Cognitive, Affective, & Behavioral Neuroscience
https://doi.org/10.3758/s13415-020-00775-8

The neural bases of cognitive emotion regulation: The roles of strategy and intensity

Craig A. Moodie[1] · Gaurav Suri[2] · Dustin S. Goerlitz[3] · Maria A. Mateen[4] · Gal Sheppes[5] · Kateri McRae[6] · Shreya Lakhan-Pal[7] · Ravi Thiruchselvam[8] · James J. Gross[1]

Abstract

When confronted with unwanted negative emotions, individuals use a variety of cognitive strategies for regulating these emotions. The brain mechanisms underlying these emotion regulation strategies have not been fully characterized, and it is not yet clear whether these mechanisms vary as a function of emotion intensity. To address these issues, 30 community participants (17 females, 13 males, M_{age} = 24.3 years) completed a picture-viewing emotion regulation task with neutral viewing, reacting to negative stimuli, cognitive reappraisal, attentional deployment, and self-distancing conditions. Brain and behavioral data were simultaneously collected in a 3T GE MRI scanner. Findings indicated that prefrontal regions were engaged by all three regulation strategies, but reappraisal showed the least amount of increase in activity as a function of intensity. Overall, these results suggest that there are both brain and behavioral effects of intensity and that intensity is useful for probing strategy-specific effects and the relationships between the strategies. Furthermore, while these three strategies showed significant overlap, there also were specific strategy-intensity interactions, such as frontoparietal control regions being preferentially activated by reappraisal and self-distancing. Conversely, self-referential and attentional regions were preferentially recruited by self-distancing and distraction as intensity increased. Overall, these findings are consistent with the notion that there is a continuum of cognitive emotion regulation along which all three of these strategies lie.

Keywords Emotion regulation · fMRI · Strategy · Cognitive control · Intensity · Activation

Introduction

According to the process model of emotion regulation, there are several stages at which emotions may be altered throughout the emotion-generative process (Gross, 1998b; Gross, 2002; Gross, 2015a, b). Researchers have found it useful to distinguish broadly among situational strategies (situation selection and situation modification), cognitive strategies (attentional deployment and cognitive change), and behavioral strategies (response modulation). One basic prediction of the process model is that strategies that have their impact earlier in the emotion-generative process (e.g., situational) often are more effective than strategies that have their impact later (e.g., response modulation; Webb, Miles, & Sheeran, 2012).

It is less clear, however, whether the impact of timing applies to distinctions among strategies within a narrower range (e.g., attentional deployment versus cognitive change). One perspective holds that processes that act as an early selection filter, such as attentional deployment, should be less effortful and more effective (particularly at high intensity levels) than later-stage, semantic-based processing strategies, such as cognitive reappraisal (Sheppes et al., 2014). This differentiation suggests the possibility that there may be a continuum of cognitive emotion regulation strategies, extending from

Electronic supplementary material The online version of this article (https://doi.org/10.3758/s13415-020-00775-8) contains supplementary material, which is available to authorized users.

✉ James J. Gross
gross@stanford.edu

1 Department of Psychology, Stanford University, Stanford, CA, USA
2 San Francisco State University, San Francisco, CA, USA
3 University of Colorado Denver, Denver, CO, USA
4 University College London, London, UK
5 Tel Aviv University, Tel Aviv, Israel
6 University of Denver, Denver, CO, USA
7 University of Minnesota, Minneapolis, MN, USA
8 Hamilton College, Clinton, NY, USA

attentional strategies to cognitive reappraisal (Ochsner & Gross, 2005). In order to determine whether these two strategies are subsumed by a single dimension, and also to investigate whether the effects of emotion intensity vary as a function of where strategies fall on this continuum, it is helpful to identify an emotion regulation strategy that lies approximately at the midpoint of the theorized continuum. One candidate is self-distancing, a cognitive emotion regulation strategy that involves reducing the personal relevance of a particular emotional stimulus or event. This process is thought to involve both attention shifting and cognitive change components and, hence, should show significant overlap with both distraction and reappraisal strategies (Ochsner & Gross, 2005; Fig. 1). It also stands to reason that the effects of intensity on self-distancing would be intermediate with regards to distraction and reappraisal. Hence, in the present study, we compare cognitive reappraisal, self-distancing, and distraction while varying emotional intensity.

