Cerebral Cortex June 2011;21:1379–1388
doi:10.1093/cercor/bhq216
Advance Access publication November 1, 2010

How to Regulate Emotion? Neural Networks for Reappraisal and Distraction

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The regulation of emotion is vital for adaptive behavior in a social environment. Different strategies may be adopted to achieve successful emotion regulation, ranging from attentional control (e.g., distraction) to cognitive change (e.g., reappraisal). However, there is only scarce evidence comparing the different regulation strategies with respect to their neural mechanisms and their effects on emotional experience. We, therefore, directly compared reappraisal and distraction in a functional magnetic resonance imaging study with emotional pictures. In the distraction condition participants performed an arithmetic task, while they reinterpreted the emotional situation during reappraisal to downregulate emotional intensity. Both strategies were successful in reducing subjective emotional state ratings and lowered activity in the bilateral amygdala. Direct contrasts, however, showed a stronger decrease in amygdala activity for distraction when compared with reappraisal. While both strategies relied on common control areas in the medial and dorsolateral prefrontal and inferior parietal cortex, the orbitofrontal cortex was selectively activated for reappraisal. In contrast, the dorsal anterior cingulate and large clusters in the parietal cortex were active in the distraction condition. Functional connectivity patterns of the amygdala activation confirmed the roles of these specific activations for the 2 emotion regulation strategies.

Keywords: affect, amygdala, fMRI, mental arithmetic, PPI

Introduction

Cognitively influencing emotional experience is highly relevant for adaptive social behavior and mental and physical health (Eftekhari et al. 2009). Different strategies can be applied to regulate emotional responses ranging from attentional control to cognitive change (Ochsner and Gross 2005). While attentional control enables the individual to focus away from an emotional stimulus (distraction), cognitive change yields an altered interpretation of an emotional situation (reappraisal). Both strategies have been shown to successfully modulate the subjective emotional state and activation in brain areas relevant for emotional processing including the amygdala (Kim and Hamann 2007; Van Dillen et al. 2009). However, we know little as to whether distraction and reappraisal differ in their effects on emotional experience and in the neural networks underlying the different regulation strategies (McRae et al. 2010). We, therefore, directly compared distraction and reappraisal using functional magnetic resonance imaging (fMRI).

Reappraisal is typically examined by instructing participants to alter their emotional response to images or other types of stimuli by reinterpreting their meaning (Ochsner et al. 2002; Eippert et al. 2007). It has been shown to reliably downregulate subjective emotional experience, psychophysiological indicators of emotion such as electrodermal activity and heart rate (Kalisch et al. 2005), and brain responses related to emotion as measured with electroencephalography (Hajcak et al. 2010) or fMRI (Urry et al. 2006; Kim and Hamann 2007; Kalisch 2009). Specifically, activation of the amygdala is reduced during reappraisal. Functional connectivity analyses showed that this reduction in amygdala activation during reappraisal is negatively related to activity in a neural network of control areas (Banks et al. 2007; Walter et al. 2009). A recent meta-analysis identified the dorsolateral and dorsomedial prefrontal cortex (dlPFC and dmPFC), the orbitofrontal cortex (OFC), and the parietal cortex (Kalisch 2009) as the most important nodes of this network.

Distraction, in contrast, relies on attentional control to focus on a concurrent task, thereby reducing emotional responding. A number of studies showed its efficiency in attenuating subjective emotional experience and amygdala activity (Pessoa et al. 2002; Blair et al. 2007; Erk et al. 2007; Van Dillen and Koole 2007). A recent study by Van Dillen et al. (2009) clearly demonstrated that amygdala downregulation is related to the difficulty of the concurrent task. More difficult tasks also engage areas in the dlPFC and superior parietal cortex that typically respond to task demands (de Fockert et al. 2001). The study provides some indication that activity in these control areas covaries with amygdala activation, but clear evidence for the connectivity of the amygdala during distraction is still lacking.

To data, the only study that aimed at comparing reappraisal and distraction combined reappraisal with a working memory task (McRae et al. 2010). They presented emotional pictures, and participants reinterpreted the images during reappraisal or kept a 6-letter string in memory during distraction. The authors reported activation of the dmPFC, dlPFC, and inferior parietal cortex for both tasks. Reappraisal yielded additional activations in the dmPFC and dlPFC, while distraction additionally activated the superior parietal cortex but also dlPFC. Interestingly, amygdala downregulation was stronger during distraction than reappraisal.

The present study aimed at further probing the 2 emotion regulation strategies to elucidate which parts of an emotion regulation network are common to reappraisal and distraction and which mechanisms are distinct to each strategy. Also, the reported data suggest similar, but not identical, effects of both strategies on emotional responses that we will test by contrasting reappraisal and distraction. A number of more specific questions remain: First, do the effects described by McRae et al. (2010) generalize to other distracting tasks? Here, it is also clinically relevant to show that easy, potentially self-generated tasks can regulate emotions. We, therefore, chose to present arithmetic tasks in the distraction condition. Second, McRae et al. (2010) presented the regulation instructions prior to the emotional images. Thus, it is unclear if the effects differ for already elicited emotions. Again, this is clinically highly relevant as it is mainly fully developed emotional responses that need to be regulated in real-life situations. To address this, we included an emotion induction phase before the regulation instructions were presented. Third, in contrast to McRae et al., we included not only negative stimuli but also positive stimuli, as little is known about the effect of different emotion regulation strategies on emotional responses to negative and positive stimuli. And fourth, while we know that the amygdala is negatively coupled with prefrontal control regions during reappraisal (Urry et al. 2006; Banks et al. 2007), there is little evidence for the connectivity pattern during distraction and none directly comparing connectivity during the 2 regulation strategies. Therefore, we also compared functional connectivity of the amygdala during reappraisal and distraction.

To address these questions, we conducted an emotion regulation task where individuals were presented with neutral or emotional (negative and positive) images and, after a short emotion induction phase, passively viewed the images, reappraised their emotional meaning, or performed a simultaneously presented arithmetic task (distraction). We hypothesized that both active task conditions downregulate amygdala activity but that the neural networks subserving this regulation differ for reappraisal and distraction. Common network nodes should include regions in the dlPFC and dmPFC, as well as inferior parietal sites (McRae et al. 2010). In contrast, OFC activation should be observed for reappraisal only (Kalisch 2009), whereas distraction should yield activation specific to attentional control (e.g., dorsal anterior cingulate) and task-related activity in mainly superior parietal sites (Dehaene et al. 2004). Contrasting the connectivity patterns of the amygdala during reappraisal and distraction should corroborate these neural networks.

Materials and Methods

Participants

Thirty healthy volunteers (17 females, aged 18–27 years, mean age 21.8 ± 2.1 years) participated in the study. Twenty-six participants were right-handed, and 4 participants were left-handed according to the Edinburgh Handedness Inventory (Oldfield 1971). All participants had normal or corrected-to-normal vision and were medically healthy, reported no history of mental disorders as verified by the Structured Clinical Interview for Diagnostic and Statistical Manual of Mental Disorders IV (SCID-I and -II, First et al. 1997; German version, Wittchen et al. 1997), no history of serious head injury, or neurological disorder. The study was approved by the Ethics Committee of the University of Heidelberg, and all participants gave written informed consent prior to participation.

Experimental Paradigm and Procedure

The paradigm (Fig. 1) modifies and combines previous designs to study emotion regulation (Eippert et al. 2007; Van Dillen et al. 2009). Three task conditions were presented. In the view condition, participants attended the content of the picture but did not manipulate the emotional response to it. The distraction condition required participants to solve an arithmetic problem and to decide whether the displayed solution was correct or incorrect. The main focus of the reappraisal condition was to decrease any emotional response by reinterpreting the displayed situation, for example, as produced by actors and therefore not real, as meaning something else, or having a different outcome than initially suggested by the picture. Participants were also instructed to distance themselves from the image by reinterpreting the entire situation, for example, by reminding yourself that it is a photograph you are viewing, you are lying in a magnetic resonance scanner and are safe. To ensure that different results for reappraisal and distraction are not due to differences in task difficulty, a separate sample of 13 healthy volunteers performed the experimental task and rated the difficulty and effort required for each condition. These ratings were not significantly different (reappraisal $M = 5.1$, SD = 1.9; distraction $M = 4.6$, SD = 1.3; $F_{1,12} = 0.8$, $P > 0.35$).

