

Effects of valence and divided attention on cognitive reappraisal processes

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Numerous studies have investigated the neural substrates supporting cognitive reappraisal, identifying the importance of cognitive control processes implemented by prefrontal cortex (PFC). This study examined how valence and attention affect the processes used for cognitive reappraisal by asking participants to passively view or to cognitively reappraise positive and negative images with full or divided attention. When participants simply viewed these images, results revealed few effects of valence or attention. However, when participants engaged in reappraisal, there was a robust effect of valence, with the reappraisal of negative relative to positive images associated with more widespread activation, including within regions of medial and lateral PFC. There also was an effect of attention, with more lateral PFC recruitment when regulating with full attention and more medial PFC recruitment when regulating with divided attention. Within two regions of medial PFC and one region of ventrolateral PFC, there was an interaction between valence and attention: in these regions, divided attention reduced activity during reappraisal of positive but not negative images. Critically, participants continued to report reappraisal success even during the Divided Attention condition. These results suggest multiple routes to successful cognitive reappraisal, depending upon image valence and the availability of attentional resources.

Keywords: affect; cognition; emotion; prefrontal; regulation; fMRI

INTRODUCTION

What are the building blocks of a life that flourishes and is subjectively 'happy'? Happiness and emotional well-being are certainly high on most individuals' lists of essential life goals (see Suh *et al.*, 1998), and research has shown that intentional activity, such as consciously regulating emotions to make ourselves feel better (Lyubomirsky *et al.*, 2005a), contribute to our happiness. Indeed, as suggested by Lyubomirsky *et al.* (2005b), 'intentional activities [may] offer the best potential route to higher and sustainable levels of happiness' (p. 115).

Emotion regulation is one cognitive process that is an important part of psychological health and well-being (for a review, see Nyklicek *et al.*, 2011), allowing individuals to flexibly assess and respond to situations in ways that permit them to minimize negative or maximize positive affect (Gross, 1998). Regulatory processes of emotion regulation can help attenuate inappropriate, unchecked or extreme emotional reactions that could be seen or felt as personally, socially or behaviorally unwanted or abnormal (Parrott, 1993; Cicchetti *et al.*, 1995; Gross and Munoz, 1995; Mayer and Salovey, 1995; Paulhus *et al.*, 1997).

There are a number of strategies that lead to successful emotion regulation via the up-regulation or down-regulation of an emotional response to a stimulus. Specifically, antecedent-focused strategies are those that are evoked as input is initially being processed, and response-focused strategies are those that act on the output from the system rather than its inputs (Gross, 1998). In this experiment, we focus on the antecedent-focused strategy of reappraisal, which has been defined as 'changing the way we think in order to change the way we feel' (Ochsner and Gross, 2004, p. 2). Individuals can use

cognitive reappraisal to up-regulate or to down-regulate the intensity of an emotional response, and to influence the resultant physiological (e.g. Mauss *et al.*, 2007), cognitive (e.g. Gross, 2003) or social outcomes (e.g. Gross, 2003) associated with the emotional reaction. It is one of the most effective means for emotion regulation (Gross and John, 2003), and it has been widely studied using behavioral and cognitive neuroscientific approaches (reviewed by Gross and Thompson, 2007).

Reappraisal may rely on many of the same cognitive control processes that are used to modify or inhibit other behavioral responses (Davidson and Irwin, 1999; Ochsner and Feldman Barrett, 2001; Kanske *et al.*, 2011). Studies examining the effect of cognitive reappraisal on simultaneous or subsequent task performance have provided behavioral evidence for a role of cognitive control in reappraisal: actively reappraising emotions can disrupt performance on cognitively demanding tasks performed simultaneously or shortly after the reappraisal (Richards, 2004; Baumeister *et al.*, 2007), suggesting that reappraisal may utilize, and thereby deplete, cognitive resources. Neuroimaging studies have further linked reappraisal to cognitive control processes. Cognitive reappraisal has been tied to activation in various regions of the prefrontal cortex (PFC), including the dorsolateral PFC, ventrolateral PFC, ventromedial PFC (often extending into the cingulate gyrus) and dorsomedial PFC. These regions have been implicated in working memory and selective attention, response selection and inhibition, monitoring processes and the reflection on affective states, respectively (e.g. Beauregard *et al.*, 2001; Levesque *et al.*, 2004; Ochsner *et al.*, 2004; Kalisch *et al.*, 2005, 2006; Phan *et al.*, 2005; Urry *et al.*, 2006; Eippert *et al.*, 2007; Kim and Hamann, 2007). Not only are these regions recruited during cognitive reappraisal, but their recruitment is also correlated with participants' success in regulating their emotions (e.g. Ochsner *et al.*, 2002; Goldin *et al.*, 2008; McRae *et al.*, 2010).

Although much research points to a role for cognitive control in the reappraisal process, it is less clear how individuals implement these reappraisal processes when cognitive resources are taxed. Despite the fact that cognitive reappraisal processes are typically attention-demanding, there is evidence for successful reappraisal even in populations with depletion of cognitive resources (e.g. older adults;

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Urry and Gross, 2010) and in conditions where distractions are present (e.g. Leroy *et al.*, 2012). This finding raises the question of whether depletion of cognitive resources leads to a potential emotion regulation ‘workaround’, so that effective reappraisal can still be realized in depleted conditions. This workaround could reflect a shift from a more demanding to a less demanding reappraisal strategy. For instance, evidence suggests that a distancing approach (detached reappraisal) is impaired in old age, but a re-framing approach (positive reappraisal) is enhanced (Shiota and Levenson, 2009). More generally, it could reflect multiple neural routes to the same reappraisal outcome, although evidence for such routes has not yet been demonstrated. These possibilities raise the question of whether or how the depletion of cognitive resources in younger adults affects the engagement of cognitive reappraisal processes. We address this question by asking participants either to devote their full attention to a cognitive reappraisal task or to divide their attention between a reappraisal task and an auditory-discrimination task while undergoing an functional magnetic resonance imaging (fMRI) scan.

