influences processes engaged when participants are explicitly instructed to make themselves feel more negative, we expected that individuals who ruminate might differentially recruit brain systems supporting the active, goal-directed use of cognitive reappraisal to increase negative emotion. To address this question, multiple regressions were performed to relate levels of trait rumination to the magnitude of activation in regions involved when reappraisal was used to increase negative responses. These regions were identified in the increase > look contrasts for negative and neutral pictures, respectively (Table 1). When reappraisal was used to increase

**Table 1**
**Results of Regression Analyses Correlating Level of Rumination With Magnitude of Activation in Regions Identified From Contrasts**

| Region of Activation | BA | Coordinates | | | $z$ | Volume | SV | |
|---|---|---|---|---|---|---|---|---|
| | | $x$ | $y$ | $z$ | Score | (mm³) | Uncorrected | Corrected |
| | | | Increase Neutral > Look Neutral | | | | | |
| Inferior frontal gyrus | L47 | −32 | 18 | −10 | 3.56 | 36 | $p < .001$ | |
| Putamen | L | −20 | 8 | 2 | 3.81 | 88 | $p < .001$ | |
| Parahippocampal gyrus | R30 | 16 | −40 | −6 | 3.51 | 17 | $p < .001$ | |
| Precentral gyrus | R6 | 50 | −2 | 52 | 3.34 | 12 | $p < .001$ | |
| Fusiform gyrus | L | −30 | −58 | −14 | 3.66 | 22 | $p < .001$ | |
| Middle temporal gyrus | R19 | 30 | −54 | −2 | 3.56 | 19 | $p < .001$ | |
| Amygdala* | L | −22 | 0 | 16 | 3.72 | 75 | $p < .001$ | $p = .008$ |
| Amygdala* | R | 22 | −2 | −16 | 2.67 | 34 | $p < .004$ | $p = .067$ |
| | | | Increase Negative > Look Negative | | | | | |
| Amygdala* | L | −16 | −4 | −18 | 2.25 | 18 | $p < .012$ | $p = .142$ |
| Amygdala* | R | 20 | 2 | −22 | 2.99 | 33 | $p < .001$ | $p = .029$ |
| | | | Look Negative > Look Neutral | | | | | |
| Inferior frontal gyrus | L47 | −34 | 16 | −18 | 3.72 | 89 | $p < .001$ | |
| Amygdala* | L | −26 | 2 | 16 | 2.96 | 16 | $p < .002$ | $p = .039$ |
| Amygdala* | R | 28 | 2 | −16 | 2.03 | 13 | $p < .021$ | $p = .223$ |
| | | | Decrease Negative > Look Negative | | | | | |
| — | – | – | – | – | – | – | — | — |
| | | | Look Negative > Decrease Negative | | | | | |
| Anterior cingulate | L32 | −10 | 48 | −4 | 3.38 | 52 | $p < .001$ | |
| Anterior cingulate | R32 | 6 | 36 | −10 | 4.41 | 234 | $p < .001$ | |
| Anterior cingulate | L24 | −4 | 32 | −2 | 3.42 | 26 | $p < .001$ | |
| Medial frontal gyrus | L10 | −8 | 50 | −2 | 3.38 | 58 | $p < .001$ | |
| Medial frontal gyrus | R10 | 6 | 50 | −2 | 3.55 | 35 | $p < .001$ | |
| Amygdala* | L | −24 | −4 | −26 | 1.95 | 11 | $p < .026$ | $p < .221$ |
| Amygdala* | R | 20 | −4 | −24 | 3.22 | 46 | $p < .001$ | $p < .015$ |

Note—SV, small volume. Clusters with 10 or more contiguous voxels at $p < .001$ uncorrected are reported. Coordinates reported are in MNI space. *Small volume and two-tailed corrected at $p < .05$. Fisher's $z$ analyses revealed no differences between strategy groups, so analyses were collapsed across groups.

