

Brain activation during cognitive reappraisal depending on regulation goals and stimulus valence

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Abstract

Neural bases of cognitive reappraisal may depend on the direction of regulation (up- or downregulation) and stimulus valence (positive or negative). This study aimed to examine this using a cognitive reappraisal task and conjunction analysis on a relatively large sample of 83 individuals. We identified regions in which activations were common for all these types of emotion regulation. We also investigated differences in brain activation between the ‘decrease’ and ‘increase’ emotional response conditions, and between the regulation of negative and positive emotions. The common activation across conditions involved mainly the prefrontal and temporal regions. Decreasing emotions was associated with stronger involvement of the dorsolateral prefrontal cortex, while increasing with activation of the amygdala and hippocampus. Regulation of negative emotions involved stronger activation of the lateral occipital cortex, while regulation of positive emotions involved stronger activation of the anterior cingulate cortex extending to the medial prefrontal cortex. This study adds to previous findings, not only by doing a conjunction analysis on both emotional valences and regulation goals, but also doing this in a bigger sample size. Results suggest that reappraisal is not a uniform process and may have different neural bases depending on regulation goals and stimulus valence.

Key words: reappraisal; emotion regulation; conjunction analysis; regulation goals; stimulus valence

Introduction

Effective emotion regulation is crucial for affective, cognitive and social functioning and protects against psychopathology (Ochsner *et al.*, 2002). Gross (1998) describes emotion regulation as the process that influences which emotions we experience, when we experience them, and how they are experienced and expressed. Cognitive reappraisal is the effortful modification of a situation’s meaning in order to change its emotional impact (Gross, 2015). Two possible regulation goals of two possible valences are usually discussed: we can upregulate/downregulate positive/negative emotions. Upregulating positive emotions and downregulating negative emotions are the more intuitive processes and they are both important for managing affective arousal, for coping with adverse situations and for increasing one’s sense of happiness (Fredrickson and Levenson, 1998; Gross, 2015). Downregulating negative emotions is important for the control of intrusive negative emotions (De Vaus *et al.*, 2018), while upregulating positive emotions is important for managing stress (Folkman and Moskowitz, 2000) and facilitating recovery from negative experiences (Fredrickson and Levenson, 1998). In real-life situations, different regulation goals are often implemented simultaneously—for example, intentional efforts to diminish negative affect and increase positive emotions (Webb *et al.*, 2012; Schwager and Rothermund, 2013).

Increasing negative and decreasing positive emotions, although less common, may play an important role in psychopathology and social functioning. Increasing negative affect, for example through rumination, is a common symptom of depression (Papageorgiou and Wells, 2003). On the other hand, decreasing positive affect can be appropriate in some social situations, such as at a funeral. Diminished positive affect occurs in depression and anxiety disorders, which are often associated with diminished upregulation and increased downregulation of positive emotions (Carl *et al.*, 2013).

Most neuroimaging studies on emotion regulation have investigated the neural correlates of downregulation of negative emotions, while studies that included other regulation goals have frequently conflated the regulation of positive and negative emotions. Stimulus valence may play a crucial role in how one processes emotional content. Negative stimuli may involve the fight or flight response and biased attention to threat (Carretié *et al.*, 2009; Todd *et al.*, 2012). On the other hand, positive stimuli broaden the scope of attention in a way that distributed attention is linked to more global perceptual processing (Fredrickson and Branigan, 2005; Srinivasan and Hanif, 2010). Thus, research to date does not paint a full picture of the neural basis of cognitive reappraisal.

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To date, there has only been one study that examined all regulation conditions: Kim and Hamann (2007) directly compared the brain activation involved in decreasing positive and negative emotions and showed that decreasing negative emotions engaged the lateral prefrontal cortex, dorsomedial prefrontal cortex (dmPFC), orbitofrontal cortex (OFC) and anterior cingulate cortex (ACC); increasing negative emotions involved greater activation of the dmPFC. On the other hand, increasing positive emotions engaged the rostromedial and lateral prefrontal cortices and amygdala. However, the study's small sample size (10 participants) limits the strength of these results.

Based on their meta-analysis, Kohn *et al.* (2014) proposed the heuristic model of neural correlates of cognitive emotion regulation, which suggests that the brain structures most involved in regulation are the amygdala, ventrolateral prefrontal cortex (vlPFC), dorsolateral prefrontal cortex (dlPFC), insula, cingulate cortex, superior temporal gyrus (STG), and supplementary motor area (SMA). However, it is worth noting that their meta-analysis did not differentiate between either the regulation goals or the valence of stimuli.

A recent meta-analysis by Morawetz *et al.* (2017) was a step in the right direction, as differences related to regulation goal (up-/downregulation) were investigated. Yet, no analyses have been performed with regard to stimulus valence (positive/negative) due to the insufficient number of studies using positive stimuli. Their study also suggests that the increase in emotions tends to involve the SMA and insula more strongly, while decreasing emotions involves the dlPFC and inferior parietal lobule (IPL). Morawetz *et al.* (2017) used conjunction analysis to determine significant voxels during both increasing and decreasing emotions and found that the vlPFC, dmPFC and SMA were activated in both conditions. The results regarding activations during reappraisal, regardless of the regulation goal, were largely consistent with those presented by Kohn *et al.* (2014): namely, that it involved the bilateral vlPFC, dlPFC, dmPFC, as well as the middle temporal gyrus (MTG), STG, IPL, pre-supplementary motor areas (pre-SMA) and SMA. Importantly, the authors note that 62% of all studies in the meta-analysis used the decrease in negative emotions in response to negative pictures from the International Affective Picture System. Therefore, the results of previous studies may not only reflect only one regulation goal but may also be stimuli specific. On the other hand, Morawetz *et al.* (2017) indicated that activation related to reappraisal is largely independent of stimulus type.

The processing of positive stimuli is less studied. One study suggests that reducing positive emotions involves activation in the superior medial frontal gyrus and dlPFC as well as deactivation in the insula, lingual gyrus and operculum (Mak *et al.*, 2009). Another study by Li *et al.* (2018) suggests that while both regulation goals involve the activation of the vlPFC, dmPFC, ACC and STG to a similar degree, increasing positive emotions involved stronger activation in the bilateral occipital lobe compared to the decrease condition.

Our study fills this gap in the literature by implementing a more balanced, factorial experimental design, exploring brain activation during increasing and decreasing of positive and negative emotions. The study examines both the common brain activation patterns for cognitive reappraisal, as well as those specific to different goals of emotion regulation and different stimuli valence. It does so using conjunction analyses that combine goal- and stimuli-specific effects. Our study also provides a more reliable measurement of regulation processes by using

a larger sample size—and thus having more power—than most previous studies.