We also address the possibility that the effect of divided attention on cognitive reappraisal processes may differ depending upon the valence of the information reappraised. Though most neuroimaging research has examined the reappraisal of responses to negative stimuli (e.g. Ochsner *et al.*, 2002, 2004; Eippert *et al.*, 2007; Goldin *et al.*, 2008; Hayes *et al.*, 2010; McRae *et al.*, 2010), a few studies have also examined the cognitive reappraisal of positive stimuli (Beauregard *et al.*, 2001; Kim and Hamann, 2007; Mak *et al.*, 2009). The extant data suggest that regulation of negative pictures may recruit a more widespread network of frontal regions (including medial, lateral, orbitofrontal and cingulate cortex), whereas the regulation of positive stimuli may recruit a more concise network of frontal regions (including medial PFC). For example, Kim and Hamann (2007)—when comparing the up- and down-regulation of images to passively viewing them—found that the regulation of negative images activated the dorsomedial PFC, lateral PFC, anterior cingulate gyrus and orbitofrontal cortex, whereas the regulation of positive pictures activated the dorsomedial and orbital PFC. Similarly, Mak *et al.* (2009)—when comparing hedonic regulation to viewing of images—found that the regulation of negative pictures activated orbitofrontal cortex, anterior cingulate, lateral PFC, precuneus and middle occipital gyrus, whereas the regulation of positive images activated dorsomedial and dorsolateral PFC.

Some research suggests that, at least in young adults, negative or threatening stimuli may be processed more automatically (Vuilleumier *et al.*, 2001; Gläscher and Adolphs, 2003; Kimura *et al.*, 2004) or preferentially (Dijksterhuis and Aarts, 2003; Zhao and Li, 2006; De Martino *et al.*, 2009) than neutral and/or positive stimuli. For instance, fearful faces are more likely to capture attention than happy faces (Bradley *et al.*, 2000), and negative stimuli are associated with stronger sensory activity than are positive stimuli (for a review, see Kensinger, 2009), perhaps suggesting that they provide stronger bottom-up input. For further discussion, see Murphy and Isaacowitz (2008) for a meta-analysis of emotional memory and attention. We hypothesized that this prioritized processing of negative stimuli would lead participants to recruit additional cognitive control processes to regulate such stimuli; if participants prioritize negative stimuli, emotional responses may start faster (be more ‘full blown’ within the first 5 s), thus requiring more regulation. Although we expected to find some evidence for additional recruitment of such processes even when full attention could be devoted to the regulatory task, consistent with Kim and Hamann (2007) and Mak *et al.* (2009), we hypothesized that these valence effects would be exaggerated when participants were placed under cognitive load.

This study addressed these hypotheses by using fMRI to examine how image valence and the attention devoted toward the regulation task affected the neural processes recruited during successful cognitive reappraisal. Participants were presented with positive, negative or neutral images and either (i) passively viewed the stimuli (passive view) or (ii) attempted to increase or decrease their emotional reactions to the images (reappraisal). Half of the participants performed the reappraisal task with full attention, whereas half of the participants performed the task along with an auditory-discrimination task, thereby dividing their attention. We replicate prior findings, showing that reappraisal recruits both lateral and medial PFC regions, with a number of regions activated more for the reappraisal of negative than positive images. We additionally demonstrate a novel effect of attention, with divided attention leading to increased recruitment of medial PFC and reduced recruitment of lateral PFC. We further show that, in a few regions of PFC, the effect of divided attention depends upon the valence of the stimuli being reappraised: divided attention reduces the neural activity engaged during the regulation of positive but increases the activity during the reappraisal of negative stimuli.

METHODS

Participants

Thirty-nine volunteers participated in this study. All participants were native English speakers with normal or corrected-to-normal vision, and they reported no history of psychiatric, neurological or learning disorders. In addition, participants reported no history of psychiatric or psychoactive medication use. Participants received \$75 for their participation. The data from five participants were not included in analyses due to excessive head motion in the scanner. The final sample included 34 participants (18 female and 16 male; aged 18–34 years, mean = 22.7 years). Of these, 16 adults (9 female) performed the regulation task with full attention devoted to the task, whereas 18 adults (9 female) completed the task with divided attention. Informed consent was obtained from all participants in a manner approved by Boston College and Massachusetts General Hospital Institutional Review Boards.

Materials

The cognitive reappraisal task was adapted from a previous study by Ochsner *et al.* (2004). Stimuli were 105 images selected from the International Affective Picture System (IAPS) database (Lang *et al.*, 2008). The 105 images were presented across five scan runs of 21 images. Images in each run were selected to represent three valence categories, with 9 positive, 9 negative and 3 neutral images presented in each run, for a total of 45 positive, 45 negative and 15 neutral images. The negative and positive pictures were equated in normative arousal ratings ($P = 0.11$) and in absolute valence (i.e. distance from neutral valence; $P = 0.61$). Valence and arousal ratings from the IAPS database are reported on a scale from 1 to 9, such that 1 equates to a low rating on each dimension (i.e. very negative valence, low arousal), and 9 equates to a high rating on each dimension (i.e. very positive valence, high arousal). Negative images held a mean normative valence rating of 2.99 (s.d. = 0.85) and a mean arousal rating of 5.73 (s.d. = 0.59), and positive images received a mean normative valence rating of 7.15 (s.d. = 0.56) and a mean arousal rating of 5.55 (s.d. = 0.70). Negative and positive images were selected to be significantly more arousing than neutral images; neutral pictures received a mean normative valence rating of 5.26 (s.d. = 0.36) and a mean arousal rating of 3.63 (s.d. = 0.75). Images from each valence category did not differ significantly (all P s > 0.50) in terms of ratings of visual complexity or general scene content (i.e. images containing people, animals, buildings or landscapes).