negative responses to neutral images (increase neutral > look neutral), participants with a greater tendency to ruminate showed a greater magnitude of activation in the left amygdala ($p < .001$ uncorrected, $p = .008$ corrected for small volume; see Table 1; Figures 2B, 2C) with a trend toward a similar effect in the right amygdala ($p < .004$ uncorrected, $p = .067$ corrected; see Table 1; Figures 2B, 2D). Also, the magnitude of activation in a region of left ventrolateral prefrontal cortex (BA 47) correlated positively with a tendency to ruminate ($p < .001$ uncorrected, $p = .078$ corrected; see Figure 2A). In the context of negative pictures (increase negative > look negative), trait rumination predicted the magnitude of activation in the right amygdala ($p < .001$ uncorrected, $p = .029$ corrected; see Table 1). Trait rumination was not predictive of the magnitude of activation in the left amygdala after correcting for volume ($p < .012$ uncorrected, $p = .142$ corrected; see Table 1).

**Relationship between trait rumination and unregulated responses to negative events**. To the extent that the processes supporting rumination are active even when participants are not explicitly instructed to make themselves feel more negative, we expected that individuals who tend to ruminate might differentially recruit brain systems involved with negative information when they were told to "let themselves respond naturally." To address this question, a multiple regression was performed relating levels of trait rumination to the magnitude of brain activation in the contrast between trials when participants simply looked at negative or neutral pictures (look negative > look neutral) and let themselves respond naturally. In this condition, trait rumination correlated with the magnitude of activity in the left amygdala ($p < .002$ uncorrected, $p < .039$ corrected) and left ventrolateral prefrontal cortex region BA 47 ($p < .001$ uncorrected, $p = .055$ corrected).

**Relationship between rumination and the use of reappraisal to decrease negative affect**. To the extent that rumination, which involves the use of cognition to mentally review aversive events, influences the ability to regulate negative emotion in general, we expected that individuals who ruminate might differentially recruit brain systems supporting the use of reappraisal to decrease their negative feelings. To address this question, separate multiple regressions were performed to correlate levels of trait rumination with the magnitude of brain activation in regions supporting reappraisal used to decrease negative affect and with the magnitude of activation in those regions representing negative affect being modulated by reappraisal. These two contrasts are,