Each trial started with a fixation cross presented with a jitter of 3000–5025 ms and followed by 1) an emotion induction phase, 2) the instruction and regulation phase (i.e., view, reappraisal, or distraction), and 3) a rating phase. During the induction phase (1000 ms), participants passively viewed a picture to elicit an initial emotional response. One of 3 instructions (view, decrease, or an arithmetic problem) was then presented for 1000 ms as a transparent overlay on the picture. The picture was presented for another 5000 ms. The arithmetic problem was continuously presented to allow for a solution of the problem. As soon as participants pressed a button to indicate whether the presented equation was correct or incorrect, a thin white frame line was presented around the arithmetic problem overlay. After picture presentation, participants rated their current emotional state on a 9-point scale using the Self-Assessment Manikins (SAM) ranging from unpleasant to pleasant (4000 ms).

Each picture was presented in the view, distraction, and reappraisal condition, except for the neutral images that were not presented for reappraisal. The experiment consisted of 128 trials, which were presented in a pseudorandomized order and lasted about 35 min. Participants received 6 training trials prior to the experiment, to familiarize them with the procedure and practice the emotion regulation strategies.

Stimuli

Pictures were selected from the International Affective Picture System (IAPS) based on normative ratings in valence and arousal (Lang et al. 2005). Sets of 16 negative, 16 neutral, and 16 positive stimuli were created (see Supplementary data 1 for a complete list of stimuli). Negative and positive stimuli were highly arousing, and neutral stimuli were rated low in arousal (see Table 1 for mean ratings). An analysis of variance (ANOVA) confirmed the selection, showing significant effects of picture category on valence and arousal ratings ($F_{2,45} = 1332.84$, $P < 0.001$ and $F_{2,45} = 176.65$, $P < 0.001$, respectively). Differences in valence ratings were observed for each category (all $P < 0.001$), while arousal ratings did not differ for positive versus negative but for emotional versus neutral stimuli ($P < 0.001$). The pictures were controlled for contents with all pictures (also neutral) displaying humans and for sex differences in valence and arousal ratings. Furthermore, differences in luminance and complexity were kept minimal. After the main experiment, all pictures were rated by the study participants on a 9-point scale using the Self-Assessment Manikins (see Table 1). The results were comparable to the normative IAPS ratings but differed in arousal ratings for the positive pictures, which were rated less arousing than negative pictures ($P < 0.001$).

All arithmetic problems were formed with 3 operands including a subtraction and an addition (e.g., $4 + 9 - 6 = 7$). Participants were asked to solve the problems and decide whether the displayed solution was correct or incorrect. Initially, 130 arithmetic problems were tested in an independent sample of 10 healthy participants. From these, 48 equations were selected such that they were correctly solved by at least 75% of the sample. These selected equations were randomly assigned to the background picture condition (negative, neutral, or positive) such that there were no differences in reaction times or number of errors (all $P > 0.25$).

MRI Data Acquisition

MRI data were collected on a 3-T scanner (Magnetom TIM Trio; Siemens Medical Solutions) at the Central Institute of Mental Health, Mannheim, Germany. A high-resolution T_1-weighted 3D image was acquired (slice thickness = 1.1 mm, field of view (FOV) = 256 × 256 × 256 mm, matrix = 256 × 256 × 256). Functional images were obtained

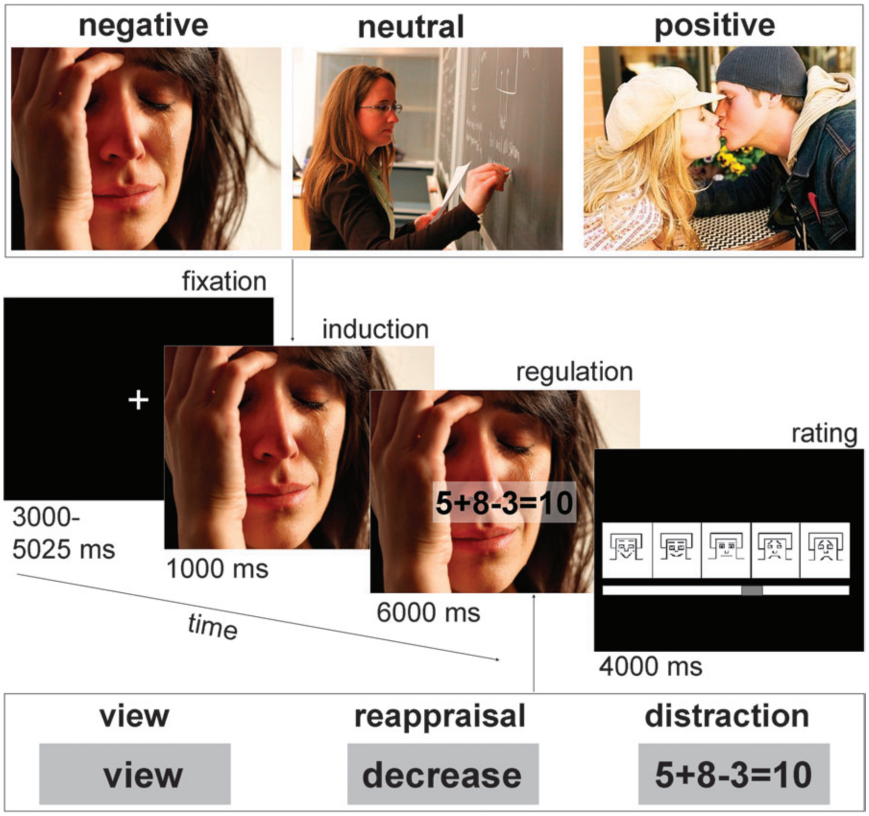

Figure 1. Sequence of events in a trial. The example pictures resemble those in the experiment but are not part of the IAPS.

Table 1
Mean valence and arousal ratings and standard deviations (in parentheses) for the picture selection

	Normative IAPS ratings		Sample ratings	
	Valence	Arousal	Valence	Arousal
Negative	1.87 (0.21)	6.28 (0.64)	2.48 (0.49)	6.00 (1.00)
Neutral	4.92 (0.28)	2.98 (0.34)	5.19 (0.42)	1.77 (0.35)
Positive	7.38 (0.39)	6.29 (0.68)	7.21 (0.35)	5.16 (0.60)

Note: Normative IAPS ratings and the ratings of the present sample are displayed.

from 40 gradient-echo T_2*-weighted slices (slice thickness = 2.3 mm) per volume. A single-shot echo planar sequence with parallel imaging GRAPPA technique (acceleration factor 2) was used with a time repetition of 2700 ms, a flip angle of 90°, time echo = 27 ms, FOV = 220 × 220 mm, matrix = 96 × 96, and a slice gap of 0.7 mm.

fMRI Data Analysis

Image processing and statistical analysis was done with SPM5 (http://www.fil.ion.ucl.ac.uk/). Functional images were realigned, slice-time corrected, and spatially normalized using the Montreal Neurological Institute (MNI) template. For normalization, images were resampled every 3 mm using sinc interpolation. Images were smoothed using a 9 × 9 × 9-mm Gaussian kernel.