Procedure

Participants first completed a short battery of cognitive tasks. They were then given instructions for the emotion regulation task (similar to those given by Kim and Hamann, 2007). Participants viewed emotional and neutral images and were instructed to either INCREASE or DECREASE the intensity of their emotional reaction to the image. In an additional control condition, participants were asked to VIEW emotional or neutral images without intentionally changing the intensity of their emotional reaction. For all conditions, the instructions included a computerized practice during which participants were familiarized with the task. This practice included a number of self-paced trials, example regulation strategies (similar to those presented to participants in Ochsner et al., 2004), and an actual-speed practice. Participants had the option to repeat any or all sections of the practice until they understood the instructions and were able to reliably come up with reappraisal strategies within the allotted time period. Each trial began with an image and arousal rating scale. Participants first rated their emotional arousal in response to the image on a scale from 1 (low emotional arousal) to 5 (high emotional arousal). They then had 5 s to enter their response for each image using an MRI-compatible button box. The rating scale remained on the screen until a response was entered, after which a blank black screen replaced it. Participants then viewed the images again for 8 s with one of the three regulation instructions (INCREASE, DECREASE, VIEW; Figure 1). During this period, participants were instructed to reappraise their original emotional reaction to the image in the direction indicated (or to VIEW the image without intentionally altering the intensity of their emotional reaction in the case of VIEW instructions). After the regulation period, participants were presented with the same arousal rating scale for a maximum of 3 s and provided a post-regulation rating of their perceived emotional arousal. Responses from the second presentation were compared to those at the first presentation to calculate a difference score representing the change in emotional reaction to each image as a function of the reappraisal attempt.

After each trial, an inter-trial fixation cross was presented for a variable duration, ranging between 5 and 13 s, to provide jitter (Dale, 1999). Participants completed 105 trials: 30 INCREASE trials (15 negative, 15 positive), 30 DECREASE trials (15 negative, 15 positive) and 45 VIEW trials (15 negative, 15 positive, 15 neutral). Trials from each of these experimental conditions were presented in a pseudorandomized order across scanning runs, with no more than two trials of a given valence or condition presented consecutively. Each participant saw each image only once (i.e. in only one of the conditions).

Once participants had completed the full set of 105 regulation trials (one full attention participant only completed 84 trials) and exited the scanner, they then freely recalled as many of the images as they could

remember; however, post-scan data will not be discussed here. Participants were debriefed as a method of ensuring task compliance.

Divided auditory attention paradigm

The divided attention participants underwent identical screening, instruction and scanning as outlined earlier, but with an additional task in the scanner. During each 8 s regulation phase, participants in the Divided Attention condition monitored a sound pattern that played throughout the phase and indicated, by button press, whenever the sound pattern changed. The sounds were pre-selected to ensure that the pattern changes could be detected while in the noisy MRI environment, yet these pattern changes were sufficiently difficult to distinguish that they had previously been shown to interfere with performance of a memory tasks ('hard' sounds adapted from Kensinger et al., 2003).

Image acquisition and preprocessing

Participants were scanned on a Siemens Avanto 1.5 T MR scanner at the Martinos Center for Biomedical Imaging in Charlestown, MA. Detailed anatomical data were acquired using a T1*-weighted MP-RAGE sequence, and functional images were acquired using a T2*-weighted echo-planar imaging sequence with the following parameters: TR = 2000 ms, TE = 40 ms, FOV = 200 mm and flip angle = 90°. Twenty-six axial-oblique slices, aligned in the plane along the AC-PC axis (with a 3.125 mm slice thickness and 20% skip between slices), were acquired in an interleaved fashion.

Preprocessing

Preprocessing and data analysis were conducted in SPM8 (Wellcome Department of Cognitive Neurology, London) implemented in MATLAB R2009b (The Mathworks, USA). Standard preprocessing was conducted on the functional data, including slice-timing correction, rigid-body motion correction, normalization to the Montreal Neurological Institute (MNI) template and spatial smoothing (using a 8 mm full-width half-maximum isotropic Gaussian kernel).

Block-design fMRI data analysis

We defined a successful trial as one in which the post-regulation arousal rating value was greater than (for INCREASE trials), less than (for DECREASE trials) or within one point of the pre-regulation arousal rating value (for VIEW trials). Therefore, a successful INCREASE trial was a post-regulation minus pre-regulation score from 1 to 4, a successful DECREASE trial was a score from -1 to -4 and a successful VIEW score was between -1 and 1. Participants were successful on 81.3% (s.e. = 1.9%) of trials in the Full Attention condition, and successful on 75.3% (s.e. = 2.0%) of trials in the Divided Attention condition. The leeway on the VIEW trials allowed for mild changes in

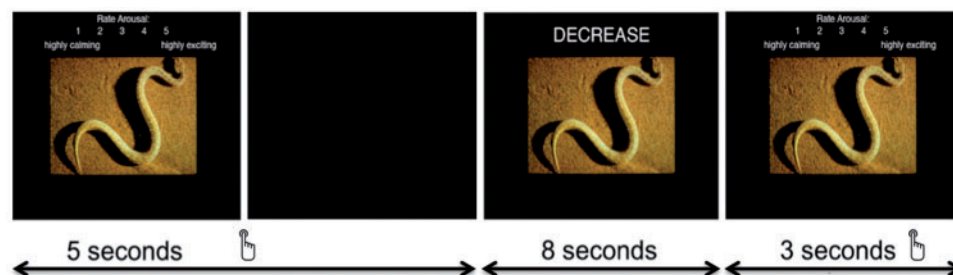


Fig. 1 Participants were given 5 s to make an initial arousal rating (left frame). An instruction to INCREASE, DECREASE or VIEW was then presented with the image for 8 s (center frame). After this regulation period, participants had a maximum of 3 s to provide a post-regulation rating of emotional arousal (right frame).

experienced intensity in the VIEW condition that may occur even in the absence of any strategic ER strategy. All other trials were binned as unsuccessful. All analyses were additionally conducted with more conservative scoring, with successful VIEW trials defined as a change score of 0. Using this more conservative scoring method, participants were successful on 74.2% (s.e. = 2.7%) of trials in the Full Attention condition and 71.8% (s.e. = 2.9%) of trials in the Divided Attention condition. The far right column of [Tables 1–3](#) reports whether regions remained active using this more conservative scoring. Out of a possible maximum arousal change of four points, the majority of successful reappraisal trials had a change of 1 or 2 points, whereas the majority of successful view trials had a change of 0 points. See [Supplementary Figure S1](#) for a breakdown of the arousal change scores for successful trials.