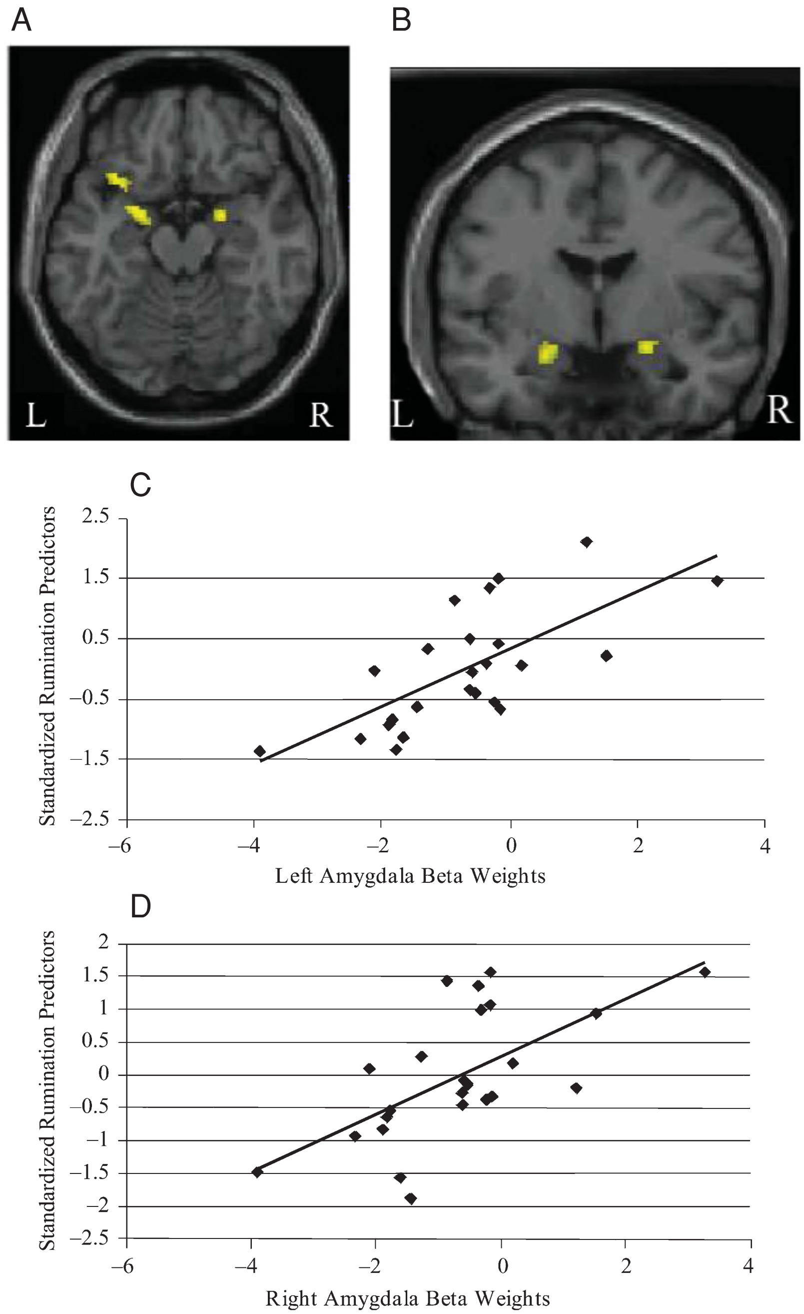


**Figure 2. (A) Axial slice showing bilateral amygdala and lateral BA 47 ($p < .05$) while negative affect to neutral pictures was increased (increase neutral > look neutral) for participants who tended to ruminate. (B) Coronal slice with left and right amygdala regions of interest thresholded at $p < .05$. (C) Scatterplot graph of the standardized predictor rumination scales regressed on to beta weights in the left amygdala ($R^2 = .481$; $p < .008$ small-volume corrected). (D) Scatterplot graph of the standardized predictor rumination scales regressed on to beta weights in the right amygdala ($R^2 = .396$; $p < .067$ small-volume corrected).**

respectively, decrease > look trials and look > decrease trials for negative images (Table 1). Regression analysis for the contrast decrease negative > look negative did not reveal any regions whose magnitude significantly correlated with the tendency to ruminate. However, the multiple regression for the look negative > decrease negative contrast revealed that individual differences in rumination predicted the magnitude of activation in multiple regions of ACC and MPFC (including bilateral anterior regions BA 24 and 32 and medial region BA 10; see Table 1; Figures 3A, 3B) implicated in self-referential processing in previous research (Craik et al., 1999; Fossati et al., 2003; Johnson et al., 2002; Kelley et al., 2002; Kircher et al., 2002; Lieberman et al., 2004), as well as emotion-processing areas such as the right amygdala ($p < .001$ uncorrected, $p = .015$ corrected).

For those who report higher rumination, the finding of greater magnitude of activation in medial prefrontal regions in the look > decrease negative contrast could reflect a chronic tendency to recruit medial prefrontal regions across all conditions to engage self-referential processing in order to increase negative emotion. If this is the case, differential recruitment of MPFC might not be detected in contrasts of increase and look trials because medial prefrontal regions could be recruited during look as well as increase trials, though possibly at different magnitudes. To address this possibility, for all three foci of medial prefrontal activation, post hoc analyses were performed on anatomically defined ROIs, and levels of trait rumination correlated with the magnitude of activation in both the increase negative > look negative and increase neutral > look neutral contrasts, as well as in the look negative > look neutral contrast. In these contrasts, the magnitude of activation of all three medial prefrontal areas showed modest significant positive correlations with the tendency to ruminate ($p < .05$ uncorrected, $p < .2$ small-volume corrected).

## DISCUSSION

Little is known about how the tendency to ruminate may facilitate or inhibit the use of cognitive reappraisal to think about situations as much worse or much better. This study provides the first evidence regarding the relationship between individual differences in rumination and the neural bases of cognitive reappraisal for regulating affect.