Analysis of Regional Brain Activations

Individual participants' data were analyzed using a General Linear Model for blood oxygen level-dependent (BOLD) signal changes due to the experimental conditions. Movement parameters calculated during realignment were included as parameters of no interest to control for movement artifacts. Individual statistical parametric maps were calculated for the following contrasts of interest in order to investigate BOLD signal changes: 1) for the initial emotional response during the induction phase (emotional vs. neutral pictures), 2) for the emotional response in the view condition (view emotional vs. view neutral conditions in the instruction phase), 3) for distraction (distraction emotional vs. view emotional in the instruction phase), and 4) for reappraisal (reappraisal emotional vs. view emotional in the instruction phase), and (5) to evaluate distinct neural correlates of distraction and reappraisal, we directly contrasted these 2 conditions (reappraisal emotional vs. distraction emotional in the instruction phase). In the first step, all analyses were done for positive and negative emotional stimuli separately, which yielded largely comparable results. Also, directly comparing the 2 emotional categories only yielded stronger activation for negative stimuli in the occipital cortex (see Supplementary data 2), which is not part of the emotion regulation networks. To enhance statistical power, we thus, pooled positive and negative stimuli, creating 1 emotional condition for the analyses reported here.

Two types of second-level random-effects analyses were conducted. First, 1-sample *t*-tests were calculated on the above-mentioned individual contrast images. Here, activations were thresholded at a whole-brain false discovery rate (FDR)-corrected $P < 0.01$ with an extent threshold of 20 voxels in order to protect against false-positive activations. Anatomically defined regions of interest (ROIs) from the automated anatomical labeling atlas in WFU PickAtlas v2.0 (Tzourio-Mazoyer et al. 2002) were used to examine amygdala activation (P-FDR < 0.05). Amygdala activations that were significant in the ROI analysis, but not in the whole-brain statistic, are marked in the results tables. Second, in order to evaluate common effects of distraction and reappraisal, we used the respective contrasts as inclusive masks and thresholded both contrasts at $P = 0.01$, yielding voxels whose probability of being activated randomly in both contrasts was $P < 0.001$ (according to the Fisher method for combining P values, see also Kampe et al. 2003).

Analysis of Functional Connectivity

To assess functional connectivity of the amygdala activation under reappraisal and distraction, we performed a psychophysiological interaction (PPI) analysis as implemented in SPM5 (Friston et al. 1997). Our goal was to identify brain regions that have a downregulating effect on the amygdala, that is, regions showing an activation increase accompanied by an activation decrease in the amygdala. In the first step, a 5-mm spherical seed region around the peak activation in the anatomically defined amygdala ROI was identified for each participant when contrasting the combined reappraisal and distraction conditions with the view condition (reappraisal + distraction emotional vs. view emotional). Then, the deconvolved time series in the seed region (left amygdala) was extracted for each participant as the first regressor in the PPI analysis (physiological variable). The second regressor represented the experimental condition (reappraisal emotional vs. distraction emotional; psychological variable). The regressor of interest was the interaction between the time series of the seed region and the experimental condition (PPI). A negative correlation of this interaction term with activity in other brain regions indicates that an activation increase in these brain regions is related to a decrease in amygdala activity under reappraisal. In contrast, a positive correlation indicates that an activation increase in certain brain regions is associated with a decrease in amygdala activity under distraction. In the last step, the individual contrast images were entered into a second-level random-effects analysis, and 1-sample *t*-tests with a whole-brain FDR-corrected $P < 0.05$ were calculated.

For graphical display of the fMRI data, MRIcroN (http://www.cabiatl.com/mricro/index.html) was used with the MNI template brain.

Statistical Analyses of Behavioral Data

The emotional state ratings were analyzed with SPSS (version 15.0; SPSS Inc.). The first 1-way ANOVA was conducted to analyze the effect of the emotional picture presentation (negative, neutral, or positive) on emotional state in the viewing condition. A second 2 × 3 repeated-measures ANOVA including the factors emotion (negative or positive) and task (distraction, view, and reappraisal) was calculated to elucidate the effects of regulation on emotional state. The neutral condition was neglected for the second analysis as there were no neutral pictures in the reappraisal condition. All effects with a $P < 0.05$ were treated as statistically significant.

Results

Behavioral Data

Ratings

Analysis of the emotional state ratings after each trial (see Fig. 2) revealed a significant main effect of emotion in the viewing condition ($F_{2,58} = 165.3$, $P < 0.001$). Planned comparisons showed that negative and positive trials differed from neutral trials (negative vs. neutral: $F_{1,29} = 184.6$, $P < 0.001$; positive vs. neutral: $F_{1,29} = 95.4$, $P < 0.001$).

The second analysis regarding the regulation effects showed a significant main effect of emotion ($F_{1,29} = 113.8$, $P < 0.001$) and an interaction of emotion and task ($F_{2,58} = 105.5$, $P < 0.001$). Repeated contrasts regarding the interaction yielded significant effects (emotion × distraction-view: $F_{1,29} = 104.0$, $P < 0.001$; emotion × reappraisal-view: $F_{1,29} = 163.6$, $P < 0.001$), indicating that the emotional pictures were rated less negative or positive during distraction and reappraisal compared with the view condition. There was no main task effect ($F_{2,58} = 1.5$, $P > 0.20$).

fMRI Data

Induction Phase

To identify the regions involved in mere emotional processing of the stimuli, we analyzed, in the first step, activity for emotional versus neutral images in the preinstruction/emotion induction phase (see Table 2). Here, we observed activity bilaterally in the amygdala, insula, and in a large cluster in the ventromedial prefrontal cortex (vmPFC), including the subgenual anterior cingulate (sgACC). Furthermore, extensive activation in the occipital and more ventral temporal cortices and in the precuneus was observed for emotional pictures.

Main Effect of Emotion

In the second step, to identify the regions involved in emotional processing, we contrasted emotional and neutral pictures in the simple viewing condition (see Table 2). This analysis also yielded activation in the left amygdala, the left insula, and the vmPFC bilaterally, including the sgACC. Also, there was extensive activation in the occipital and ventral temporal cortices and in the posterior cingulate cortex.

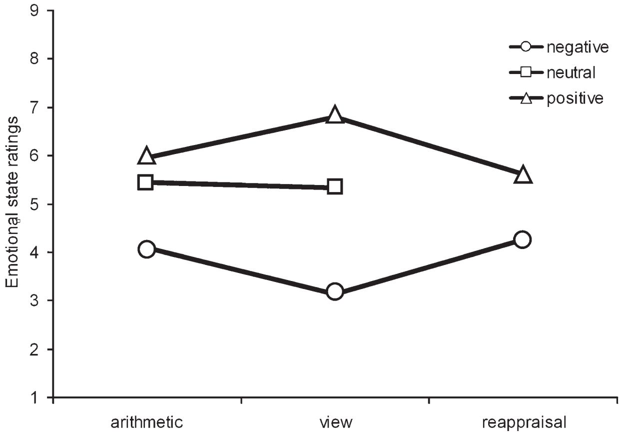

Figure 2. Emotional state ratings during the experiment. The means of SAM valence rating (1 = negative to 9 = positive) are displayed.

Table 2
Activations for emotional versus neutral pictures in the view condition

	H	BA	MNI coordinates			CS	CI	*T*
			x	*y*	*z*			
Induction phase: emotional–neutral								
Precuneus		7	0	−60	36		a	7.54
Temporal/occipital	L	37/19/18/17	48	−63	−6	10 604	**a**	9.91
	R	37/19/18/17	−51	−72	−3		a	8.59
Ventromedial frontal/anterior cingulate		25/10/11	0	24	−6		a	6.66
Insula	L	48	−48	9	0		a	3.83
	R	48	42	9	−6		a	4.01
Amygdala	L		−18	−3	−12		a	5.08
	R		18	−3	−15		a	3.44
Thalamus	R		6	−18	12		a	4.94
View emotional–view neutral								
Precuneus	L	19	−18	−81	48	26	**a**	3.95
	R	19	24	−81	48		b	5.08
Temporal/occipital	L	37/19/18/17	−48	−69	9		b	9.34
	R	37/19/18/17	48	−63	−3	3314	**b**	10.52
Ventromedial frontal/anterior cingulate	L	25/10/11	−3	27	−6	179	**c**	6.53
Posterior cingulate	L	31	−9	−51	27	240	**d**	6.15
Insula	L	48	−30	15	−15	32	**e**	6.41
Amygdala[a]	L		−18	−3	−12	14	**f**	2.98
Thalamus	L		−6	−18	6	134	**g**	4.88
	R		3	−9	6		g	4.45

Note: H, hemisphere; BA, Brodmann area; CS, cluster size in number of activated voxels; CI, cluster index; L, left; R, right; T-values for each peak are given: All peaks of 1 activation cluster are identified by the same letter; the cluster peaks are displayed in bold letters.
[a] ROI analysis.