The following seven successful trial types were modeled as regressors of interest: negative increase, negative decrease, negative view, positive increase, positive decrease, positive view and neutral view. Each of these trial types was modeled as an event with an 8 s time epoch, anchored to the onset of the reappraisal or maintenance phase (i.e. [Figure 1](#), middle panel). An additional regressor of no interest modeled the trials during which participants were unsuccessful. Trials were concatenated across the five scan runs. To account for the breaks in scanning, separate linear trend regressors were included for each of the five scans.

To confirm that the divided attention task resulted in the additional recruitment of cognitive control regions, we conducted a contrast analysis comparing successful regulation to baseline in the full attention and divided attention participants. We then examined used a one-way analysis of variance (ANOVA) to examine the effect of attention group on this activity.

Our main interest was in contrast analyses comparing the regulation conditions to the neutral view condition (e.g. negative increase > neutral view); these contrasts controlled for activation due to image viewing and, in the case of the divided attention group, for activation related to performance of the auditory monitoring task. These contrast analyses generated image files that were used in a second-level ANOVA. At this second level, the analysis collapsed across the Direction of regulation (increase or decrease) and included the within-subject factor of Valence (positive regulation or negative regulation) and the between-subject factor of Group (full or divided attention). Including the additional factor of Direction of regulation did not change the regions that showed main or interactive effects of Valence or Group. We report as significant those regions revealed by this ANOVA to consist of at least 15 contiguous voxels that were all active at a threshold of $P < 0.005$; this voxel extent and probability was shown by Monte Carlo simulations to correct for multiple comparisons at $P < 0.05$ ([Slotnick et al., 2003](#)). Coordinates were converted from MNI to Talairach space using the Brett (mni2tal) transform ([Brett et al., 2001](#)). Within active clusters, beta weights for each condition were extracted using the REX ROI

toolbox implemented within SPM8. These parameter estimates are plotted in graphs for select clusters.

RESULTS

MRI analysis results

Confirmation of cognitive control engagement with auditory discrimination task

A comparison of activity in the full and divided attention groups confirmed that the inclusion of a secondary task was sufficiently taxing to result in engagement of cognitive control regions. Numerous regions of the PFC, including the inferior frontal gyrus (MNI coordinates: 30, 28, -4; $k = 663^*$; -32, 28, 6; $k = 45$), middle frontal gyrus (40, 28, 16; sub-cluster of inferior frontal gyrus cluster), anterior cingulate gyrus (-10, 16, 48; $k = 21$) and medial frontal gyrus (8, 28, 48; $k = 40$) were more active in the divided attention participants than in the full attention participants.

Replication of previous reappraisal findings

We sought to replicate prior findings regarding the engagement of medial and lateral PFC during successful reappraisal. Because most studies have examined the ability to decrease responses to negative stimuli, the first contrast compared decrease-negative to view-negative conditions in the full attention group. Consistent with prior research, this contrast revealed widespread activity in the medial PFC (MNI coordinates: 12, 26, 42; 6, 12, 56) and lateral PFC (MNI coordinates: 32, 56, -10; 38, 48, -12); all regions depicted in [Figure 2A](#).

The next analysis used an ANOVA to more generally examine the effect of reappraisal, collapsing across valence (Positive, Negative) and group (Full, Divided Attention). This and all further MRI analyses discussed used view-neutral as comparison conditions (e.g. decrease-negative > view-neutral). This analysis revealed activity in medial (MNI coordinates: -8, 20, 50; -8, 30, 38) and lateral (MNI coordinates: 48, 38, -6; 38, 54, 24; -38, 50, 6) PFC; see [Figure 2B](#) for all regions.

Effect of divided attention and valence on cognitive reappraisal processes

The main focus of this investigation was to identify how divided attention and valence would affect the processes engaged during successful cognitive reappraisal. Therefore, a 2 (Positive or Negative Valence) \times 2 (Full or Divided Attention) ANOVA was conducted.

Effect of attention

A number of regions showed an effect of Group (Full or Divided Attention) in the 2×2 ANOVA discussed earlier ([Figure 5](#)). Results revealed greater activity in the lateral PFC in the Full Attention compared to the Divided Attention condition, as well as activity in the striatum and insula (see top panel of [Table 3](#) for all regions). In the Divided Attention condition ([Table 3](#); [Figure 5](#)), there was increased

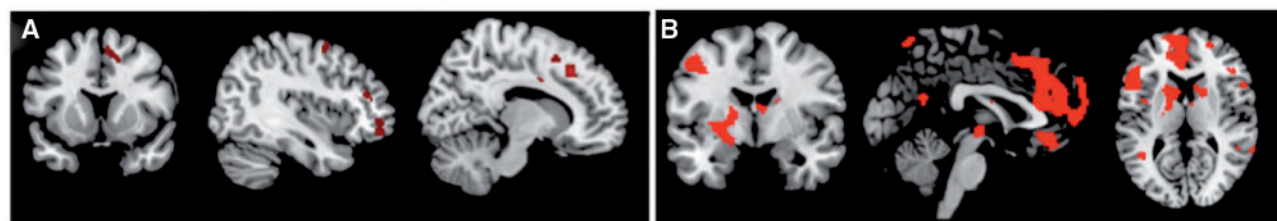


Fig. 2 (A) Activated brain regions for the contrast of Decrease Negative > View Negative in the full attention condition. (B) Main effect of regulation, collapsed across valence and regulation direction in both full and divided attention.

activity in the dorsomedial PFC (MNI: 6, 56, 44), anterior cingulate gyrus (MNI: -8, 30, -8) and orbitofrontal cortex (MNI: 14, 66, -4; see lower panel of Table 3 for all regions).

Effect of image valence

A number of regions showed an effect of Image Valence. *T*-contrasts revealed that almost all the regions that showed a main effect of valence, including widespread activity within the PFC and occipital cortex, showed stronger activity during the regulation of negative

images than during the regulation of positive images (Table 1; Figure 3). Only a single region, within the posterior cingulate gyrus (MNI coordinates: 26, -46, 28; BA: 31; *k* = 35), showed greater activation during the regulation of positive images compared with negative images.