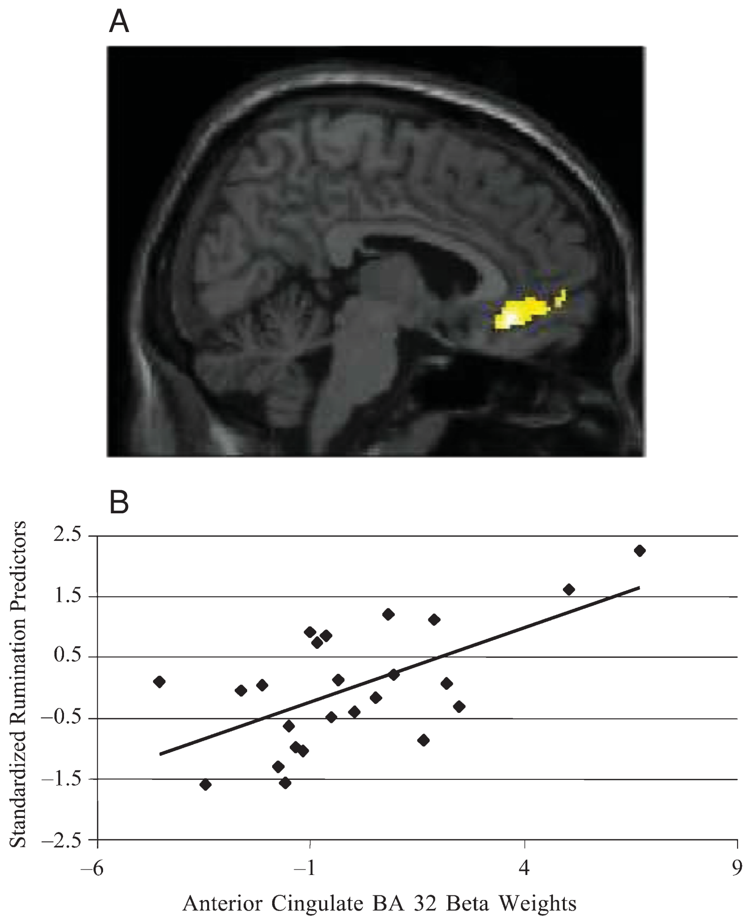


**Figure 3. (A) Sagittal slice showing increased medial prefrontal activation in medial BA 10 and anterior cingulate BA 24 and 32 ($p < .001$ uncorrected) in the contrast look negative > decrease negative for participants who tended to ruminate. (B) Scatterplot graph of the standardized predictor rumination scales regressed on to beta weights for BA 32 ($R^2 = .379$; $p < .05$ corrected for multiple comparisons).**

By looking at conditions that involved the use of cognitive reappraisal both to increase negative responses in neutral and negative contexts and to decrease negative responses, it was possible to explore the impact of individual differences in rumination on the neural bases of cognitive reappraisal. Three primary findings were observed.

The first relates to our hypothesis that rumination could be related to recruitment of neural systems involved in using reappraisal to cognitively increase negative affect. We found that when reappraisal was used for this purpose, the tendency to ruminate correlated with activation of structures involved in representing and encoding emotional value and affective salience. Specifically, when participants used cognitive reappraisal to create a negative response to neutral images, the left amygdala and to a lesser extent the right amygdala correlated with rumination scores. In addition, the left ventrolateral prefrontal cortex, which has been associated with representing changes in the affective relevance of stimuli (Bechara, Damasio, & Damasio, 2000; Ochsner, Ray, et al., 2004; O'Doherty, Dayan, Friston, Critchley, & Dolan, 2003; O'Doherty, Kringelbach, Rolls, Hornak, & Andrews, 2001; Rolls, 2000), also correlated with individual differences in rumination. Notably, a similar pattern held when cognitive reappraisal was used to increase negative affect already being generated in response to negative pictures. In this case, a greater magnitude of activation in the right amygdala correlated with tendencies to ruminate. Taken together, these findings are consistent with the idea that rumination is associated with the recruitment of brain systems involved in bottom-up encoding and representation of the affective properties of stimuli, in this case the amygdala (Anderson & Phelps, 2001; Ochsner et al., 2005), as well as of brain systems, such as the orbitofrontal cortex, that are involved in updating the contextual value of affective stimuli (Bechara et al., 2000; Ochsner, Ray, et al., 2004; O'Doherty et al., 2003; O'Doherty et al., 2001; Rolls, 2000).