Cognitive reappraisal

Cognitive reappraisal is a type of cognitive change that involves modifying the meaning of the situation in order to alter an emotion (Gross, 1998a; Gross, 2015b). Reappraisal often is used to reduce emotion and, consequently, is associated with decreases in self-reported negative affect ratings and activity in emotion-generative brain regions, such as the amygdala (Buhle et al., 2014). Reappraisal also is associated with increases in activity in regions generally associated with cognitive control processes, such as the dorsolateral prefrontal cortex (DLPFC) and ventrolateral prefrontal cortex (VLPFC), dorsal anterior cingulate cortex (dACC), dorsomedial prefrontal cortex (dmPFC), and orbitofrontal cortex (OFC), as well as other regions, such as the supplementary motor cortex (SMA) and posterior parietal cortex (Etkin, Büchel, & Gross, 2015; Morawetz, et al., 2016).

Initial evidence suggests that the neural bases of reappraisal vary with the intensity of the emotion-generating stimuli: reappraisal of high-intensity emotions was found to more strongly activate the left dlPFC and the dmPFC, and uniquely recruit the right lateral PFC and rostromedial PFC (Silvers et al., 2015). Nevertheless, several studies seeking to investigate the neural bases of different categories of cognitive change did not employ manipulations of emotional intensity (Ochsner et al., 2002; McRae et al., 2010). Hence, an important goal of the present study was to analyze separately the neural bases of applying cognitive reappraisal to both high- and low-intensity stimuli in a paradigm with very clear instructions and training designed to elicit a clear reappraisal signal, which would not be confounded with any other forms of cognitive change.

Self-distancing

On the continuum of cognitive regulation strategies, self-distancing is thought to lie between cognitive change and attentional deployment (Ochsner & Gross, 2005). The mechanism of self-distancing operates by individuals *separating* themselves from the reality of the situation by taking the perspective of a detached and objective observer, such as a doctor treating a patient or a film director observing a scene (Beauregard, Lévesque, & Bourgouin, 2001; Ochsner et al., 2004; McRae, Ciesielski, & Gross, 2012). Self-distancing has traditionally been conceptualized as a form of cognitive reappraisal, in that it is self-focused reappraisal (Gross, 2015a). However, this study will attempt to determine if self-distancing is entirely subsumed by cognitive reappraisal or whether it shows enough evidence of processes underlying attentional deployment to warrant being classified as an intermediary between cognitive change and attentional deployment.

Previous neuroimaging studies of self-distancing have found that the application of this strategy causes decreases in self-reports of both positive and negative emotion, depending on the instructions (Beauregard, Lévesque, & Bourgouin, 2001; Koenigsberg et al., 2009). These relative decreases also have been associated with increases in brain activity in the dlPFC, vlPFC, ACC, posterior cingulate cortex (PCC), and precuneus. However, to date, no studies have directly examined the influence of intensity on self-distancing as a specific strategy. For instance, Silvers et al. (2015) allowed participants to "'reinterpret the possible antecedents, outcomes and/or reality of the events" that they were presented with in a general reappraisal framework. Hence, these instructions allowed for the implementation of strategies that would fit the definition of cognitive reappraisal presented here, but also self-distancing. These authors found that the dmPFC, left dlPFC, and left vlPFC were activated by reappraisal (including self-distancing) irrespective of intensity. However, high intensity stimuli preferentially recruited right lateral and

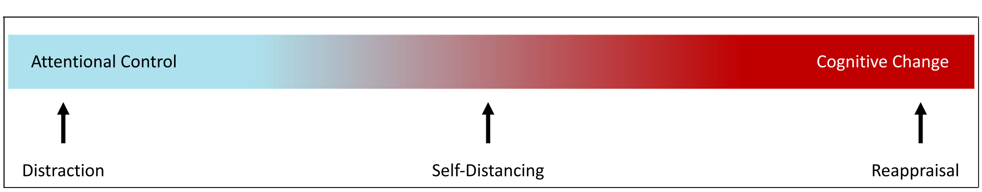


Fig. 1 Hypothetical dimension of cognitive emotion regulation

dorsomedial PFC, and significantly increased activity in the left dlPFC. Although this study conceptualizes reappraisal and self-distancing as a single strategy, the results lay the groundwork for investigating which brain regions are activated at both low and high intensities. Hence, the present study will further examine which regions are unique to each strategy at each intensity level.