Interaction between attention and image valence

A few regions within the frontal and temporal lobes showed an interaction between Valence and Group. *T*-contrasts demonstrated that nearly all of this activity reflected a tendency for divided attention to be associated with less activity (relative to full attention) during the regulation of positive images but with more activity during the regulation of negative images (Table 2; Figure 4). Only a single region of activity, within the middle temporal gyrus (MNI coordinates: 32, -62, 17; BA: 39; *k* = 40), showed the opposite pattern.

Effect of divided attention and valence on viewing emotional images

To rule out the potential confound that some of the aforementioned effects may have been due to differences in viewing images of different valences (rather than to differences in reappraisal processes *per se*), we conducted an additional second-level ANOVA, also with the factors of Valence (positive, negative) and Attention (full, divided). However, the first-level contrast analyses used for this ANOVA compared the viewing of a valenced image to the viewing of a neutral image (e.g. negative view > neutral view). At the standard threshold, this ANOVA revealed no main effect of valence, and the three clusters of activity that showed an interaction between valence and attention (MNI: 28, -10, 26; 26, 14, 12; 28, -2, 10) did not overlap with the regions revealed in the previous ANOVA. Only one cluster was more active for the main effect of attention, specifically in the Full Attention > Divided Attention contrast (MNI: 26, -52, 34; BA: 31; *k* = 18).

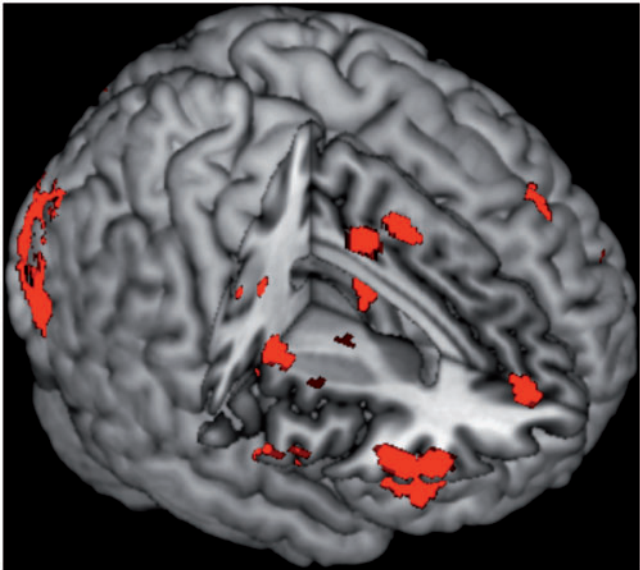


Fig. 3 Regions showing greater activity during the reappraisal of negative images than during the reappraisal of positive images.

Table 1 Regions activating for negative > positive image regulation

Region	Gyrus	Approximate Brodmann area (BA)	MNI coordinates (x, y, z)	TAL coordinates (x, y, z)	Cluster size (no. voxels)	Region active with more conservative scoring
Frontal lobe	Inferior frontal gyrus	45	-36, 28, 12	-36, 28, 10	21	Yes
—	—	46	50, 42, 10	50, 41, 9	296 ^a	Yes
—	Middle frontal gyrus	—	—	—	296 ^a	Yes
—	Middle frontal gyrus	46	42, 20, 24	42, 20, 21	55	Yes
—	Medial frontal gyrus	10	6, 52, 8	8, 51, 5	48	Yes
—	—	8	52, 10, 46	51, 12, 42	66	Yes
—	Precentral gyrus	4	54, -10, 50	51, -12, 42	154	Yes
—	—	6	-54, -4, 16	-55, -3, 17	55	Yes
—	—	6	-52, -6, 36	-51, -4, 33	83	Yes
—	Superior frontal gyrus	9	36, 50, 34	36, 50, 29	41	Yes
—	—	8	-22, 38, 46	-22, 39, 40	40	No
Temporal lobe	Superior temporal gyrus	38	-44, -10, -14	-44, 10, -11	21	Yes
—	—	38	36, -2, -10	36, -2, -8	28	Yes
—	Parahippocampal gyrus	37	30, -46, -10	30, -45, -6	41	Yes
Occipital lobe	Middle occipital gyrus	19	-42, -54, -8	-42, -53, -4	30	Yes
—	—	19	-26, -96, 20	-28, -92, 21	225	Yes
—	—	37	38, -68, 2	38, -66, 5	1521 ^a	Yes
—	Inferior occipital gyrus	—	—	—	1521 ^a	Yes
Cingulate gyrus	NA	24/32	12, 4, 38	12, 6, 35	252	Yes
Insula	NA	13	-36, 10, 12	-36, 10, 11	40	Yes
—	—	13	-26, -22, 14	-26, -21, 14	529	Yes
Putamen	NA	NA	18, 0, 14	18, 1, 13	57	No
—	—	—	30, -20, 4	30, -19, 5	87	Yes
Thalamus	NA	NA	16, -20, 8	16, -19, 8	32	No

^aCluster extends throughout these regions. *P* = 0.005, *k* = 15.

Table 2 Regions showing a Group \times Valence interaction

Region	Gyrus	Approximate BA	MNI coordinates (x, y, z)	TAL coordinates (x, y, z)	Cluster size (no. voxels)	Region active with more conservative scoring
Frontal lobe	Medial frontal gyrus	10	−14, 64, 8	−14, 62, 4	40	Yes
—	—	—	12, 56, 6	12, 55, 3	35	Yes
—	Inferior frontal gyrus	47/11	−26, 30, −6	−26, 29, −6	53	Yes
Temporal lobe	Fusiform gyrus	36	−44, −20, −14	−44, −20, −11	17	Yes
—	Middle temporal gyrus	39	32, −62, 18	32, −59, 20	29	Yes
Caudate	NA	NA	−2, 10, 2	−2, 10, 1	18	No

$P = 0.005$, $k = 15$.