The second finding also relates to the hypothesis that rumination may influence systems involved in cognitively increasing negative affect. In those trials in which no explicit reappraisal instruction was given, it was hypothesized that individual differences in rumination could shape responses to the negative and neutral pictures. This hypothesis was confirmed: When participants looked at negative pictures without instructions to regulate, the magnitude of activity in the left ventrolateral prefrontal cortex and left amygdala was greater for those with a greater tendency to ruminate. This finding is strikingly similar to that observed when participants were explicitly instructed to use reappraisal to increase negative affect and is consistent with the idea that rumination may be associated with the recruitment of brain systems associated with representing and updating the affective salience of stimuli, even when participants are not given the explicit goal to regulate their feelings.

Finally, the third finding relates to our hypothesis that rumination might impact recruitment of brain systems not typically associated with reappraisal, but systems associated with the negative self-referential thought characteristic of ruminators. This hypothesis also was confirmed: We observed that those higher in rumination—who tend to focus on negative thoughts about themselves and negative feelings—showed significantly decreased magnitudes of activation in the ACC (BA 24 and 32) and MPFC (BA 10) regions previously associated with affective awareness and self-referential thought (e.g., Gusnard & Raichle, 2001; Lane et al., 1997; Lane et al., 1998; Ochsner, Knierim, et al., 2004). This finding suggests that when individuals who typically ruminate try to think about a situation in less emotional terms, they stop attending to thoughts about themselves and their emotions in order to do so. We also observed a modest positive correlation between the magnitudes of activation of these medial prefrontal regions and trait rumination when participants deliberately used reappraisal to increase their negative emotion (increase > look). The correlation of rumination with medial prefrontal activation during both look negative and increase trials is consistent with the notion that ruminators may tend to chronically recruit medial prefrontal regions engaged in negative self-referential processing.

Intriguingly, our secondary hypothesis that rumination might inhibit recruitment of systems involved in the use of cognitive reappraisal to decrease negative affect was not clearly supported. No prefrontal areas previously identified as being involved in supporting cognitive reappraisal to decrease negative affect were recruited less as a function of the tendency to ruminate. However, rumination did predict decreases in the magnitude of activation in the right amygdala when cognitive reappraisal was employed to decrease negative responses to negative pictures. Taken together, the combination of diminished amygdala activation on decrease trials and relatively greater medial prefrontal recruitment on look negative and increase trials suggests a chronic tendency for ruminators to engage in negative self-referential thought, but it also reflects an ability to disengage this tendency when instructed, thereby decreasing amygdala and MPFC activation.

An additional surprising finding was that self-reports of negative affect did not correlate with self-reported trait rumination. Thus, individual differences in rumination neither predicted increases in self-reported affective responses to the pictures when using cognitive reappraisal to increase negative responses, nor did they predict decreases when cognitive reappraisal was used to decrease negative responses. Similarly, in the instructionally less constrained look trials, when it might be expected that individual differences would exert a greater impact on affective responses, the tendency to ruminate did not predict negative affect reports. Although the precise reason for these findings is not clear, one salient possibility has been suggested in previous work. It has been suggested that self-report measures may be the output of many processes and for that reason may be "noisier" than imaging measures of activation in brain structures that may more directly reflect processes related to processing affective information (Canli et al., 2001). On the basis of the present results, it is therefore possible that larger sample sizes may be needed to show correlations between affect and rumination, which is itself a self-report measure. Given that small sample size is typical of fMRI studies, it may be challenging to uncover modest correlations between two self-report measures.

### Significance of Relationship Between Rumination and Up-Regulatory Reappraisal

Given that this is the first study to examine the relationship between rumination and the neural systems related to emotion regulation, it is significant that many of our initial hypotheses were supported. However, like any initial study, the results raise many intriguing questions to be explored in future research. At least three aspects of the present results merit further consideration.