Distraction

As an attentional deployment strategy, distraction involves directing attention towards the non-emotional aspects of a situation, away from the emotion-eliciting situation altogether, or changing the object of one's internal focus (Gross, 1998b). This strategy is thought to alter information processing early on and, hence, it should be effective whether the emotion-eliciting context is characterized by low or high levels of emotional intensity (Kalisch et al., 2006; Kanske et al., 2011; Schönfelder et al., 2014). In this study, distraction was selected as the exemplary attentional deployment strategy, because it is a cognitive strategy that is primarily characterized by attentional processes; however, it is less confounded with self-distancing in this context.

Previous neuroimaging studies on distraction have found that the implementation of this strategy to down-regulate negative emotions resulted in the expected decreases in self-reports of negative affect and that these behavioral decreases were associated with decreases in brain activity in the amygdala (Hermann, Kress, & Stark, 2017; McRae et al., 2010). Distraction also led to significant increases in activation in left vlPFC, right lateral PFC, as well as superior parietal cortex. The neural effects of intensity on distraction have not been studied using paradigms with fixed conditions comparable to those employed in this study. However, inferences based on distraction's position on the putative dimension of cognitive emotion regulation would suggest that intensity would have an effect on brain activity associated with distraction and that these effects should align with distraction's role in shifting attention away from the emotional stimulus early in the regulation process (Uusberg, Thiruchselvam & Gross, 2014).

Comparisons among cognitive strategies

Although researchers have previously considered specific cognitive emotion regulation strategies, differences among cognitive regulation strategies have rarely been examined in the context of a single study (Naragon-Gainey, McMahon, & Chacko, 2017). The only prior neuroimaging study that we are aware of that directly contrasted more than two forms of cognitive emotion regulation is that of Dörfel et al. (2014), who directly compared four emotion regulation strategies: distraction, reinterpretation, detachment, and expressive suppression. While the names of the strategies used by Dörfel and colleagues differ with those used here, reinterpretation parallels cognitive reappraisal as used in this context. Similarly, detachment also is referred to as distancing or self-focused reappraisal, and the instructions for detachment are very similar to those used to for self-distancing in this study. Finally, the distraction strategy utilized in their experiment is comparable to the one implemented in the current experiment. While this study compared four different strategies, there was no manipulation of intensity, which is novel in this study.

Contrary to some previous findings, their results indicated that reinterpretation (reappraisal) did not decrease activity in the amygdala and recruited a left vlPFC and orbitofrontal gyrus (OFC) control network that was distinct from the right prefronto-parietal network observed in all of the other regulation conditions. As mentioned before, self-distancing has traditionally been considered a form of reappraisal, but the observation of common activation in the right inferior parietal cortex (IPC) and DLPFC led Dörfel and colleagues to consider it to be much more similar to distraction. These intriguing findings clearly bear replication and extension to clarify the brain bases of cognitive emotion regulation and to assess the differential impact of intensity.

The present study

Cognitive emotion regulation strategies have been proposed to fall along a gradient. On one side, attention regulation strategies, such as distraction, can be deployed effectively irrespective of intensity before the stimuli or information have been processed very deeply. On the other side of the gradient, cognitive change strategies, such as reappraisal, seem to be most effective when intensity is low rather than high. In the present study, we used a classic picture viewing paradigm to assess the behavioral and brain effects of engaging in distraction, self-distancing, and cognitive reappraisal with negative emotion-inducing stimuli that were either low or high intensity.

Methods

Participants

Thirty healthy volunteers (17 females, M_{age} = 24.3 years) participated in this study. The sample size for this study was selected based on the sample sizes of comparable fMRI studies that had been conducted in the affective domain using IAPS or other similar picture stimuli. For instance, the sample size for this study is larger than most picture-based reappraisal studies that were included in the Buhle et al. (2014) reappraisal meta-analysis.