Effects of Reappraisal

Activation in the bilateral amygdala and the vmPFC/sgACC was increased when comparing emotional pictures in the viewing condition to the reappraisal condition (see Table 3 and Fig. 3), indicating a reduction of activation in these areas through reappraisal. In contrast, reappraisal elicited enhanced activation in the OFC, the dlPFC, and the dmPFC. Other regions involved in reappraisal included the inferior parietal cortex, left middle temporal gyrus, and bilateral precuneus (see Fig. 4).

Table 3

Activations for reappraisal and distraction versus emotional pictures in the view condition

	H	BA	MNI coordinates			CS	CI	*T*
			x	*y*	*z*			
View emotional–reappraisal								
Postcentral	L	2/3	−39	−27	57	105	**a**	4.01
	R	2/3	51	−24	36	138	**b**	5.41
Temporal/occipital	L	37/19/18/17	−45	−78	−3		c	7.77
	R	37/19/18/17	48	−63	−6	4564	**c**	8.81
Ventromedial frontal/anterior cingulate	L	25/10/11	−3	30	−12	440	**d**	5.57
Posterior cingulate	R	30	12	−51	12	49	**e**	4.64
Insula	L	48	−42	−9	18	155	**f**	5.28
Amygdala	L		−21	−6	−18	69	**g**	4.65
	R		24	−3	−21		c	4.37
Caudate	L		−6	15	15		h	4.52
	R		3	18	12	49	**h**	5.02
Thalamus	L		−3	−15	6	51	**i**	4.29
	L		−21	−27	−3	33	**j**	4.22
Reappraisal–view emotional								
Superior/medial frontal	L	6/8	−12	12	63	270	**a**	6.23
	R	6/8	12	15	66		a	5.87
Middle frontal	L	6/9/46	−45	12	45	213	**b**	5.77
	R	6/9/46	39	36	42	128	**c**	6.5
	L	46	−30	45	12	28	**d**	4.87
	R	46	36	45	27	44	**e**	4.17
Orbitofrontal	L	47	−36	45	−3	119	**f**	5.42
	R	47	39	45	−9	84	**g**	7.94
Inferior parietal	L	39/40	−60	−51	33	416	**h**	7.86
	R	39/40	60	−54	39	343	**i**	8.19
Precuneus	L	7	−6	−69	36	90	**j**	5.58
	R	7	9	−66	36		i	3.89
Middle temporal	L	22	−54	−39	−3	214	**k**	6.32
Inferior temporal	L	20	−48	−3	−36	20	**l**	6.12
Middle cingulate	L	23	−6	−21	27	31	**m**	4.71
	R	23	6	−21	30		m	4.04
View emotional–distraction								
Superior medial frontal	L	8/9/10	−6	54	39	1046	**a**	10.39
Temporal/occipital	L	37/19	−51	−72	12	587	**b**	10.49
	R	37/19/18/17	45	−69	0	13 343	**c**	12.35
Ventromedial frontal/anterior cingulate	L	25/10/11	−3	48	−9	702	**d**	13.35
Insula	L	48	−33	−15	6		c	6.44
Amygdala	L		−21	−6	−21		c	9.72
	R		27	−3	−18		c	8.58
Distraction–view emotional								
Anterior cingulate/dorsomedial frontal	L	6/8/32	−12	12	48		a	7.39
	R	6/8/32	12	21	45		a	6.63
Middle frontal	L	6/44/45/46	−39	3	33		a	8.68
	R	9/44/45/46	45	33	27	342	**b**	7.53
Superior frontal	L	6/8	−21	6	57		a	7.02
	R	6/8	27	6	54		a	6.46
Superior parietal	L	7	−27	−63	45	6098	**a**	11.26
	R	7	33	−66	57		a	6.94
Inferior parietal	L	39/40	−45	−39	45		a	10.97
	R	39/40	45	−45	48		a	8.22
Precuneus	L	7	−12	−63	48		a	9.15
	R	7	9	−63	48		a	8.17
Inferior temporal	L	20/37	−54	−57	−12	85	**c**	5.68
Middle cingulate	L	23	−6	−24	27		a	8.09
	R	23	6	−24	27		a	7.62
Insula	L	48	−33	18	18		a	7.43
	R	48	33	21	0	97	**d**	7.83
Cerebellum	R		12	−78	−21	28	**e**	4.99

Note: H, hemisphere; BA, Brodmann area; CS, cluster size in number of activated voxels; CI, cluster index; L, left; R, right; T-values for each peak are given: All peaks of 1 activation cluster are identified by the same letter; the cluster peaks are displayed in bold letters.

Effects of Distraction

Similarly to reappraisal, activation in the bilateral amygdala and the vmPFC/sgACC was increased when comparing emotional pictures in the viewing condition to the distraction condition (see Table 3), here reflecting a reduction of activation in these areas through distraction. Distraction yielded enhanced activity in the dlPFC and the dmPFC, which included the dorsal ACC (dACC). Additionally, large clusters bilaterally in the parietal cortex, overlapping with and superior to the activation for reappraisal, were activated in the distraction condition. Further activity was observed in the bilateral insula (see Fig. 4). As the distraction condition differed from view and reappraisal in the continuous display of the overlay on the images, we compared emotional and neutral pictures in the distraction and view conditions to exclude the possibility that the overlay prevented perception and processing of the pictures. This analysis yielded conjunct activity in a number of areas including the insula (for details, see Supplementary data 3).

Common Effects of Reappraisal and Distraction

The analyses revealed 2 common effects of reappraisal and distraction: first, a downregulation of the amygdala and the vmPFC/sgACC for both regulation conditions as indicated by increased activity in these regions for the view condition as compared with distraction and reappraisal (see Fig. 3 and Table 4); second, overlapping activation increases for the 2 regulation strategies in the dmPFC and dlPFC, as well as in the precuneus and in the inferior parietal cortex (see Table 4).

Distinct Effects of Reappraisal and Distraction

To identify regions that were strongly engaged in one of the regulation strategies, we directly contrasted reappraisal and distraction, using inclusive masks of the respective main effects of each strategy (e.g., reappraisal-distraction was masked with reappraisal-view). This analysis showed that OFC activity was enhanced for reappraisal, while the dACC/dmPFC, large clusters in the parietal cortex, and the insula showed stronger activation for distraction (see Table 4). When repeating this analysis without the masks, we found the same pattern of activations and additionally a stronger reduction in activity in the bilateral amygdala and vmPFC/sgACC for distraction over reappraisal (see Table 4).

Functional Connectivity Analysis

To confirm the identified control networks for reappraisal and distraction, functional connectivity of the amygdala was calculated. To this end, amygdala connectivity in the 2 regulation conditions was directly contrasted (see Table 5). During reappraisal, an activation increase in a number of frontal areas including the OFC, as well as inferior parietal and middle temporal cortex was related to a decrease in amygdala activity. In contrast, an activation increase in the dACC/dmPFC, large clusters in the parietal cortex, as well as the right insula was associated with a decrease in amygdala activation in the distraction condition.