The goal of this study was to characterize the neural correlates of emotion regulation depending on the regulation goal and stimuli valence. More specifically, our goals were (i) to examine brain activations across multiple conditions using conjunction analysis depending on goal and valence; (ii) to investigate the differences in brain activation between 'decrease' and 'increase' conditions; and (iii) to investigate the differences in brain activation between the regulation of negative and positive emotions. Based on previous studies, we expected to obtain goal-specific effects—that is, different goals ('decrease' vs 'increase') would involve the activation of distinct brain structures. We expected that decreasing emotions would involve higher activation in the lateral prefrontal cortex, OFC, ACC and IPL, while increasing emotions would involve higher activation in the dmPFC, SMA and insula (Kim and Hamann, 2007; Morawetz *et al.*, 2017). Given the importance of context-dependent stimuli, we also expected to find stimulus-specific effects—that is, different valences (negative vs positive) would engage the activation of separate regions. We expected that negative stimuli would involve higher activation in the dmPFC, lateral prefrontal cortex, ACC, OFC, insula and lingual gyrus, while positive stimuli would involve higher activation in the superior medial frontal gyrus, dmPFC, dlPFC and OFC (Kim and Hamann, 2007; Mak *et al.*, 2009).

Materials and methods

Participants

The study group consisted of 83 young adults (41 women) aged 19–25 ($M = 21.66$; $s.d. = 1.83$), recruited from a community sample. Out of 90 recruited participants, one was rejected due to magnetic resonance imaging (MRI) contraindications, two did not finish the cognitive reappraisal task, and data from additional four subjects were discarded due to insufficient coverage of the amygdala. The exclusion criteria were the declared presence of neurological or psychiatric disorders; traumatic brain injury; addiction to alcohol, drugs or other psychoactive substances; or any MRI contraindications. The participants all gave written informed consent and received a sum equivalent to 60 euros for taking part in the study. Approval was granted by the local ethics committee at the University of Warsaw. The study adhered to the guidelines of the Declaration of Helsinki.

Stimuli

The emotional stimuli were selected from a standardized database based on their arousal and valence values: 48 positive, 48 negative and 16 neutral pictures from the Nencki Affective Picture System (NAPS, Marchewka *et al.*, 2014) were used. The images depicted social situations, people and faces. The valence values ranged from 0 (very negative) to 9 (very positive). Arousal values ranged from 0 (low arousal) to 9 (high arousal). Table 1 reports the mean valence and arousal scores of the selected stimuli. The three groups of pictures were different in terms of valence. It was unavoidable that positive and negative stimuli had different levels of arousal, because relatively few pictures in the database met the inclusion criteria and pictures with negative valence were significantly more arousing than those with positive valence ($P < 0.001$).

Cognitive reappraisal task

A cognitive reappraisal task was used to measure brain activation during emotion regulation. Images were presented against

Table 1. Emotional stimuli used in the reappraisal task

	Valence		
	Neutral M (s.d.)	Positive M (s.d.)	Negative M (s.d.)
Valence	5.28 (0.26)	7.24 (0.43)	3.22 (0.46)
Arousal	4.68 (0.34)	5.02 (0.35)	6.13 (0.29)

a gray background using Presentation version 20.1 (Neurobehavioral Systems, Inc., Berkeley, CA). A mock scanner was used to familiarize the participants with the scanner and experimental procedure. Subjects received instructions and training about regulation strategies prior to the scan. Participants verbally indicated to a researcher that they understood the task and had practiced the strategies with different stimuli. They were given feedback until they could effectively use the strategies.

The task was adapted from previous studies (Ochsner et al., 2004; Kim et al., 2013; McLaughlin et al., 2015). It comprised two emotion regulation goals ('decrease' and 'increase') and a control condition ('look'). The participant's goal in the 'decrease' condition was to downregulate their emotional response through either reinterpreting the situation in a less negative/positive way, rationalizing it (looking at it in a more objective way), or self-distancing (observing detachedly and becoming psychologically distant). The participant's goal in the 'increase' condition was to upregulate their emotional response through either reinterpreting the situation in a more negative/positive way, engaging with the situation, becoming subjectively closer or perceiving the situation as being real. For the 'look' condition, participants did not modulate their emotional response. The participants were told to use the strategy which was most suitable, which they are most familiar with, and which would be most effective in the given situation.

Images were presented using a block design. Each block consisted of an instruction (5 s) followed by four pictures with the same valence. They were shown for 5 s in a randomized fashion in all conditions. The regulation goal of each block was indicated to participants by symbols displayed under each picture: a downward arrow ('decrease'), an upward arrow ('increase') or a dash ('look'). After the regulation phase, participants rated the strength of their emotions on a 'thermometer' (see Figure 1), after which a fixation cross was displayed until the next block.

There were seven task conditions: two regulation goals ('increase' and 'decrease') \times 2 stimuli valence ('negative' and 'positive'), and 'look' control conditions consisting of negative, positive and neutral stimuli. The task consisted of 28 blocks in total—4 blocks for each condition. Block order was pseudorandomized: no more than two blocks of the same condition could be shown in a row. The task design is shown in Figure 1.

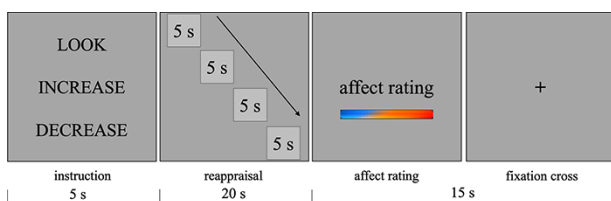


Fig. 1. Design of the reappraisal task. Each block started with an instruction that was followed by four pictures of the same valence ('positive', 'negative' or 'neutral'). Participants rated their affect after the regulation phase and then a fixation cross was shown until the next experimental block.

MRI data acquisition and preprocessing

Whole-brain functional and structural images were acquired using a 3T MRI scanner (Trio TIM, Siemens, Germany) equipped with a 32-channel head coil. First, a localizer and high-resolution T1-weighted images were obtained. Repetition time (TR)/inversion time (TI)/echo time (TE) = 2530/1100/3.32 ms; flip angle = 7°; parallel acquisition techniques (PAT) factor = 2; field of view (FoV) = 256 mm; voxel dimensions = 1 mm isotropic and 256 \times 256 voxel resolution. Functional images were acquired using a T2-weighted, gradient-echo echo planar imaging pulse sequence during a single functional run. A total of 570 whole-brain volumes were recorded with the following parameters: TR/TE = 2000/30 ms; flip angle = 90°; 64 \times 64 matrix size; FoV = 224 mm; 3.5 \times 3.5 mm voxel size; 35 slices (interleaved ascending) and 3.5 mm slice thickness.