Table 3 Regions showing a main effect of Group

Region	Gyrus	Approximate BA	MNI coordinates (x, y, z)	TAL coordinates (x, y, z)	Cluster size (no. voxels)	Region active with more conservative scoring
Full Attention > Divided Attention						
Frontal lobe	Inferior frontal gyrus	10	−36, 44, 2	−36, 43, 0	274 ^a	Yes
—	Middle frontal gyrus	46	—	—	274 ^a	Yes
—	Middle frontal gyrus	6	24, −4, 46	24, −2, 42	51	Yes
Parietal lobe	Inferior parietal lobe	40	−52, −44, 32	−51, −41, 32	320	Yes
Caudate	NA	NA	−10, −8, 24	−10, −7, 22	118	Yes
Putamen	NA	NA	22, −2, 18	22, −1, 17	134	Yes
Thalamus	NA	NA	8, −10, 20	8, −9, 19	29	No
Insula	NA	13	−50, −24, 20	−50, −22, 20	16	No
Divided Attention > Full Attention						
Frontal lobe	Medial frontal gyrus	9	6, 56, 44	6, 56, 38	56	Yes
—	Paracentral lobule	6	8, −30, 50	8, −27, 47	55 ^a	Yes
—	Medial frontal gyrus	—	—	—	55 ^a	Yes
—	Superior frontal gyrus	10	14, 66, −4	14, 64, −7	30	Yes
—	—	8	24, 26, 50	24, 27, 45	17	No
Parietal lobe	Inferior parietal lobule	7	28, −62, 32	28, −60, 32	823	Yes
—	—	13	44, −40, 24	44, −38, 24	31	Yes
—	—	40	44, −38, 36	44, −35, 35	32	Yes
Temporal lobe	Middle temporal gyrus	19	38, −62, 8	38, −60, 10	25	No
—	Parahippocampal gyrus	34	−12, −4, −16	−12, −5, −13	31	Yes
—	—	19	−18, −50, −8	−18, −49, −4	49	Yes
—	—	36	22, −40, −10	22, −39, −6	79 ^a	Yes
—	Fusiform gyrus	37	—	—	79 ^a	Yes
Occipital lobe	Cuneus	17	−18, −68, 8	−18, −66, 11	71	Yes
—	—	19	−24, −88, 40	−24, −83, 41	135	Yes
—	—	31	30, −74, 16	30, −71, 18	15	Yes
—	—	31	24, −80, 26	24, −76, 28	26	Yes
—	—	30	4, −76, 4	4, −73, 7	326 ^a	Yes
—	Lingual gyrus	17	—	—	326 ^a	Yes
Hippocampus	NA	NA	36, −10, −12	36, −10, −10	33	No ^b
Cingulate gyrus	NA	30	8, −52, 14	8, −50, 15	33	Yes
—	—	31	−18, −54, 36	−18, −51, 36	73	Yes
—	—	24	−8, 30, −8	−8, 29, −8	50	No
—	—	32	−16, 32, 18	−16, 32, 15	17	Yes
Thalamus	NA	NA	16, −14, −2	16, −14, −1	27	Yes

^aCluster extends throughout these regions.

^bBut new hippocampal cluster at 38, −24, −16.

$P = 0.005$, $k = 15$.

DISCUSSION

Cognitive reappraisal is one of the most effective antecedent-focused cognitive regulation strategies. In this study, we demonstrated that the neural mechanisms supporting reappraisal differ depending upon the attention granted to the reappraisal task and the valence of the stimuli. Because analyses focus on trials with reported reappraisal success, and because both the full and divided attention participants reported success on the majority of trials, these results suggest multiple neural routes to successful cognitive reappraisal, depending upon image valence and the availability of attentional resources.

Across all conditions, we replicate prior findings regarding the role of lateral and medial PFC in the cognitive reappraisal process.

Participants consistently engaged these regions during successful reappraisal. These results are consistent with prior proposals (Davidson and Irwin, 1999; Ochsner and Feldman Barrett, 2001; McRae *et al.*, 2012) that cognitive reappraisal relies on many of the same cognitive processes used to control other types of thoughts and behaviors.

When attention was divided, however, this affected the particular PFC processes that were engaged. Most notably, while participants in the Full Attention condition disproportionately recruited lateral PFC in the service of cognitive reappraisal, participants in the Divided Attention condition disproportionately recruited medial PFC regions. In many of the PFC regions, this shift occurred for both positive and negative images (i.e. many of the regions that showed a main effect of