Discussion

The present study yielded several new insights into the neural correlates of emotion regulation. First, we could demonstrate

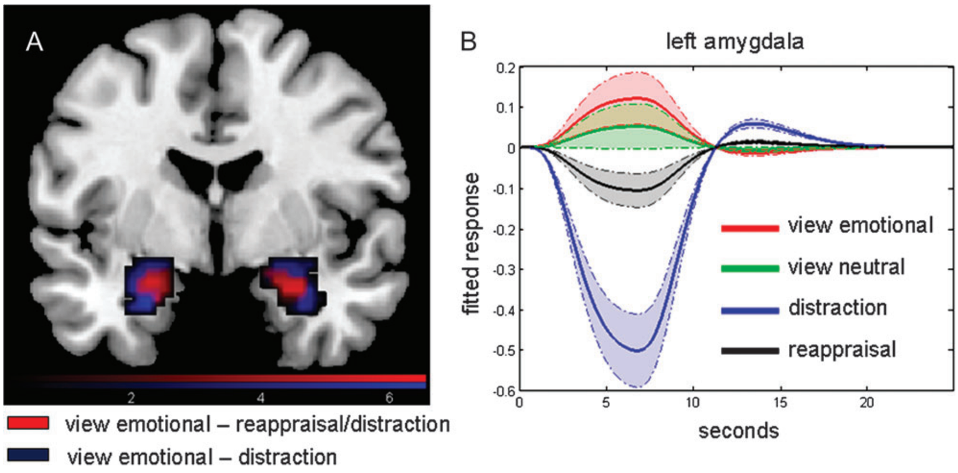

Figure 3. Reduction in amygdala activity (*A*) for the conjunction of reappraisal and distraction (in red, inclusive masking with $P < 0.01$ for each contrast, yielding a combined $P < 0.001$, see Methods) and the additional effect of distraction (in blue, exclusive masking with same thresholds). There was no additional effect of reappraisal. (*B*) Time-course of left amygdala activity for the different task conditions.

that 2 different regulation strategies, attentional control (distraction), and cognitive change (reappraisal) are effective in downregulating ongoing emotional responses to positive and negative stimuli on a neural and behavioral level. Second, this downregulation is subserved by a common network of control areas, including dlPFC, dmPFC, and parietal cortex. Third, both regulation strategies involve specific neural networks, which include the OFC for reappraisal and superior parietal sites, the dACC/dmPFC, and the insula for distraction. The role of these regulation networks was confirmed by functional connectivity of the left amygdala. Thereby the data extend recent findings from a study comparing reappraisal and a distracting memory task (McRae et al. 2010) showing that the effects generalize to different types of distraction, to emotions of different valence, to already elicited ongoing emotional responses, and to connectivity patterns of the distinct neural networks for reappraisal and distraction.

The 2 emotion regulation strategies investigated in the present study largely differ in their psychological mechanisms. While distraction relies on attentional control to shift the focus away from an emotional stimulus, for reappraisal, the focus remains on the emotional stimulus, but its meaning and personal relevance is reevaluated. Despite these differences, we found largely overlapping activations forming a common neural network underlying distraction and reappraisal including areas in the dlPFC, dmPFC, and inferior parietal cortex. These brain regions have been widely discussed for emotion regulation via reappraisal (Kalisch 2009) but also in the literature on attentional control (Egner and Hirsch 2005a, 2005b; Luks et al. 2007). Different types of conflict tasks such as Stroop or flanker paradigms as well as other executive control tasks reliably activate dlPFC, dmPFC, and parietal sites. Also the few studies that investigated emotion regulation through distraction from emotional stimuli yielded activation in these areas (Van Dillen et al. 2009; McRae et al. 2010). Therefore, both strategies draw on resources of a general cognitive control network that regulates the activity in brain areas denoted to the current task demands (e.g., fusiform face area in a face-word Stroop task, Egner and Hirsch 2005a; limbic regions in emotional interference tasks, Dillon et al. 2007) and thereby ensure coherent goal-directed behavior and efficient task performance.

Despite the described communalities of neural networks subserving reappraisal and distraction, we also found activity specific to each emotion regulation strategy. Bilaterally, the OFC was activated for reappraisal only and was also negatively coupled with left amygdala activity for reappraisal over distraction. OFC activation has been consistently reported in several reappraisal studies, both for down- and upregulation of an emotional response (e.g., Eippert et al. 2007). This regulating function of the OFC is in line with its involvement in affective reversal learning tasks (Kringelbach and Rolls 2003) as reappraisal can be described as a self-induced change in emotional responding during constant unchanged stimulation. Interestingly, patients with lesions in the OFC show deficits in the actualization of a current context (Schnider and Ptak 1999; Schnider 2003). In line with these data, the OFC is involved in distinguishing presently relevant from previously relevant information (Schnider et al. 2002). Reappraisal shares with these processes that the momentary relevance and meaning of a stimulus is changed. While the picture of a threatening event may be perceived as highly relevant and emotionally negative at first, its reappraisal as “just a picture taken in the past and presently irrelevant to me lying in the MR-Scanner” may render it neutral. The actualization of the present context and the reversal of the emotional meaning of a stimulus are specific to reappraisal, distinguish it from emotion regulation through attentional control, and rely on the OFC.

In contrast, the attentional control condition is characterized by orienting attention away from the emotional stimulus to a cognitive task, by the commitment of resources to the processing of this task, and by the detection of potential conflicts between task processing and emotional activation. Thereby attentional control secures the continuous dedication of resources to task processing. The dorsal portion of the anterior cingulate cortex has been widely discussed as a major node in the attentional control network, in particular for the monitoring of conflict between opposing activations (e.g., opposing response tendencies as in the Stroop task, see Botvinick et al. 2004). Interestingly, the activation of the dACC/dmPFC cluster in the present study was stronger in the distraction than the reappraisal condition. The PPI results also indicate enhanced negative coupling of the amygdala and the