Statistical Parametric Mapping (SPM12, Wellcome Department of Cognitive Neurology), implemented in MATLAB (2018, MathWorks Inc.) was used for all analyses. For preprocessing, images were spatially realigned, slice-time corrected (to the middle slice), coregistered to the first functional image, segmented and normalized to the standard Montreal Neurological Institute (MNI) template, producing volumes with 2 mm³ isotropic resolution that underwent spatial smoothing with an 8-mm isotropic Gaussian kernel. A gray matter mask was implemented in the statistical models to restrict the analyses to only the gray matter volume.

Data analyses

Behavioral data

The visual affect scale was converted to a continuous scale whose scores ranged from 0 (low affect) to 100 (high affect). To measure whether cognitive reappraisal was related to change in affect, dependent t-tests were performed with mean affect rating in 'increase', 'decrease' and 'look' conditions separately for positive and negative stimuli. Analyses were conducted using IBM SPSS Statistics.

fMRI data

First-level analysis. In the first-level analysis, data from a single experimental run for each subject was modelled using a general linear model (GLM). The regressors used in the model were (i) 'decrease negative'; (ii) 'decrease positive'; (iii) 'increase negative'; (iv) 'increase positive'; (v) 'look negative'; (vi) 'look positive'; (vii) 'look neutral'; (viii) instructions; (ix) affect rating and (x) fixation crosses. These regressors were each convolved with a canonical hemodynamic response function. The model included regressors of no interest to account for head motion. Extended head movements were identified with the Artifact Detection Tool toolbox, and volumes exceeding 2 mm or 0.05 rad movement thresholds were excluded from analyses. Four separate first-level contrasts were modelled, that is 'decrease negative' > 'look negative'; 'decrease positive' > 'look positive'; 'increase negative' > 'look negative' and 'increase positive' > 'look positive'. Single-subject contrasts for all four conditions were submitted to second-level analyses.

Second-level analysis. Conjunction analyses were performed to identify common brain activations in two or more distinct contrasts during cognitive reappraisal depending on the regulation goals and stimulus valence. To examine the brain activation related to reappraisal regardless of regulation goals and stimulus valence, the [('decrease negative' > 'look negative') + ('decrease

positive' > 'look positive') + ('increase negative' > 'look negative') + ('increase positive' > 'look positive') contrast was used.

GLM1 and GLM2 were used to investigate the goal-specific effects. In GLM1, we examined activations when decreasing emotions using the following contrast: [('decrease negative' > 'look negative') + ('decrease positive' > 'look positive')]. In GLM2, we examined activations when increasing emotions using the following contrast: [('increase negative' > 'look negative') + ('increase positive' > 'look positive')].

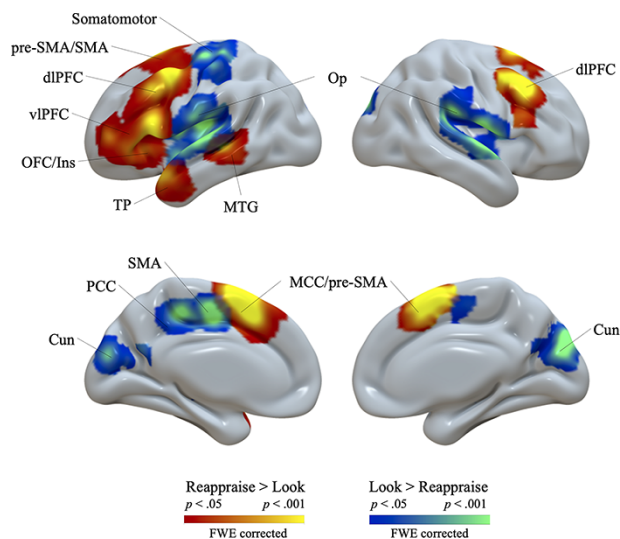


Fig. 2. Conjunction analysis across all conditions for the 'reappraise' ('decrease' + 'increase') negative and positive vs 'look' (negative + positive) contrast. Red-yellow colors indicate stronger activation during the 'reappraise' condition; blue-green colors indicate stronger activation during the 'look' condition. Abbreviations: Cun—cuneus; Ins—insula; Op—operculum.

GLM3 and GLM4 were used to investigate the stimulus-specific effects. In GLM3, we examined activations related to negative valence using the following contrast: [('decrease negative' > 'look negative') + ('increase negative' > 'look negative')]. In GLM4, we examined the activations related to positive valence using the following contrast: [('decrease positive' > 'look positive') + ('increase positive' > 'look positive')].

GLM5 and GLM6 were used to test the differences related to different goals and stimulus valence. In GLM5, we examined differences between increase and decrease goals using the following contrast: [('decrease negative' + 'decrease positive') vs ('increase negative' + 'increase positive')]. In GLM6, we examined differences between activation during regulation of stimuli of negative and positive valences using the following contrast: [('decrease negative' + 'increase negative') vs ('decrease positive' + 'increase positive')].

Additionally, the four reappraisal conditions were analyzed separately, and results are reported in Supplementary material. All voxelwise maps were thresholded using a height threshold of $P < 0.001$ and an extent threshold of $P < 0.05$ family-wise error (FWE) corrected. Coordinates are reported in MNI space.

Results

Affect rating

The affect rating was significantly lower in the 'decrease' conditions than in the 'look' conditions and higher in the 'increase' conditions than in the 'look' conditions for negative and positive conditions (all P values < 0.001). Detailed statistics are reported in Supplementary material.