Participants were recruited from the community surrounding Palo Alto, CA, via SONA (Sona Systems Ltd.), and

Craigslist advertisements. Participants were screened via email, phone, and in-person administration of the Structured Clinical Interview for the Diagnostic and Statistical Manual of Mental Disorders IV (DSM-IV; APA, 1994). All participants provided informed consent according to the Institutional Review Board at Stanford University and were paid $175.00 for their participation in the study. Those who met the following criteria were admitted to the study: (1) right-hand dominant, (2) English as a native language, (3) fMRI compatible (no metal in body, not pregnant, not claustrophobic), (4) no current psychiatric diagnoses, and (5) no current use of psychoactive medications.

Task training

Before entering the scanner, participants went through training on the experimental task. Training consisted of extensive verbal instructions from the researcher, followed by verbal practice, and finally an in-scanner practice session. Participants were told that they would be presented with a series of images and then were instructed to attend to each image and either allow any emotional response to arise or to control their emotions while viewing the image using one of three cognitive strategies: distraction, reappraisal, and distancing. Participants were given very detailed instructions for the implementation of each strategy, and extensive training ensured that there was no confusion between strategies (Supplementary Information).

Following the cues "View" (look-neutral) and "Watch" (look-negative), participants were instructed to look at and respond naturally to the image. Following the cue "Distract" (distraction), they were instructed to visualize something completely unrelated in order to turn their attention toward something other than the image (e.g., visualize themselves doing mundane household chores). Following the cue "Separate" (distancing), they were instructed to take the perspective of a detached and objective observer (e.g., the perspective of a documentary film director). Following the cue "Rethink" (reappraisal), they were instructed to change how they thought about the situation within the image such that there would be a neutral or positive outcome (e.g., think of the situation as improving over time). It was explicitly stated that the situations depicted within each image should be treated as real and not as fake or from a nondocumentary film (more details available in Supplementary Information).

Task

This strategy comparison task was used to empirically test affective differences between three emotion regulation strategies—reappraisal, self-distancing, and distraction—and also the effect of intensity within and across these strategies. This task was comprised of nine blocks total, where three counterbalanced blocks were used for each regulation strategy. Within each block, three instructional cues were used: "View"; "Watch"; or one of the three regulation strategy labels. There were 25 trials per block and, when considering intensity, trials were in 1 of 5 overall conditions per block: 3 View-neutral (VN), 3 Watch high-intensity (WH), 3 Watch low-intensity (WL), 8 Regulate high-intensity, and 8 Regulate low-intensity trials (Fig. 2a).

Over the course of the experiment, participants completed 225 experimental trials during which they viewed pictures from the International Affective Picture System (IAPS; Lang, Bradly, & Cuthbert, 2008), as well as pictures from an in-house set that were rated as having similar valence and arousal to those from the IAPS set (Supplementary Information). Each trial had the following structure: 2-s fixation cross, 2-s instructional cue, 6-s image display/emotion regulation, 8-s negative intensity rating (Fig. 2b). For negative intensity ratings, participants were asked to rate how negative they felt about the image viewed, on a scale of 1-9 (1 = no negative emotion, 9 = extremely intense negative emotion). Images were categorized into low- and high-negative intensity subgroups using normative valence and arousal ratings obtained via a pre-study online pilot ($M_{\text{Low-intensity valence}} = 3.02$, $M_{\text{Low-intensity arousal}} = 4.76$; $M_{\text{High-intensity valence}} = 2.03$, $M_{\text{High-intensity arousal}} = 6.18$). Following each block was 8-s each of two task difficulty and effectiveness ratings (e.g., "How difficult was it for you to Rethink in this block?" and "How effectively were you able to decrease your negative emotion using Rethink in this block?"). Task difficulty and effectiveness ratings used a similar nine-point scale as the negative intensity ratings.