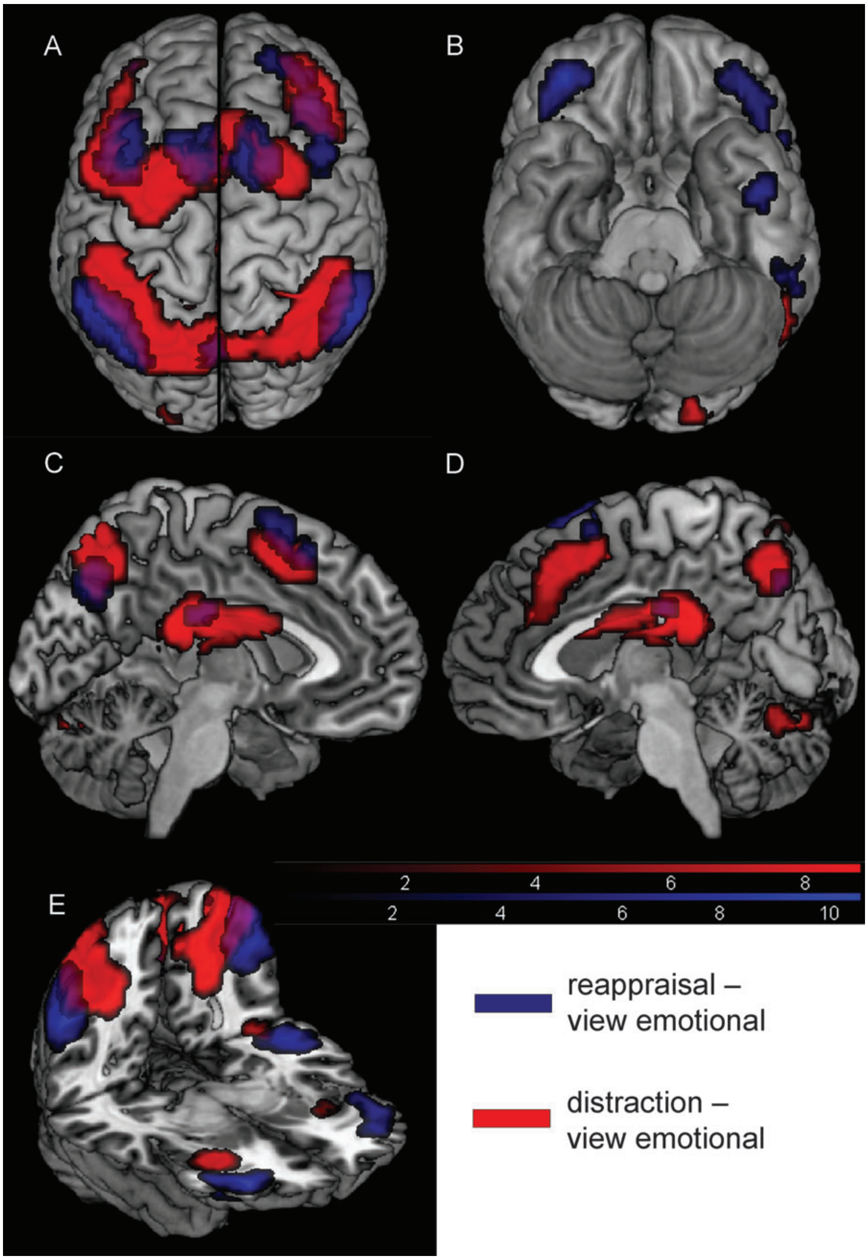

Figure 4. Activations for reappraisal (in blue) and distraction (in red) on the superior (*A*) and inferior (*B*) surface and on the opened (*E*) brain (cutting at $y = -52$ and $z = -5$). Medial effects are displayed for the left (*C*) and right (*D*) hemisphere ($x = -5$ and $x = 5$, respectively). All images are thresholded at whole-brain FDR-corrected $P < 0.01$ with an extent threshold of 20 voxels.

dACC/dmPFC for distraction, supporting the view that attentional control was particularly and more engaged in the distraction condition. We also found task-specific activations in the parietal cortex during distraction that nicely resembled previous data on mental arithmetic tasks in shape and location (Rickard et al. 2000; Fehr et al. 2007). Indeed, the processing of arithmetic problems largely involves different parts of the parietal cortex (intraparietal sulcus, inferior parietal lobule, angular gyrus, and superior parietal cortex; Menon et al. 2000; Dehaene et al. 2004; Grabner et al. 2009). Even though reappraisal also activated parts of the inferior parietal cortex, the activation elicited by distraction is larger, comprises additional areas in the superior parietal cortex, and its specific role for distraction is confirmed by the respective functional connectivity data. Distraction also yielded additional activation in the insula that was not observed for reappraisal. This is an interesting result as the insula has been mainly viewed as part of the emotional response network and is activated along with the amygdala and vmPFC/sgACC for emotional versus neutral pictures in the present study. However, the insula activation in the attentional control condition lies anterior to the emotional insula activity and can be clearly separated from it. This very anterior part of the insula has already been reported in other studies investigating mental arithmetics and is associated to task difficulty (Menon et al. 2000). Overall, the attentional control condition elicits specific activations additionally to the common regulation network that have been previously associated with executive attention (dACC) and that are

Table 4
Activations for reappraisal versus distraction and the results of the conjunction analysis

	H	BA	MNI coordinates			CS	CI	*T*
			x	*y*	*z*			
Reappraisal–distraction								
Superior medial frontal	L	6/8/9/10	−9	54	39	5324	**a**	9.97
Middle frontal	L	9	−39	15	45	76	**b**	5.22
Orbitofrontal	L	47	−48	30	−6		c	8.91
	R	47	36	39	−6	126	**d**	7.74
Inferior parietal	L	39/40	−45	−57	30	3195	**c**	8.94
	R	39/40	57	−63	36		a	8.01
Inferior temporal	L	20	−45	0	−33		c	8.54
	R	21	63	−12	−15	1127	**e**	8.37
Ventromedial frontal/anterior cingulate	L	25/10/11	−6	45	−9	555	**f**	7.14
Amygdala	L		−27	−6	−18		c	7.59
	R		30	−6	−27		e	6.33
Distraction–reappraisal								
Anterior cingulate/dorsomedial frontal	L	6/8/32	−12	12	48		a	5.11
	R	6/8/32	12	27	30		a	4.03
Superior frontal	L	6/8	−30	−3	54		a	5.94
	R	6/8	27	6	54		a	5.42
Superior parietal	L	7	−27	−60	45	4191	**a**	12.37
	R	7	30	−63	60		b	6.47
Inferior parietal	L	39/40	−48	−36	48		a	12.24
	R	39/40	45	−36	45	1035	**b**	8.6
Inferior temporal	L	20/37	−48	−60	−9	165	**c**	6.14
Insula	L	48	−30	21	−3		a	4.11
	R	48	33	21	0	67	**d**	5.24
Cerebellum	R		18	−54	−24	1183	**e**	7.64
Conjunction: reappraisal–distraction masked by reappraisal-view								
Superior medial frontal	L	6/8	−6	18	66	25	**a**	4.00
Middle frontal	L	9	−39	15	48	47	**b**	4.60
Orbitofrontal	L	47	−48	30	−12	61	**c**	7.58
	R	47	45	33	−6	33	**d**	6.41
Inferior parietal	L	39/40	−45	−57	27	193	**e**	5.69
	R	39/40	57	−60	24	235	**f**	6.26
Middle temporal	L	21	−63	−27	−6	186	**g**	5.22
Inferior temporal	L	20	−45	0	−36	23	**h**	6.90
Conjunction: distraction–reappraisal masked by distraction-view								
Anterior cingulate/dorsomedial frontal	L	6/8/32	−12	12	48	790	**a**	3.12
	R	6/8/32	9	30	33		a	3.02
Superior frontal	L	6/8	25	0	53		a	5.41
	R	6/8	25	9	54	121	**b**	4.60
Superior parietal	L	7	−28	−63	52		a	4.87
	R	7	30	−65	56		b	3.84
Inferior parietal	L	40	−42	−39	42	1235	**c**	7.82
	R	40	45	−42	51	609	**d**	6.53
Inferior temporal	L	20/37	−54	−57	−15	52	**e**	4.46
Insula	L	48	−33	18	9	58	**f**	4.11
	R	48	33	21	−5	53	**g**	3.88
Conjunction: view–reappraisal/distraction								
Middle temporal	L	37	−48	−72	12	31	**a**	3.79
	R	37	51	−60	6	123	**b**	7.55
Ventromedial frontal/anterior cingulate	L	25/10/11	−3	39	−12	373	**c**	10.03
Amygdala	L		−21	−6	−21	35	**d**	6.94
	R		24	−6	−21	223	**e**	6.07
Conjunction: reappraisal/distraction–view								
Dorsomedial frontal	L	6	−3	12	57	34	**a**	3.37
Middle frontal gyrus	L	46	−42	24	30	24	**b**	3.97
	L	6/9	−39	3	54	27	**c**	3.81
	R	9/46	39	45	30	61	**d**	3.7
Inferior parietal	L	40	−39	−54	45	114	**e**	5.44
	R	40	51	−45	51	54	**f**	4.59
Precuneus	L	7	−9	−63	45	39	**g**	6.25
	R	7	9	−66	42	27	**h**	5.07
Middle cingulate	R	23	3	−27	24	70	**i**	4.81

Note: H, hemisphere; BA, Brodmann area; CS, cluster size in number of activated voxels; CI, cluster index; L, left; R, right; T-values for each peak are given: All peaks of 1 activation cluster are identified by the same letter; the cluster peaks are displayed in bold letters.

specific to the present arithmetic task (broad parietal cluster) or are related to task difficulty (anterior insula). The functional role of these regions is corroborated by their increased negative coupling with the left amygdala for distraction over reappraisal.