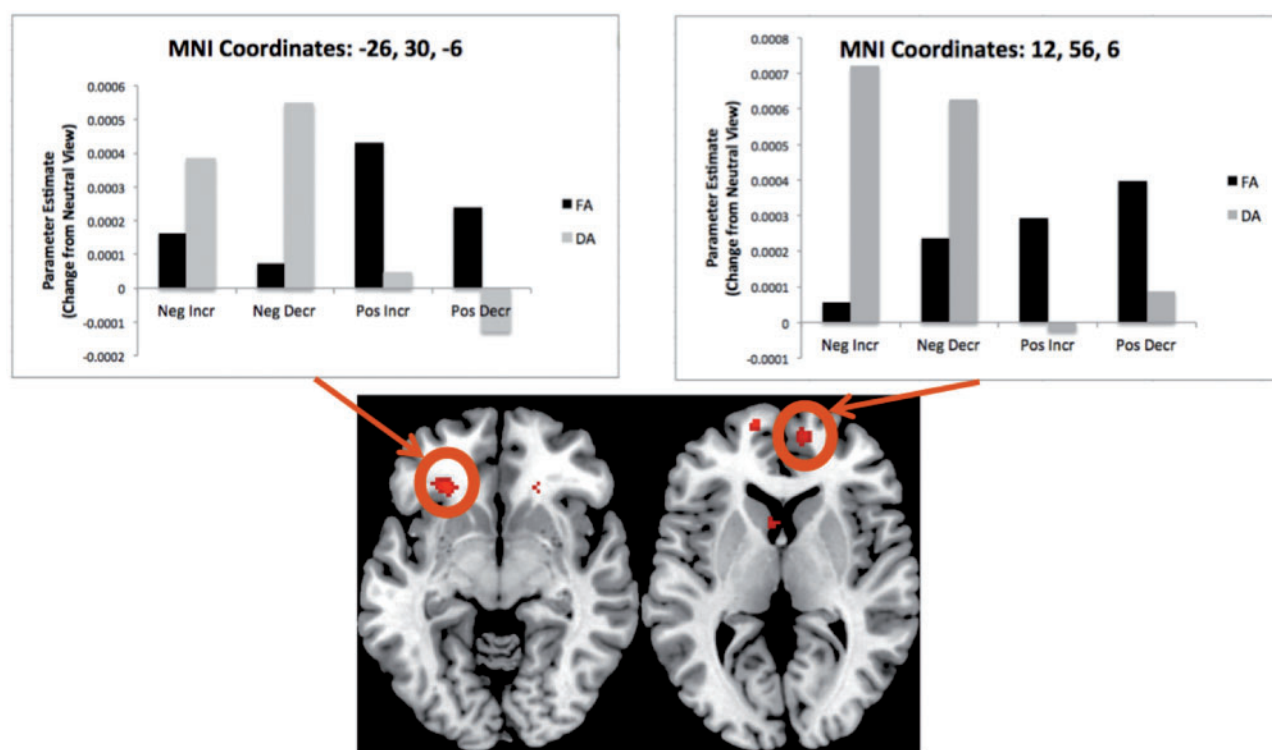


Fig. 4 Regions showing a Group \times Valence interaction. Graphs depict activity in demarcated PFC clusters. These graphs reveal that these regions showed greater activity when regulating negative images in the Divided Attention condition, but greater activity when regulating positive images in the Full Attention condition.

Attention showed no Attention \times Valence interaction). The reduced engagement of lateral PFC during divided attention suggests that these processes require cognitive resources not available when attention is divided. In contrast, individuals may implement the medial PFC processes effectively even when cognitive resources are taxed. This suggestion would be consistent with evidence suggesting that older adults, a population known to have impaired cognitive control (e.g. in tasks requiring the inhibition of irrelevant information; Prull *et al.*, 2000; Salthouse *et al.*, 2003; Hedden and Gabrieli, 2004), may rely more on medial PFC than lateral PFC processes for some forms of emotion processing and emotion regulation (Urry *et al.*, 2006; Sakaki *et al.*, 2013).

The lateral and medial PFC engagement in the full and divided attention groups, respectively, is particularly interesting given that all analyses focused on successful reappraisal trials. Thus, the two groups used different processes to impact subjective arousal ratings in the desired direction. These results suggest that there is more than one way to successfully reappraise an emotional response, and that the cognitive resources available may influence the mechanism participants use.

Because reappraisal is defined by the ability to reframe a situation to alter its affective meaning, there could be multiple routes to effect that change, and the availability of cognitive resources may alter the route that is dominant. This change in dominant route could reflect the fact that multiple neural routes could influence an affective response. The change in dominant route could also reflect changes in the strategy used to elicit reappraisal. When participants are placed under cognitive load, they may use different, less cognitively demanding strategies, to change their affective response. For instance, they may use detached reappraisal rather than positive reappraisal to decrease their negative affect, as the former is thought to be less cognitively demanding (Shiota and Levenson, 2009). The different neural correlates could

therefore reflect engagement of different strategies to evoke the same regulatory outcome. Future research, asking participants to report their strategy use on a trial-by-trial basis, could examine whether different reappraisal strategies are associated with different neural signatures.

The present results also reveal an interesting effect of valence on the processes engaged by reappraisal, and further suggest that the effect of valence may depend upon the cognitive resources available. Participants in both the Full and Divided Attention conditions recruited more PFC and occipital processes during the reappraisal of negative images than during the reappraisal of positive images. This enhanced neural engagement during the reappraisal of negative images occurred when participants devoted full attention toward the reappraisal of the images, consistent with two prior studies (Kim and Hamann, 2007; Mak *et al.*, 2009). One possible explanation for this finding is that, because the processing of negative stimuli is often prioritized by young adults (e.g. Öhman *et al.*, 2001; Charles *et al.*, 2003), and because negative stimuli are often processed with more sensory detail than positive stimuli (e.g. Kensinger *et al.*, 2007; Mickley and Kensinger, 2008), negative stimuli may create stronger representations than positive stimuli, thus requiring additional processes for the successful cognitive reappraisal of those representations. This imbalance between the processes required to reappraise negative and positive stimuli may increase with task demands, as evidenced by the larger effects of valence in the participants in the divided attention condition.

In young adults, emotion regulation relies on PFC processes engaged during tasks that rely on regions implicated in cognitive control. This study replicates those findings but reveals additional complexity in the way PFC regions are recruited. Specifically, this study demonstrates three different patterns of emotion-regulation response within the PFC. Within many lateral PFC and medial PFC/ACC regions