Brain activation during reappraisal independent of regulation goal and stimulus valence

The conjunction analysis across all conditions was used to study brain activations related to cognitive reappraisal regardless of

Table 2. Conjunction analysis across all conditions for the reappraise vs look contrast

Brain region(s)		BA	x	y	z	T	k	Cluster P-value (FWE)
'Reappraise' > 'Look'								
pre-SMA/SMA	L	6	-4	6	66	8.16	7672	<0.001
dlPFC	L	6	-42	8	56	6.99	lm	
vlPFC	L	45	-52	18	2	6.76	lm	
MTG	L	21	-52	-36	-4	5.50	389	0.038
dlPFC	R	8	46	24	44	5.48	929	0.001
dlPFC	R	8	46	10	48	4.56	lm	
vlPFC	R	44	48	18	18	3.46	lm	
'Look' > 'Reappraise'								
Central opercular	R	40	62	-12	10	4.98	1721	<0.001
Planum polare	R	22	58	-2	0	4.29	lm	
Heschl's gyrus	R	41	52	-10	0	4.21	lm	
Central opercular/Insula	L	13	-38	0	14	4.91	2064	<0.001
Insula	L	13	-36	-18	18	4.53	lm	
Planum temporale	L	41	-58	-20	8	4.37	lm	
SMA	L	24	-10	-10	48	4.65	588	0.009
Precentral gyrus	L	5	-10	-34	50	4.42	lm	
Postcentral gyrus	L	31	-16	-38	46	3.93	lm	
Cuneus	R	19	12	-86	32	4.64	846	0.002
Cuneus	R	18	4	-84	24	4.22	lm	
Cuneus	L	18	0	-72	18	3.74	lm	
Postcentral gyrus	L	1	-50	-28	58	4.28	608	0.008
Precentral gyrus	L	6	-36	-16	66	4.13	lm	
Postcentral gyrus	L	1	-32	-30	66	3.95	lm	

k, cluster size (voxels); L, left hemisphere; lm, local maximum; R, right hemisphere. Regions are defined by MNI coordinates.

regulation goals and stimulus valence. It revealed activation in the frontoparietal regions, including the bilateral dlPFC, pre-SMA and vlPFC extending into the OFC and anterior insula. There was also activation in the temporal region: left MTG and temporal pole (TP). A relative decrease in activation was found in the medial parts of the brain, including the bilateral cuneus and left posterior cingulate cortex (PCC), as well as in the posterior insula and temporal and central operculum ($P < 0.05$, FWE corrected; Figure 2; Table 2).

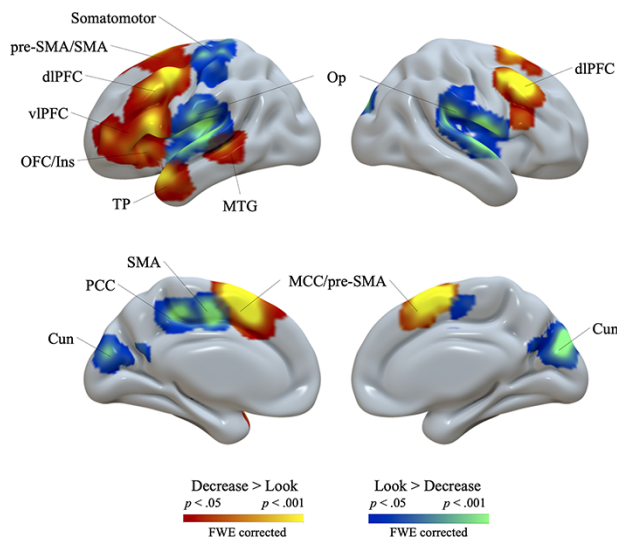


Fig. 3. Conjunction analysis for the 'decrease' ('positive' + 'negative') vs 'look' ('positive' + 'negative') contrast. Red-yellow colors indicate stronger activation during the 'decrease' condition; blue-green colors indicate stronger activation during the 'look' condition.

Goal-specific effects

GLM1 was used to examine activations during the decrease in negative and positive emotions. There was increased activation in the prefrontal cortex: in the left vlPFC extending to the OFC and anterior insula as well as the bilateral dlPFC extending to the pre-SMA and midcingulate cortex (MCC) medially. Activation was also found in temporal areas, including the MTG and TP. We found decreased activation in medial structures, including the bilateral cuneus and left PCC as well as in the bilateral temporal and central operculum extending to the left posterior insula ($P < 0.05$, FWE corrected; Figure 3; Table 3).

GLM2 was used to examine activations during the increase in negative and positive emotions. Analysis revealed activation in the left prefrontal cortex (dlPFC and vlPFC) extending to the OFC and anterior insula. Activations were also found in the left TP, pre-SMA, MCC, and the right cerebellum. There was a relative decrease in activation in the bilateral PCC, SMA, somatomotor cortex, temporal and central operculum, and left posterior insula ($P < 0.05$, FWE corrected; Figure 4; Table 4).

Stimulus-specific effects

GLM3 was used to examine activations during the regulation of negative emotions. The conjunction analysis revealed activation in the bilateral prefrontal cortex (dlPFC and vlPFC) extending to the left OFC, anterior insula, pre-SMA and MCC. Activations were also found in the left temporal regions, including the MTG and TP. There was deactivation in the medial structures, including the bilateral cuneus and PCC, as well as in the bilateral temporal and central operculum extending to the left posterior insula ($P < 0.05$, FWE corrected; Figure 5; Table 5).

GLM4 was used to examine activations during the regulation of positive emotions. The conjunction analysis showed robust activation in the bilateral frontal regions: in the vlPFC extending to the OFC and anterior insula as well as the dlPFC extending to the

Table 3. Conjunction analysis for the decrease (positive + negative) vs look (positive + negative) contrast

Brain region(s)		BA	x	y	z	T	k	Cluster P-value (FWE)
'Decrease' > 'Look'								
pre-SMA/SMA	L	6	-4	6	64	8.21	7516	<0.001
dlPFC	L	6	-42	8	56	7.04	lm	
vlPFC	L	45	-50	18	2	6.61	lm	
dlPFC	R	8	46	24	44	5.90	873	0.001
dlPFC	R	8	46	10	48	4.52	lm	
vlPFC	R	44	48	18	18	3.55	lm	
MTG	L	21	-50	-36	-4	5.07	337	0.04
'Look' > 'Decrease'								
Central opercular	R	40	62	-12	10	5.18	1985	<0.001
Central opercular	R	44	36	6	14	4.63	lm	
Planum polare	R	22	58	0	2	4.54	lm	
Central opercular	L	13	-34	2	14	5.09	2375	<0.001
Insula	L	13	-36	-18	18	4.60	lm	
Planum temporale	L	41	-58	-20	8	4.59	lm	
SMA	L	24	-12	-10	48	4.73	623	0.004
Precentral gyrus	L	5	-10	-34	50	4.49	lm	
Postcentral gyrus	L	31	-16	-38	46	4.23	lm	
Cuneus	R	19	10	-86	30	4.62	889	0.001
Cuneus	R	18	4	-82	24	4.43	lm	
Cuneus	L	18	0	-72	18	3.89	lm	
Postcentral gyrus	L	1	-50	-28	58	4.24	550	0.006
Precentral gyrus	L	6	-36	-18	64	4.02	lm	
Postcentral gyrus	L	1	-32	-30	66	3.96	lm	

k, cluster size (voxels); L, left hemisphere; lm, local maximum; R, right hemisphere. Regions are defined by MNI coordinates.