Table 5
Results of the PPI analysis

	H	BA	MNI coordinates			CS	CI	*T*
			x	*y*	*z*			
PPI reappraisal								
Superior medial frontal	L	10	−6	63	15	63	**a**	3.59
		9	0	45	48	144	**b**	4.02
Superior frontal	R	6	21	−12	75	2764	**c**	4.76
Inferior orbitofrontal	L	47	−33	33	−12	20	**d**	3.83
	R	47	33	36	−12	25	**e**	4.31
Inferior parietal	R	39	54	−69	33	117	**f**	3.55
Middle temporal	L	20	−45	−9	−18	349	**g**	3.88
	R	22	63	−15	15	277	**h**	3.39
Ventromedial frontal/anterior cingulate	L	25/10/11	−9	27	−6	391	**i**	4.28
Amygdala	R		36	0	−18	185	**j**	4.89
PPI distraction								
Anterior cingulate/dorsomedial frontal	R	6/8/32	6	24	48	169	**a**	4.72
Middle frontal	L	44	−48	27	30	42	**b**	3.49
	L	6	−54	6	36	84	**c**	3.43
	R	44/46	48	30	36	50	**d**	3.82
Parietal	L	7/40	−42	39	45		e	4.68
	R	7/45	39	−45	45	79	**f**	3.63
Precuneus	L	7	−24	−60	42		e	3.53
	R	7	27	−60	45	99	**g**	3.51
Occipital	L	17/18/19	−24	−99	9	3359	**e**	7.46
Insula	R	47/48	36	24	−3	59	**h**	3.9

Note: H, hemisphere; BA, Brodmann area; CS, cluster size in number of activated voxels; CI, cluster index; L, left; R, right; T-values for each peak are given: All peaks of 1 activation cluster are identified by the same letter; the cluster peaks are displayed in bold letters.

As the neural networks for emotion regulation through attentional control and reappraisal are similar, so are the effects on behavioral and neural emotional responding. Emotional pictures reliably elicited an emotional response as could be seen in the online emotional state ratings and in activation in the amygdala, the vmPFC/sgACC, and the insula. These regions have been described as part of a ventral stream, which is supposed to be involved in the differentiation of emotional from nonemotional stimuli (Sabatinelli et al. 2009), emotional appraisal, and the production of an emotional state (Phillips et al. 2003; Stein et al. 2007). In line with previous studies, attentional control as well as cognitive change attenuated emotional responses (Goldin et al. 2008; Van Dillen et al. 2009). Subjective emotional state ratings as well as activity in the amygdala, vmPFC/sgACC, and the insula were lowered after reappraisal and distraction when compared with passive picture viewing. This corroborates recent data from McRae et al. (2010) and extends their findings to the regulation of both positive and negative emotions. Importantly, as the present experiment allows a direct comparison of the effects of reappraisal and distraction, we could also show a stronger and more extended reduction in amygdala activity in the distraction condition. This effect has to be interpreted with some care, as there was a continuous overlay on the images in the distraction condition, while the instruction overlay disappeared after 1 s during reappraisal and view. The overlay did not prevent participants from perceiving the images (see Supplementary data 3), but part of the reduction in amygdala activation could be due to the presence of this additional visual input. Nevertheless, the stronger effect for distraction is in line with other recent data (McRae et al. 2010). As described above, distraction differs from reappraisal in that it focuses attention away from the emotional content of a stimulus, while it is necessary to focus on the emotional aspects of a stimulus in order to reappraise their meaning. This potentially leads to stronger activation in the ventral emotional stream for the reappraisal as compared with the distraction condition. Thus, as a short-term strategy for reducing an emotionally stressful response, distraction may prove to be an efficient intervention. This could also be relevant for psychotherapy in patients with difficulties in emotion regulation, for example in Borderline Personality Disorder or Bipolar Depression (Wessa et al. 2007; Gratz et al. 2009). Arithmetic tasks are particularly favorable in this regard as they are easy to implement and can be self-generated in emotionally stressful situations. It is also clinically relevant that the present study shows effects of reappraisal and distraction on ongoing emotional responses that have already been elicited (in contrast to McRae et al. (2010) who presented emotional stimuli after the regulation instruction), which is the primary challenge for patients in everyday situations. The present study did not address the duration of emotion regulation effects and future studies should elucidate the stability of the downregulating effects of reappraisal and distraction. The impact on long-term emotional responding may differ from the short-term effects reported here as memory for emotional stimuli is enhanced by reappraisal and impaired after distraction (Dillon et al. 2007; Sheppes and Meiran 2007). Furthermore, in a study comparing a distancing form of reappraisal to distraction during the recall of a depression experience, Kross and Ayduk (2008) showed that reappraisal protected against depressive affect 1 and 7 days after the experiment. Distraction and reappraisal may, therefore, differ in their long- and short-term effects, raising the important clinical question if different emotion regulation strategies should be taught with respect to specific situations and goals in psychotherapy (e.g., reduce present anger or long-term depressive feelings).

Despite the strong and consistent results of BOLD response changes and subjective emotional state changes during reappraisal and distraction, the interpretation of our results are limited by the lack of additional measures, such as eye movement patterns (van Reekum et al. 2007) as well as physiological indicators of emotional responsivity (e.g., electrodermal activity, heart rate). These indicators are highly correlated to subjective evaluation of emotional state (Cuthbert et al. 1996) and to the downregulation of anxiety (Kalisch et al. 2005) but not necessarily to the emotion regulation per se (Eippert et al. 2007). Whether these measures are sensitive to the different regulation strategies and which mechanisms of emotion regulation are reflected by the physiological indicators remain unclear and should be investigated in future studies.

To conclude, we confirmed and extend recent findings on neural correlates of reappraisal and distraction (McRae et al. 2010) showing that these different emotion regulation strategies are effective in downregulating ongoing subjective and physiological responses to emotional stimuli of different valence. The combination of 2 emotion-regulation strategies allowed us to identify a common neural control network in dlPFC, dmPFC, and inferior parietal cortex and to additionally show distinct strategy-specific activations in the OFC for reappraisal and the dACC, parietal cortex, and insula for attentional control (distraction). Moreover, an important and new insight from the present study was that these strategy-specific activations showed increased negative coupling with the left amygdala when reappraisal and distraction were compared. Emotional state ratings and downregulation of the initially elicited amygdala activation indicated robust effects of both strategies on emotional responding.

Supplementary Material

Supplementary material can be found at: http://www.cercor.oxfordjournals.org/.

Funding

Deutsche Forschungsgemeinschaft (We3638/3-1).

Notes

We wish to thank Heike Schmidt for help with the data acquisition. *Conflict of Interest*: None declared.

References

Banks SJ, Eddy KT, Angstadt M, Nathan PJ, Phan KL. 2007. Amygdala-frontal connectivity during emotion regulation. Soc Cogn Affect Neurosci. 2:303–312.

Blair KS, Smith BW, Mitchell DG, Morton J, Vythilingam M, Pessoa L, Fridberg D, Zametkin A, Sturman D, Nelson EE, et al. 2007. Modulation of emotion by cognition and cognition by emotion. Neuroimage. 35:430–440.

Botvinick MM, Cohen JD, Carter CS. 2004. Conflict monitoring and anterior cingulate cortex: an update. Trends Cogn Sci. 8:539–546.

Cuthbert BN, Bradley MM, Lang PJ. 1996. Probing picture perception: activation and emotion. Psychophysiology. 33:103–111.

de Fockert JW, Rees G, Frith CD, Lavie N. 2001. The role of working memory in visual selective attention. Science. 291:1803–1806.

Dehaene S, Molko N, Cohen L, Wilson AJ. 2004. Arithmetic and the brain. Curr Opin Neurobiol. 14:218–224.

Dillon DG, Ritchey M, Johnson BD, LaBar KS. 2007. Dissociable effects of conscious emotion regulation strategies on explicit and implicit memory. Emotion. 7:354–365.

Eftekhari A, Zoellner LA, Vigil SA. 2009. Patterns of emotion regulation and psychopathology. Anxiety Stress Coping. 22:571–586.

Egner T, Hirsch J. 2005a. Cognitive control mechanisms resolve conflict through cortical amplification of task-relevant information. Nat Neurosci. 8:1784–1790.

Egner T, Hirsch J. 2005b. The neural correlates and functional integration of cognitive control in a Stroop task. Neuroimage. 24:539–547.