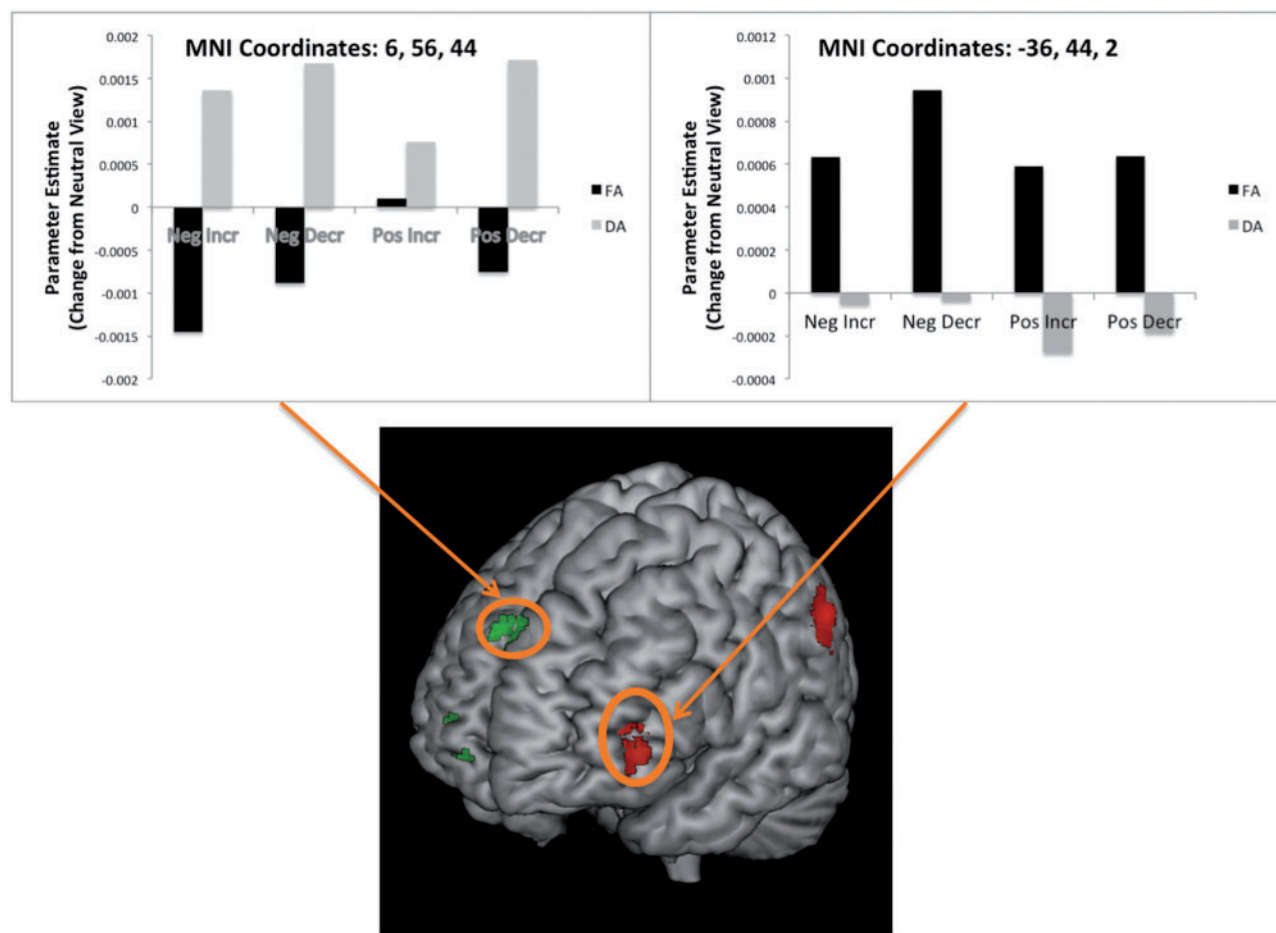


Fig. 5 Regions showing activity for the contrast of Divided > Full (green) and Full > Divided (red). Graphs depict activity in demarcated clusters. These graphs reveal that lateral regions were preferentially engaged during the regulation of all images with full attention, but medial regions were preferentially engaged during the regulation of all images with divided attention.

(Figure 5), there was only an effect of attention, with lateral PFC recruited when full attention could be granted toward the regulation task and dorsomedial PFC and ACC regions recruited when resources were taxed by divided attention. These regions showed the same pattern for negative and positive stimuli. Within other lateral PFC and medial PFC/ACC regions (Figure 3), however, there was only a main effect of valence, with stronger activity for negative than positive stimuli. Within a small set of PFC regions, two medial and one lateral (Figure 4; Table 2), there was an interaction between attention and valence, such that divided attention was associated with increased activity during the reappraisal of negative images but with decreased activity during the reappraisal of positive images.

Two limitations of this study are noteworthy. First, we cannot rule out that, rather than using a different mechanism to achieve cognitive reappraisal, the DA group may have used another strategy. Although one such strategy would be distraction, their reliance on this strategy seems unlikely for a few reasons. First, the literature on distraction (i.e. Anderson *et al.*, 2004; Kalisch *et al.*, 2006) suggests that it recruits left-lateralized PFC regions, not the medial PFC regions disproportionately recruited by the DA group. Second, upon debriefing, all participants reported that they were able to obey task instructions a high percentage of the time, suggesting that they were not regularly engaging in a non-instructed strategy. Finally, while it is clear how distraction would help to decrease emotional reactions, it is less clear how it would similarly enable successful performance on INCREASE trials. Because this study combines instances of increasing and decreasing affective responses,

distraction seems an unlikely strategy to be consistently effective. A more tenable alternative is that participants in the DA group may have relied more on shifts of attention during scene viewing than participants in the FA group. For instance, when asked to downregulate their emotions, participants in the DA group may have shifted their attention away from the emotional portions of the scenes (see Van Reekum *et al.*, 2007 for evidence of such gaze shifts with instructions to reappraise) rather than remaining focused on those portions and using cognitive processes to change the way they feel. This possibility could be examined in future research by simultaneously measuring eye gaze and neural activity during both Full and Divided Attention conditions, or by comparing the neural activity engaged when participants are instructed to use cognitive reappraisal or instructed to use selective attention to regulate their emotions.

A second limitation is that the present behavioral results could be susceptible to demand characteristics. Because participants were aware they were being instructed to regulate emotion, they could have selected ascending or descending numbers on the scale to fit with the regulation instructions. Because it would take some effort to hold the initial ratings in mind for the 8 s duration of the regulatory period, because accuracy rates were below ceiling, and because no participants reported inflating their success on the regulation trials, demand characteristics may have played a relatively minor role. However, we cannot rule out that our analyses included some trials that were binned as successful not because regulation was achieved but because demand characteristics influenced participants' ratings.

Despite these limitations, these findings reveal the complexity of the PFC processes implemented in the service of emotion regulation and emphasize that not only are lateral and medial distinctions important, but that even among lateral or medial regions, the specific roles of the regions can depend upon both the valence of the stimuli reappraised and the attentional resources available to implement the reappraisal. It will be interesting for future research to assess whether the reappraisal processes engaged by young adults in the Divided Attention condition parallel those used by older adults, who often experience relative depletion of cognitive resources as compared with younger adults. Future research could also examine how dividing attention in older adults, who already have depleted resources, may further affect the behavioral and neural signatures of reappraisal.

SUPPLEMENTARY DATA

Supplementary data are available at SCAN online.

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