Table 4. Conjunction analysis for the increase (positive + negative) vs look (positive + negative) contrast

Brain region(s)		BA	X	y	z	T	k	Cluster P-value (FWE)
'Increase' > 'Look'								
pre-SMA/SMA	L	6	-6	4	68	7.65	2190	<0.001
pre-SMA/SMA	L	6	-6	10	58	7.15	lm	
Midcingulate cortex	L	32	-10	20	36	5.01	lm	
dIPFC	L	6	-40	10	60	7.01	2828	<0.001
vIPFC	L	45	-50	18	2	6.11	lm	
Insula	L	45	-30	28	2	3.89	lm	
Cerebellum	R		38	-66	-28	6.04	699	0.004
Cerebellum	R		18	-78	-26	5.69	lm	
TP	L	38	-46	14	-20	4.78	532	0.013
MTG	L	21	-52	-2	-20	4.18	lm	
TP	L	38	-38	10	-34	3.38	lm	
'Look' > 'Increase'								
Planum temporale	L	1	-62	-20	10	5.48	1556	<0.001
Planum temporale	L	41	-50	-30	12	4.61	lm	
Central opercular/Insula	L	1	-38	-16	18	4.55	lm	
Planum temporale/STG	R	41	64	-18	10	5.22	5091	<0.001
Precentral gyrus	L	5	-8	-30	48	5.15	lm	
Postcentral gyrus	R	1	44	-32	54	4.98	lm	
Postcentral gyrus	L	1	-24	-30	74	4.69	1799	<0.001
Precentral gyrus	L	6	-38	-16	66	4.66	lm	
Postcentral gyrus	L	7	-18	-44	64	4.32	lm	

k, cluster size (voxels); L, left hemisphere; lm, local maximum; R, right hemisphere. Regions are defined by MNI coordinates.

Table 5. Conjunction analysis for the reappraise negative (decrease + increase) vs look negative contrast

Brain region(s)		BA	X	y	z	T	k	Cluster P-value (FWE)
'Reappraise negative' > 'Look'								
pre-SMA/SMA	L	6	-4	8	64	8.23	8834	<0.001
dIPFC	L	6	-40	8	56	7.47	lm	
vIPFC	L	45	-52	18	2	6.56	lm	
MTG	L	21	-50	-36	-4	5.40	365	0.045
'Look' > 'Reappraise negative'								
Central opercular/Insula	L	13	-38	0	14	5.43	2112	<0.001
Insula	L	13	-40	-4	-10	4.71	lm	
Parietal operculum	L	40	-54	-26	20	4.33	lm	
Central opercular	R	40	62	-14	10	5.06	1598	<0.001
Central opercular	R	13	38	4	12	4.37	lm	
CO/Heschl's gyrus	R	22	58	-2	0	4.22	lm	
Cuneus	R	19	10	-84	30	4.82	964	0.001
Cuneus	R	18	4	-82	24	4.65	lm	
Cuneus	L	18	0	-72	18	3.90	lm	
SMA	L	24	-12	-10	48	4.34	491	0.017
Precentral gyrus	L	5	-10	-34	50	4.12	lm	
SMA	L	6	-6	-14	54	4.10	lm	

k, cluster size (voxels); L, left hemisphere; lm, local maximum; R, right hemisphere. Regions are defined by MNI coordinates.

pre-SMA, MCC and dmPFC. Activation was found in the temporal regions (bilateral MTG, left STG and left TP) as well as in the occipital regions, including the bilateral occipital cortex extending to the bilateral fusiform gyrus and left temporoparietal junction. There was increased activation in bilateral subcortical structures (caudate, thalamus and putamen) and the cerebellum. We found deactivation in the left somatomotor cortex and right parietal operculum ($P < 0.05$ FWE corrected; Figure 6; Table 6).

Differences between distinct goals and stimuli valence

GLM5 was used to examine differences between decreasing and increasing emotions. The 'decrease' > 'increase' contrast revealed

activation in the right dIPFC ($P < 0.05$, FWE corrected). The 'increase' > 'decrease' contrast showed activation in the bilateral subcortical cluster containing the hippocampus extending to the left amygdala ($P < 0.05$, FWE corrected). The results are shown in Table 7 and Figure 7.

GLM6 was used to examine differences between the regulation of negative and positive emotions. The 'negative' > 'positive' contrast revealed activation in the right superior lateral occipital cortex ($P < 0.05$, FWE corrected). The 'positive' > 'negative' contrast showed increased activation in the bilateral anterior cingulate cortex, extending to the frontal medial cortex ($P < 0.05$, FWE corrected). The results are shown in Table 8 and Figure 8.

Table 6. Conjunction analysis for the reappraise positive (decrease + increase) vs look positive contrast

Brain region(s)		BA	x	y	z	T	k	Cluster P-value (FWE)
'Reappraise positive' > 'Look'								
pre-SMA/SMA	L	6	-8	10	62	11.25	15 885	<0.001
vlPFC	L	45	-52	20	4	9.84	lm	
dIPFC	L	6	-36	2	46	9.20	lm	
MTG	L	21	-54	-36	-2	9.63	10 482	<0.001
Cerebellum	R		36	-64	-26	8.20	lm	
SMG	L	39	-56	-48	22	6.52	lm	
dIPFC	R	8	44	8	50	6.90	3912	<0.001
vlPFC	R	47	52	26	-4	6.77	lm	
dIPFC	R	6	40	4	62	5.76	lm	
STG/MTG	R	21	48	-32	0	6.06	571	0.008
Caudate	R	48	18	4	14	5.34	512	0.013
Caudate/Putamen	R	48	18	10	8	4.95	lm	
Globus pallidus	R	51	14	4	2	4.64	lm	
'Look' > 'Reappraise positive'								
Postcentral gyrus	L	1	-48	-30	60	6.02	382	0.037
Postcentral gyrus	L	1	-54	-24	54	5.07	lm	
Postcentral gyrus	L	1	-36	-36	68	4.81	lm	
Parietal operculum	R	40	46	-24	22	4.76	589	0.007
Parietal operculum	R	40	36	-24	24	3.94	lm	
Central opercular	R	1	52	-12	18	3.73	lm	

k, cluster size (voxels); L, left hemisphere; lm, local maximum; R, right hemisphere. Regions are defined by MNI coordinates.