Eippert F, Veit R, Weiskopf N, Erb M, Birbaumer N, Anders S. 2007. Regulation of emotional responses elicited by threat-related stimuli. Hum Brain Mapp. 28:409–423.

Erk S, Kleczar A, Walter H. 2007. Valence-specific regulation effects in a working memory task with emotional context. Neuroimage. 37:623–632.

Fehr T, Code C, Herrmann M. 2007. Common brain regions underlying different arithmetic operations as revealed by conjunct fMRI-BOLD activation. Brain Res. 1172:93–102.

First MB, Gibbon M, Spitzer RL, Williams JBW. 1997. Structured clinical interview for DSM IV axis I disorders (SCID-I). Arlington (TX): American Psychiatric Publishing, Inc.

Friston KJ, Buechel C, Fink GR, Morris J, Rolls E, Dolan RJ. 1997. Psychophysiological and modulatory interactions in neuroimaging. Neuroimage. 6:218–229.

Goldin PR, McRae K, Ramel W, Gross JJ. 2008. The neural bases of emotion regulation: reappraisal and suppression of negative emotion. Biol Psychiatry. 63:577–586.

Grabner RH, Ansari D, Koschutnig K, Reishofer G, Ebner F, Neuper C. 2009. To retrieve or to calculate? Left angular gyrus mediates the retrieval of arithmetic facts during problem solving. Neuropsychologia. 47:604–608.

Gratz KL, Tull MT, Reynolds EK, Bagge CL, Latzman RD, Daughters SB, Lejuez CW. 2009. Extending extant models of the pathogenesis of borderline personality disorder to childhood borderline personality symptoms: the roles of affective dysfunction, disinhibition, and self- and emotion-regulation deficits. Dev Psychopathol. 21:1263–1291.

Hajcak G, MacNamara A, Olvet DM. 2010. Event-related potentials, emotion, and emotion regulation: an integrative review. Dev Neuropsychol. 35:129–155.

Kalisch R. 2009. The functional neuroanatomy of reappraisal: time matters. Neurosci Biobehav Rev. 33:1215–1226.

Kalisch R, Wiech K, Critchley HD, Seymour B, O'Doherty JP, Oakley DA, Allen P, Dolan RJ. 2005. Anxiety reduction through detachment: subjective, physiological, and neural effects. J Cogn Neurosci. 17:874–883.

Kampe KK, Frith CD, Frith U. 2003. "Hey John": signals conveying communicative intention toward the self activate brain regions associated with "mentalizing," regardless of modality. J Neurosci. 23:5258–5263.

Kim SH, Hamann S. 2007. Neural correlates of positive and negative emotion regulation. J Cogn Neurosci. 19:776–798.

Kringelbach ML, Rolls ET. 2003. Neural correlates of rapid reversal learning in a simple model of human social interaction. Neuroimage. 20:1371–1383.

Kross E, Ayduk O. 2008. Facilitating adaptive emotional analysis: distinguishing distanced-analysis of depressive experiences from immersed-analysis and distraction. Pers Soc Psychol Bull. 34: 924–938.

Lang PJ, Bradley MM, Cuthbert BN. 2005. International affective picture system (IAPS): affective ratings of pictures and instruction manual. Technical report A-6. Gainesville (FL): Center for Research in Psychophysiology, University of Florida.

Luks TL, Simpson GV, Dale CL, Hough MG. 2007. Preparatory allocation of attention and adjustments in conflict processing. Neuroimage. 35:949–958.

McRae K, Hughes B, Chopra S, Gabrieli JD, Gross JJ, Ochsner KN. 2010. The neural bases of distraction and reappraisal. J Cogn Neurosci. 22:248–262.

Menon V, Rivera SM, White CD, Glover GH, Reiss AL. 2000. Dissociating prefrontal and parietal cortex activation during arithmetic processing. Neuroimage. 12:357–365.

Ochsner KN, Bunge SA, Gross JJ, Gabrieli JD. 2002. Rethinking feelings: an FMRI study of the cognitive regulation of emotion. J Cogn Neurosci. 14:1215–1229.

Ochsner KN, Gross JJ. 2005. The cognitive control of emotion. Trends Cogn Sci. 9:242–249.

Oldfield RC. 1971. The assessment and analysis of handedness: the Edinburgh inventory. Neuropsychologia. 9:97–113.

Pessoa L, McKenna M, Gutierrez E, Ungerleider LG. 2002. Neural processing of emotional faces requires attention. Proc Natl Acad Sci U S A. 99:11458–11463.

Phillips ML, Drevets WC, Rauch SL, Lane R. 2003. Neurobiology of emotion perception I: the neural basis of normal emotion perception. Biol Psychiatry. 54:504–514.

Rickard TC, Romero SG, Basso G, Wharton C, Flitman S, Grafman J. 2000. The calculating brain: an fMRI study. Neuropsychologia. 38:325–335.

Sabatinelli D, Lang PJ, Bradley MM, Costa VD, Keil A. 2009. The timing of emotional discrimination in human amygdala and ventral visual cortex. J Neurosci. 29:14864–14868.

Schnider A. 2003. Spontaneous confabulation and the adaptation of thought to ongoing reality. Nat Rev Neurosci. 4:662–671.

Schnider A, Ptak R. 1999. Spontaneous confabulators fail to suppress currently irrelevant memory traces. Nat Neurosci. 2:677–681.

Schnider A, Valenza N, Morand S, Michel CM. 2002. Early cortical distinction between memories that pertain to ongoing reality and memories that don't. Cereb Cortex. 12:54–61.

Sheppes G, Meiran N. 2007. Better late than never? On the dynamics of online regulation of sadness using distraction and cognitive reappraisal. Pers Soc Psychol Bull. 33:1518–1532.

Stein JL, Wiedholz LM, Bassett DS, Weinberger DR, Zink CF, Mattay VS, Meyer-Lindenberg A. 2007. A validated network of effective amygdala connectivity. Neuroimage. 36:736–745.

Tzourio-Mazoyer N, Landeau B, Papathanassiou D, Crivello F, Etard O, Delcroix N, Mazoyer B, Joliot M. 2002. Automated anatomical labeling of activations in SPM using a macroscopic anatomical parcellation of the MNI MRI single-subject brain. Neuroimage. 15:273–289.

Urry HL, van Reekum CM, Johnstone T, Kalin NH, Thurow ME, Schaefer HS, Jackson CA, Frye CJ, Greischar LL, Alexander AL, et al. 2006. Amygdala and ventromedial prefrontal cortex are inversely coupled during regulation of negative affect and predict the diurnal pattern of cortisol secretion among older adults. J Neurosci. 26:4415–4425.

Van Dillen LF, Heslenfeld DJ, Koole SL. 2009. Tuning down the emotional brain: an fMRI study of the effects of cognitive load on the processing of affective images. Neuroimage. 45:1212–1219.

Van Dillen LF, Koole SL. 2007. Clearing the mind: a working memory model of distraction from negative mood. Emotion. 7:715–723.

van Reekum CM, Johnstone T, Urry HL, Thurow ME, Schaefer HS, Alexander AL, Davidson RJ. 2007. Gaze fixations predict brain activation during the voluntary regulation of picture-induced negative affect. Neuroimage. 36:1041–1055.

Walter H, von Kalckreuth A, Schardt D, Stephan A, Goschke T, Erk S. 2009. The temporal dynamics of voluntary emotion regulation. PLoS One. 4:e6726.

Wessa M, Houenou J, Paillere-Martinot ML, Berthoz S, Artiges E, Leboyer M, Martinot JL. 2007. Fronto-striatal overactivation in euthymic bipolar patients during an emotional go/nogo task. Am J Psychiatry. 164:638–646.

Wittchen H-U, Zaudig M, Fydrich T. 1997. SKID-I. Strukturiertes Klinisches Interview für DSM-IV [Structural clinical interview for DSM-IV axis I disorders]. Göttingen (Germany): Hogrefe.