Imaging and task parameters

Whole-brain fMRI data were acquired on a 3T GE Discovery MR750 scanner (GE Medical Systems). Anatomical (T1) images were collected with one 3D FSPGR 0.9 mm slice (TI = 450 ms, flip angle = 12°, FOV = 23.0 cm). Forty-two axial slices were acquired with a T2*-sensitive EPI BOLD sequence (TR = 2,000.0 ms, TE = 30.0 ms, flip angle = 77°, FOV = 23.2 cm, acquisition matrix = 80 x 80, voxel size = 2.9-mm^3 isotropic). All participants completed 9 functional runs lasting approximately 8 minutes each, during which 236 functional volumes were acquired. The first three TRs of all scans were excluded due to magnetization stabilization effects. Visual stimuli were presented via the PsychoPy presentation software v1.82.01 on a 47" flat panel/3D display by Resonance Technology and a double mirror mounted on a Nova Medical 32-channel head coil. Participant responses were recorded with a fORP 5-button response cylinder (Current Designs, Inc.).

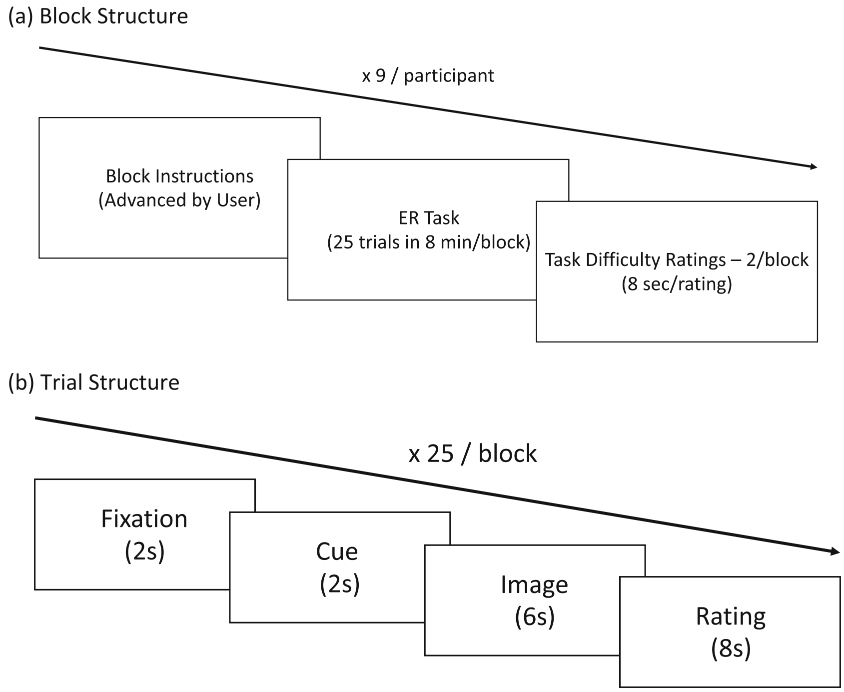


Fig. 2 Task design. (**a**) Block structure. (**b**) Trial structure

fMRI preprocessing

All brain imaging data were preprocessed using the FSL version 5.0.9 statistical software package (https://fsl.fmrib.ox.ac.uk/fsl/fslwiki/FSL). Pre-statistical processing steps included high pass temporal filtering (108s = 0.009 Hz), motion correction via the MCFLIRT linear registration algorithm (Jenkinson et al., 2002), BET brain extraction, MELODIC ICA data exploration, and spatial smoothing with a 6-mm full width half-maximum Gaussian kernel. All functional scans were then residualized with respect to the motion parameters calculated when motion correction was performed. For each participant, the functional scans were registered to their high resolution T1 images and then to the 2-mm standard-space MNI brain using nonlinear algorithms with a 2-mm resampling resolution and 10-mm warp kernel (Andersson et al., 2007).

fMRI analyses

All event files, contrasts, and general linear models (GLM) were constructed using FSL's FEAT tool. All explanatory variable regressors within each condition were convolved with a double gamma hemodynamic response function. All first-level, fixed effects, and group-level mixed-effects models employed cluster-based inference with a cluster z-threshold of 3.1 and cluster significance level of $p < 0.05$ in accordance with the current standards in the field (Eklund et al., 2016).