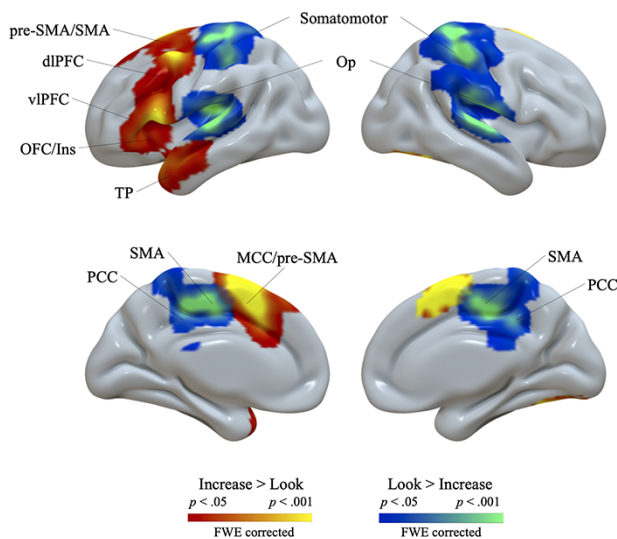


Fig. 4. Conjunction analysis for the 'increase' ('positive' + 'negative') vs 'look' ('positive' + 'negative') contrast. Red-yellow colors indicate stronger activation during the 'increase' condition; blue-green colors indicate stronger activation during the 'look' condition.

Discussion

This study aimed to characterize brain activations during cognitive reappraisal depending on regulation goal and stimulus valence. Separate conjunction models were investigated to study the neural bases of increasing and decreasing emotions, as well as the regulation of negative and positive emotions. Moreover, the differences between distinct goals and between regulation of positive and negative emotions were examined. Our study is an attempt to replicate and extend previous research (Mak et al., 2009; Morawetz et al., 2017; Li et al., 2018). Importantly, our study is the first to apply conjunction analysis in a design that includes both types of reappraisal and two valences of stimuli. This type

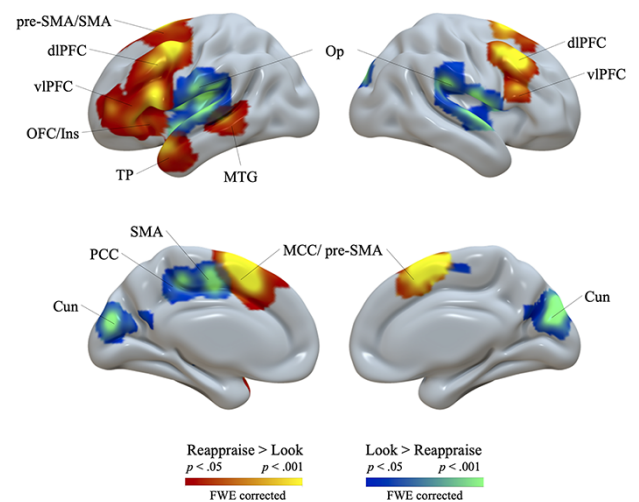


Fig. 5. Conjunction analysis for the 'reappraise' ('decrease' + 'increase') 'negative' vs 'look negative' contrast. Red-yellow colors indicate stronger activation during the 'reappraise' condition; blue-green colors indicate stronger activation during the 'look' condition.

of analysis is more effective in determining common brain activations related to specific functions across many task conditions than the approach previously used in a similarly designed study (Kim and Hamann, 2007). Our study also used a bigger sample size than similar previous studies on emotion regulation (Kim and Hamann, 2007; Mak et al., 2009; Morawetz et al., 2016b; Li et al., 2018). The contrasts we used in our models allowed us to investigate which brain regions are implicated in reappraisal independent of the regulation goal and stimulus valence; how do activations for reappraising negative emotions compare to those during reappraising positive emotions; and what are the differences in brain activity during decreasing and increasing affect.

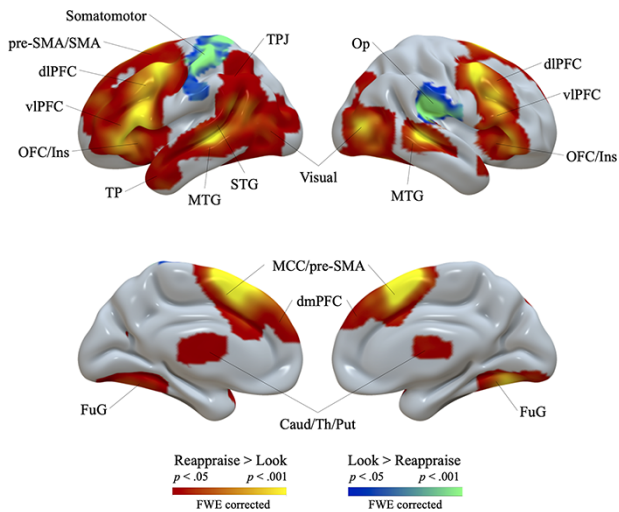


Fig. 6. Conjunction analysis for the ‘reappraise’ (‘decrease’ + ‘increase’) ‘positive’ vs ‘look positive’ contrast. Red-yellow colors indicate stronger activation during the ‘reappraise’ condition; blue-green colors indicate stronger activation during the ‘look’ condition. Abbreviations: Caud—caudate; FuG—fusiform gyrus; Put—putamen; Th—thalamus.

Where do activations occur during reappraisal, independent of the regulation goal and stimulus valence?

Conjunction analysis across all reappraisal conditions revealed the expected activations in the PFC, MCC, OFC, anterior insula and temporal cortex, and a predominantly left-lateralization of activation, which is largely in line with the meta-analysis of Morawetz et al. (2017). The PFC has been previously reported to play a crucial role in the initiation of regulation, cognitive reappraisal and controlling the amygdala’s reactivity through negative feedback (Kohn et al., 2014).

Where do activations occur during the reappraisal of negative and positive emotions?