The first is that although our hypothesis that rumination predicts recruitment of reappraisal-related systems involved in the increase of negative affect was confirmed for the amygdala and ventrolateral/orbitofrontal cortex, regions that have both been previously implicated in reappraisal (Ochsner et al., 2002; Ochsner, Ray, et al., 2004; Ochsner et al., 2005; Schaefer et al., 2002), our hypothesis was not confirmed for areas in the DLPFC that have also been associated with implementing strategic reappraisal processes. In neither negative nor neutral contexts in which cognitive reappraisal was used to increase negative responses did the tendency to ruminate correlate with the magnitude of activation in dorsolateral prefrontal areas associated with maintaining information in working memory (Miller & Cohen, 2001; Smith & Jonides, 1999). This finding suggests that rumination may not be related to differential recruitment of those areas underlying the top-down processes involved in cognitive reappraisal, but may instead contribute to heightened encoding of the affective relevance or arousing properties of stimuli; both operations have been associated with the amygdala and orbitofrontal cortex.

There could be several reasons for the fact that a heightened response is isolated to affect processing systems. One possibility is that affective systems are "tuned" to amplify responses to potentially negative information in ruminators, either because of genetic factors (Hariri et al., 2002) or as a result of repeated learning episodes involving rumination. Thus, ruminators might more efficiently recruit prefrontal systems, so that a small change in prefrontal activity predicts large changes in amygdala response. A second, related possibility is that rumination and reappraisal differ only in the content of working memory and, consequently, do not result in differential recruitment of DLPFC. Given that very little is known about the relationship between prefrontal activity and even slight variations of strategy content associated with reappraisal (Ochsner, Ray, et al., 2004), this possibility could be a fruitful avenue for future research.

The second intriguing result concerns the parallel findings between conditions in which cognitive reappraisal was used to increase negative responses to either neutral or negative images and the uninstructed condition in which participants just looked at negative images. In all of these cases, individual differences in rumination correlated with increased activation in the amygdala. In addition, both when reappraisal was used to increase negative affect to neutral images and when participants just looked at negative images, those who tended to ruminate recruited more left ventrolateral prefrontal cortex than when they simply looked at neutral images. This parallelism may reflect the ability of those who tend to ruminate to amplify the affective value of the stimuli through an affective updating process involving interactions between ventrolateral prefrontal cortex and the amygdala (e.g., O'Doherty et al., 2003; O'Doherty et al., 2001). In the increase neutral context, those who tend to ruminate may be more adept at cognitively conceiving a worsening situation, and in the look conditions, these same individuals may be more likely to amplify their negative response habitually by tying the contents of the images to themselves or their goals rather than simply passively viewing the images.

### Significance of Relationship Between Rumination and Down-Regulatory Reappraisal

We hypothesized that because rumination generally involves increasing negative emotion, we might observe a failure to effectively recruit reappraisal-related systems when participants were asked to decrease negative affect. We observed that when cognitive reappraisal was used to decrease negative affect—and also when it was used to increase negative affect—none of the areas that have been implicated in generation and maintenance of a reappraisal strategy correlated with individual differences in rumination. Thus, ruminators did not fail to recruit prefrontal cortex when reappraising. We also observed, however, that in the condition of decreasing negative affect, rumination predicted decreases in bilateral medial prefrontal area BA 10 and adjacent anterior cingulate areas BA 24 and 32. These medial frontal areas have been implicated in emotion processing (Christoff, Ream, Geddes, & Gabrieli, 2003; Steele & Lawrie, 2004), self-referential processing (Craik et al., 1999; Kelley et al., 2002; Kircher et al., 2002; Macrae, Moran, Heatherton, Banfield, & Kelley, 2004), self-reflective awareness of emotion (Johnson et al., 2002; Kjaer, Nowak, & Lou, 2002; Ochsner, Ray, et al., 2004), reasoning about the mental states of other people (Frith & Frith, 1999) and spontaneous stimulus-independent thought (Gusnard & Raichle, 2001; McGuire, Paulesu, Frackowiak, & Frith, 1996). The fact that rumination predicted decreasing activation in these areas but not in DLPFC is consistent with the idea that as they feel less negative, ruminators become less self-focused and less aware of their emotional responses. This may correspond to turning off a negative self-focused narrative that is typically used by ruminators to increase their negative affect. These areas were more active for look negative trials—in which participants were allowed to have their natural thoughts—than for decrease negative trials—in which their thoughts were constrained in accordance with task instructions. This suggests that when left to their own devices, individuals who tend to ruminate may self-reflect and thus show more activation in the MPFC areas mentioned.