Statistical tests

Behavioral analyses were conducted for manipulation checks of stimulus intensity and emotion regulation success. The in-scanner negative intensity ratings per trial were averaged across blocks within each run per condition, and then across runs per participant. The experimental conditions are as follows: VN = View Neutral, WL = Watch Low Intensity, WH = Watch High Intensity, DL = Distract Low Intensity, DH = Distract High Intensity, SL = Self-Distancing Low Intensity, SH = Self-Distancing High Intensity, RL = Reappraise Low Intensity, RH = Reappraise High Intensity. A three-strategy (reappraisal, distancing, distraction) x two intensity-level (low, high) ANOVA, as well as post-hoc paired *t*-tests, were conducted on negative intensity ratings. All *p* values from the analyses of the self-report data were corrected for multiple comparisons before establishing significance.

Several neuroimaging analyses were conducted to identify regions of activation associated with each regulation strategy, at each stimulus intensity level, and to test for differences between strategies in general, and with respect to intensity. First, manipulation checks of emotion induction were performed (WL > VN & WH > VN) and for each type of emotion regulation (e.g., RL > WL & RH > WH). To differentiate among the three regulation strategies, contrasts were performed combining both intensity levels, i.e., ignoring the effect of intensity (e.g., RL+RH > SL+SH). In addition, the interaction between intensity and each strategy comparison was tested by first testing for the effect of intensity at the first level (e.g., RH > RL & SH > SL) and then testing for