Regulation of negative emotions was associated with activation that extends from the left SMA laterally into the left dorsolateral and then vIPFC, which is consistent with previous studies (Kim and Hamann, 2007; Kohn et al., 2014). With regard to the regulation of positive emotions, we found robust activation in the bilateral lateral PFC extending to the OFC and anterior insula, but also left-sided activation in the temporal lobe and bilateral activation of the mPFC as well as subcortical structures. This is in line with the results that showed increased activation in the PFC during the regulation of positive stimuli (Mak et al., 2009; Winecoff et al., 2011, 2013), as well as those of Kim and Hamann (2007) who observed the engagement of the dmPFC and OFC in regulating positive emotions, regardless of the regulation goal. We also observed a deactivation in the operculum and posterior insula,

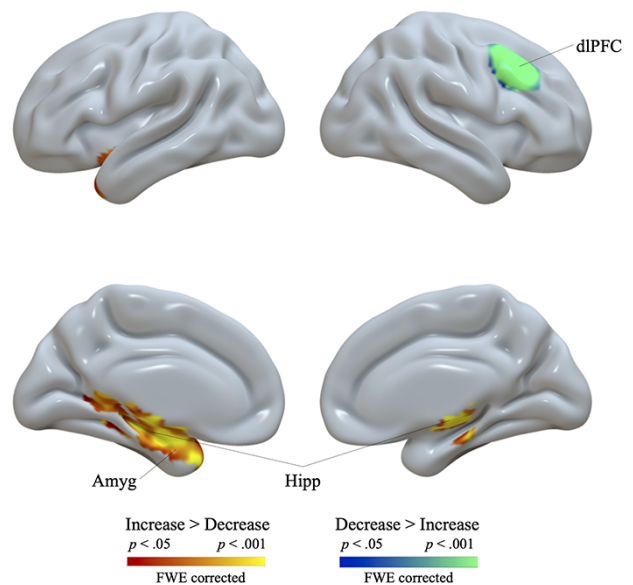


Fig. 7. Comparison of brain activations in the ‘decrease’ and ‘increase reappraisal’ conditions, independently of stimulus valence. Red-yellow colors indicate stronger activation during the ‘increase’ condition; blue-green colors indicate stronger activation during the ‘decrease’ condition. Abbreviations: Amyg—amygdala; Hipp—hippocampus.

which is partly in line with the study of Mak et al. (2009), where a decrease in activation in the operculum related to the processing of positive stimuli was reported.

What are the differences between neural activations during the up- and downregulation of emotions?

We found decreasing emotions to be associated with stronger activations in the right dlPFC, a structure previously found to be involved in cognitive control and successful reappraisal (Morawetz et al., 2016a). Downregulation requires the engagement of the frontal cortex to effectively inhibit subcortical structures’ reactivity to emotional stimuli (Kohn et al., 2014). This region was previously found to be active during explicit evaluation of affective stimuli and executive control (Lindquist et al., 2012), as well as hyperactive in association with attention to negative emotions (Ueda et al., 2003; Bermpohl et al., 2006), suggesting the involvement of this structure in the anticipation of emotional stimuli. Our results further support the notion that the dlPFC is part of the network involved in emotion downregulation, suggesting that it plays a role in response inhibition (Morawetz et al., 2020). Engagement of the dlPFC in downregulation also supports the existence of neural networks activated by the appraisal system responsible for emotional information reprocessing (Morawetz et al., 2017). We

Table 7. Comparison of brain activation in the decrease and increase reappraisal conditions

Brain region(s)		BA	x	y	z	T	k	Cluster P-value (FWE)
‘Decrease’ > ‘Increase’								
dlPFC	R	8	42	18	42	5.35	559	0.007
‘Increase’ > ‘Decrease’								
Hippocampus/Amygdala	L	54	−30	−42	4	4.78	1431	<0.001
Hippocampus	R		16	−18	−14	4.77	lm	

k, cluster size (voxels); L, left hemisphere; lm, local maximum; R, right hemisphere. Regions are defined by MNI coordinates.

Table 8. Comparison of brain activations in the reappraise negative and positive conditions

Brain region(s)		BA	x	y	z	T	K	Cluster P-value (FWE)
'Negative' > 'Positive'								
sLOC	R	7	26	-70	60	4.65	776	0.001
sLOC	R	39	30	-72	32	4.37	Lm	
sLOC	R	7	24	-74	52	4.29	Lm	
'Positive' > 'Negative'								
ACC	R	32	4	42	-2	4.10	546	0.008
ACC	L	24	-4	40	4	3.87	Lm	
dmPFC	L	32	-8	50	-2	3.76	Lm	

k, cluster size (voxels); L, left hemisphere; lm, local maximum; R, right hemisphere. Regions are defined by MNI coordinates.

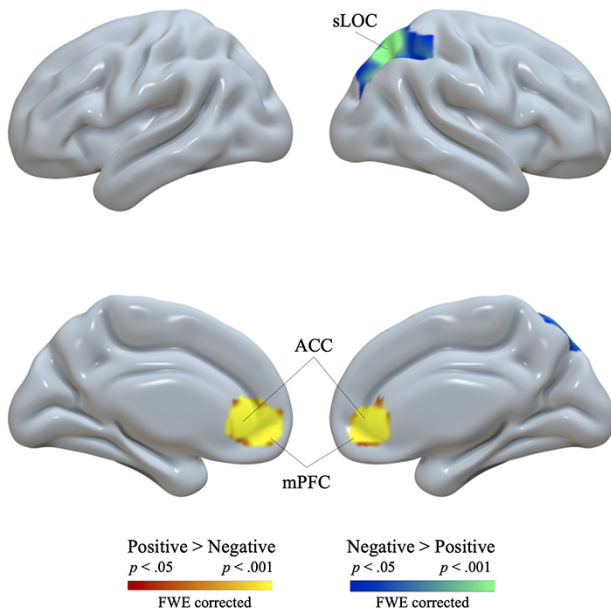


Fig. 8. Comparison of brain activations during the 'reappraise positive' and 'negative' conditions, independently of the regulation goal. Red-yellow colors indicate stronger activation during the regulation of positive emotions; blue-green colors indicate stronger activation during the regulation of negative emotions. Abbreviation: sLOC—superior lateral occipital cortex.

did not observe stronger parietal lobule activity during decreasing emotions, as could be suggested by the meta-analysis of Morawetz et al. (2017). One possible interpretation of this lack of differences could be that both regulation goals engage attentional processing (such as orienting and shifting attention) to a similar degree during the reappraisal of emotional stimuli (Dörffel et al., 2014).

Stronger activation during increasing than decreasing emotions was observed in the bilateral hippocampi extending to the left amygdala—structures that generally exhibit strong reactivity to affective stimuli (Aldhafeeri et al., 2012). Both the amygdala and the hippocampus are responsible for emotional encoding and are engaged in the retrieval of emotionally valenced contextual information (Smith et al., 2006). Engagement of the amygdala in particular is not surprising as this structure plays a crucial role in emotional functioning, being involved in the processing of emotional stimuli as well as generating emotions (Lindquist et al., 2012). This result is also in line with previous reports, as enhanced bilateral amygdala activation during the 'increase' compared to the 'decrease' condition was reported by Kim and Hamann (2007) in a region of interest analysis, while Morawetz et al. (2016b) showed

enhanced hippocampal activation during increasing emotions. The involvement of the left amygdala in increasing emotions is also supported by a meta-analysis (Frank et al., 2014), and our results provide further evidence for the role of the amygdala in increasing the strength of emotional response.