It is noteworthy that the tendency to ruminate predicted the ability to down-regulate amygdala responses when individuals used reappraisal to successfully decrease their negative emotions. This finding runs counter to the intuitive expectation that ruminators, who typically make themselves feel more negative, should be unable to make themselves feel less negative. The present results indicate that they are no worse than nonruminators in making themselves feel better, and may even decrease amygdala responses more effectively. One explanation for this finding is that by repeatedly turning over interpretations of events in their minds, those who tend to ruminate have developed the cognitive skill of representing information flexibly, in ways that can make themselves feel either worse or better. How their thoughts make them feel may be a function of chronic and contextual goals. In the context of the present experiment, they had the explicit goal of decreasing negative affect and did so both experientially and neurally. In everyday life, however, they may not have this goal, and may actually be motivated to ruminate by a goal to understand themselves, which engages negative self-referential processing that (unintentionally) ends up making them feel worse (Papageorgiou & Wells, 2003; Simpson & Papageorgiou, 2003). This interpretation runs counter to the findings of Davis and Nolen-Hoeksema (2000), who have found that depressive ruminators show an inflexible cognitive style in the Wisconsin Card Sort Test. One explanation for this discrepancy could be that their card sorting behavior has seemed inflexible because participants were distracted from correctly performing a challenging task by ruminative thoughts, whereas participants in the present experiment had the singular task of engaging cognitive operations thought to be characteristic of rumination itself. Another possible explanation for this difference is that our study combined several individual-difference measures of rumination in order to achieve a broad-based measure that was less tied to rumination on particular emotions such as anger or sadness. It is also possible that depressive rumination specifically influences executive function in a way not assessed here.

## Conclusions and Future Directions

In closing, it is worth noting that this study analyzed rumination from a process perspective that attempts to isolate processes related to turning negative self-relevant information over in one's mind, rather than from an entity perspective that would treat rumination as a global personality variable to be correlated with other measures. The former approach is characteristic of other cognitive neuroscience studies of personality and individual differences that have linked personality to hypotheses about specific processes associated with specific brain systems involved in, for example, recognizing facial expressions of emotion (Canli, Sivers, Whitfield, Gotlib, & Gabrieli, 2002; Keightley et al., 2003). The latter approach is more typical of behavioral studies that cannot examine differential recruitment of specific psychological processes that may be revealed by patterns of neural activation. The use of functional neuroimaging may therefore provide a tool for examining specific predictions about the impact of a psychological construct that varies across individuals—in this case the tendency to engage in ruminative thought—on the recruitment of specific neural mechanisms.

Finally, it is important to note that this correlational study does not directly assess the neural systems recruited when participants engage in ruminative thought, and instead examines the relationship of rumination to the mechanisms recruited when reappraising. Future research should directly compare conditions in which participants engage in ruminative thought per se with conditions in which participants reappraise in the way studied here. Such research will be crucial in further clarifying the overlap of neural processes involved in each type of cognitive control. On the basis of the present results, it might be expected that reappraisal used to increase negative affect would look very similar to rumination. However, these two processes might look very different both neurally and in terms of their affective trajectories. Direct-comparison studies of these processes could help to elucidate the mechanisms underlying the associations of rumination with depression (Morrow & Nolen-Hoeksema, 1990) and of down-regulatory reappraisal with larger social networks and positive mental health outcomes (Gross & John, 2003). We thus see our work in the context of a long tradition, going back to Plato and Aristotle, concerned with the mechanisms of reason and passion, and with how people can effect a suitable balance between them.

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## NOTE

1. Simple main effect contrasts for portions of the data presented in this study have been presented in detail elsewhere (Ochsner, Ray, et al., 2004). The present article represents a new individual-difference analysis of the data presented in that article, as well as individual-difference analyses of conditions not previously presented.

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