Brain activation during up- and downregulation may reflect both the control over the generation and regulation of emotions—both being top-down processes (Ochsner and Gross, 2007). Overall, our results suggest that downregulation is related to conscious control over emotional response, while upregulation is associated with enhancement of the more reflexive components of an emotional reaction. The former is reflected in the activation of dlPFC, which plays a role in response inhibition, and the latter is reflected in the amygdala, which plays a central role in generation of emotional response, as per the recent conclusions of Morawetz et al. (2020). Nevertheless, emotion regulation may also involve internal representations of the external emotional environment, with the hippocampus providing the context required to enhance emotions (Etkin et al., 2015).

What are the differences between neural activations during the regulation of positive and negative emotions?

Engagement of the right occipital lobe was stronger during the regulation of emotions of negative valence than during the regulation of ones of positive valence. This is in line with the study of Morris et al. (2014), who observed stronger activation in the occipital lobe during negative vs positive emotion regulation. They argued that negative stimuli are characterized by more sensory detail and representations than positive stimuli; therefore, the engagement of more cognitive and neural resources is required for effective reappraisal. Activation in the superior occipital cortex has been previously shown to be involved in both reappraisal and suppression of negative emotions (Goldin et al., 2008; Buhle et al., 2014). Moreover, activation in the occipital cortex is related to the intensity of negative emotion (Phan et al., 2005) and exhibits less adaptation to the repeated presentation of more unpleasant stimuli (Rotshtein et al., 2001). Thus, it is not surprising that we found the reappraisal of negative emotions to engage the higher-order visual cortex to a greater degree than the reappraisal of positive ones. Alternatively, given the involvement of the visual cortex in the processing of highly arousing emotions (Lindquist et al., 2012), the stronger activation in the superior lateral occipital cortex may be a result of the negative stimuli being associated with higher arousal than the positive pictures used in the study.

Compared to the reappraisal of negative emotions, the reappraisal of positive emotions involved increased and stronger activation in the bilateral ACC extending to the mPFC. Our results are in line with the study of Vrtička et al. (2011), which reported

stronger activation in the subgenual ACC to positive valence pictures compared to negative stimuli. Ventral regions of the ACC and mPFC are involved in generating emotional responses (Etkin et al., 2011), which may be related to the generation of positive emotions. It has also been shown that pleasant experiences engage activation in the ventromedial PFC (Wager et al., 2008). However, our result stands in contrast to the results of Mak et al. (2009) and Kim and Hamann (2007); both these studies showed stronger ACC activation during negative emotion regulation (although the latter study also showed enhanced activation of this structure during increasing positive emotions). The ACC has been found to be involved in self-regulation and integrates both cognitive and emotional processing (Bush et al., 2000; Posner et al., 2007). Enhanced ACC activation can be also interpreted in the context of its involvement in reinforcement-guided decision-making associated with reward representation (Rushworth et al., 2007).

Importantly, regulation of positive emotions maintains mental health and promotes resilience (Tugade and Fredrickson, 2007). It has been shown that the ACC plays a crucial role in the neural network responsible for psychological resilience (Kong et al., 2015). The ACC recruitment suggests the engagement of top-down control over emotional response, which is further related to resilience (Bolsinger et al., 2018). Our study suggests that ACC activity may be an important aspect of a functional network that supports adaptive emotion regulation processes.

General discussion

Based on the results of this study, we may speculate on the nature of the cognitive processes undergirding the reappraisal of specific emotions, particularly positive affect. Let us note that Riegel et al. (2016) indicated that happiness is the main emotion induced by the NAPS' positive stimuli. Therefore, we may ask what does it mean to regulate happiness? Up- and downregulation share common neural correlates, including areas linked to attention allocation processes (e.g. dorsolateral PFC) and different forms of evaluation (e.g. OFC and insula). Thus, these areas represent different components of perception–valuation–action sequence repeats, as postulated by Ochsner and Gross (2007). Significantly, downregulation of happiness is additionally related to deactivation in primary and secondary somatosensory cortices (see Supplementary material). In Koelsch et al. (2015) quartet theory of human emotions, these regions are postulated to be responsible for the synthesis of emotion percepts. Lieberman et al. (2011) revealed that reappraisal downregulation leads to diminished self-reported pleasure when viewing positive pictures. In the context of the model of Koelsch et al. (2015), Wood and Niedenthal (2015) argue that labeling an ongoing emotion percept may inhibit the experience of the emotion. As reappraisal and affect labeling share some common underlying mechanisms with emotion regulation (see Lieberman et al., 2011), we would like to push the argument of Wood and Niedenthal (2015) further and suggest that different forms of downregulation of happiness lead to the diminishing of the experience. We believe that this process is represented by the deactivation of areas responsible for synthesizing emotion percepts. Since NAPS' negative stimuli induce a mixture of negative emotions (Riegel et al., 2016), such speculation is not possible in this case. Nevertheless, we believe that our results may shed new light on emotion regulation.

Limitations

The main limitation of our study is the differences in the arousal of the stimuli. Although we tried to choose stimuli with similar

arousal levels, the pictures with negative valence were more arousing than the positive ones. Due to the negativity bias and the fact that negative valence is more strongly correlated with arousal than positive valence, stimuli with negative valence are usually more arousing than positive ones (Mather and Sutherland, 2009; Kuppens et al., 2013). This may have affected the results, especially those regarding the difference in activation between the regulation of positive and negative emotions. Another limitation is that the analyses did not control for the cognitive strategies used during the task. Participants were free to use a number of reappraisal strategies, which may have led to the recruitment of a variety of brain regions.

Conclusion

In summary, our study showed that, during cognitive reappraisal, there exist both goal-specific and stimulus-specific brain activation patterns. Decreasing and increasing emotions are two separate top-down emotion regulation processes. This is reflected in distinct neural activation: downregulation appears to be related to control over emotional response and appraisal of external environmental stimuli, while upregulation appears to be related to the initiation of emotional reactions. Regulation of positive and negative emotions may involve distinct processes related to stimulus arousal level and the integration of cognitive and emotional processes underlying affective self-regulation and resilience. Our study suggests that cognitive reappraisal is not a homogenous process and has different bases in the brain depending on goal and stimuli.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationship that could be construed as a potential conflict of interest.

Supplementary data

Supplementary data are available at SCAN online.

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