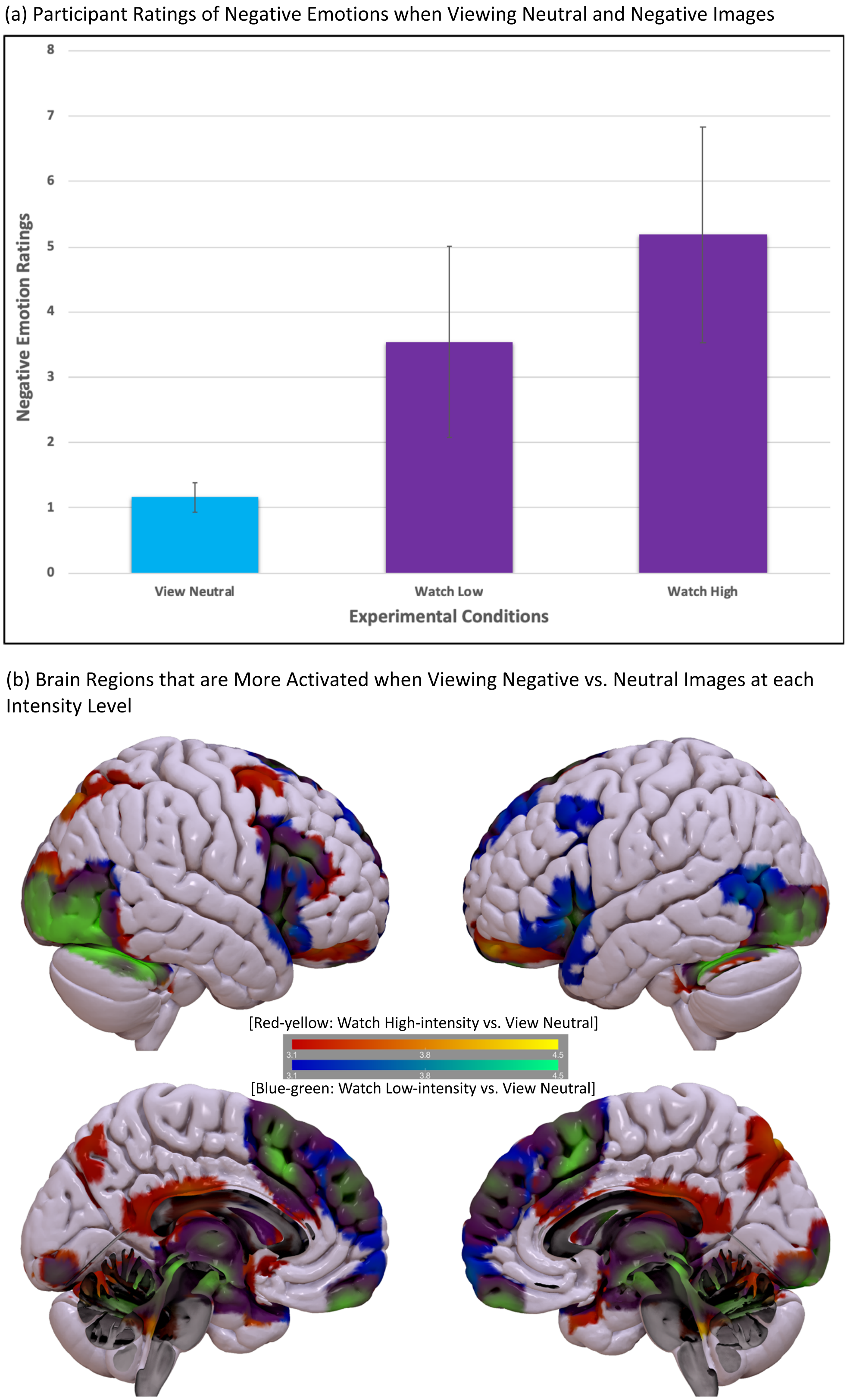


Fig. 3 Manipulation check of negative induction. (**a**) Participant ratings of negative emotions when viewing neutral and negative images. (**b**) Brain regions that are more activated when viewing negative vs. neutral images at each intensity level. Brain regions with more activation while viewing negative than neutral images at low intensities are displayed along a blue-green spectrum ($3.1 < z > 4.5$). Brain regions with more activation while viewing negative than neutral images at high intensities are displayed along a red-yellow spectrum ($3.1 < z > 4.5$). Brain regions activated more by viewing negative images at both intensities are displayed in a purple composite ($3.1 < z > 4.5$)

Table 1. Brain regions that are more activated when viewing negative vs. neutral images at each intensity level

Contrast	Brain Region(s)	Cluster Size (voxels)	P-value (corrected)	Peak Coordinates	Max Voxel z-stat
Brain Regions that are More Activated when Viewing Negative vs. Neutral Images at each Intensity Level:					
Viewing Negative vs. Neutral Images at Low Intensity	Midbrain, Brainstem & Thalamus	5596	p < 0.001	[4] [-30] [-8]	5.18
	dmPFC / pre-SMA	4200	p < 0.001	[12] [16] [62]	5.46
	Bilateral Associate Visual Cortex	3661	p < 0.001	[48] [-72] [-10]	6.47
	Right Dorsolateral Prefrontal Cortex	2170	p < 0.001	[42] [8] [28]	5.68
	Bilateral Ventrolateral Prefrontal Cortex	1699	p < 0.001	[-38] [22] [-12]	5.45
	Bilateral Inferior Temporal Gyrus	1555	p < 0.001	[-42] [-52] [-28]	6.29
Viewing Negative vs. Neutral Images at High Intensity	Bilateral Associate Visual Cortex	23868	p < 0.001	[28] [-94] [-4]	6.39
	Dorsomedial Prefrontal Cortex	1686	p < 0.001	[0] [22] [38]	4.89
	Ventromedial Prefrontal Cortex	646	p < 0.001	[8] [64] [20]	3.96
	Posterior Cingulate Cortex	422	p < 0.01	[0] [-26] [26]	3.92
	Right Dorsolateral Prefrontal Cortex	292	p < 0.05	[30] [6] [58]	3.89
	Bilateral Precuneus	241	p < 0.05	[-18] [-68] [32]	4.17

All coordinates are reported based on the MNI 152 T1 average brain template coordinate space

significant differences between these contrasts in a higher-level design (e.g., (RH > RL)>(SH > SL)). All group-level contrast maps generated from the statistical tests of the imaging data in this study will be available on Neurovault (https://www.neurovault.org/).

After the data were collected, the empirical activation effect sizes were calculated for the contrasts included in this study. For the manipulation check contrast of reacting to negative images versus viewing neutral images, based on the group-level statistic maps entered into the online power calculator on http://www.neuropowertools.org, and based on the selected and reported voxelwise and cluster-forming thresholds, voxel size and smoothing kernel, the power for a 29-person sample is 0.50. Similarly, for the contrast of reappraisal of low intensity images versus reacting to low-intensity negative images versus, a sample size of 29 subjects control comes with a power level of 0.49. Given the power calculations from these representative reactivity and regulation contrasts, it is reasonable to assume that this study has a power level of 0.5. The observed effect size is lower than expected but yielded reasonable results using the historically-justified sample size from the design.

Results

Manipulation checks

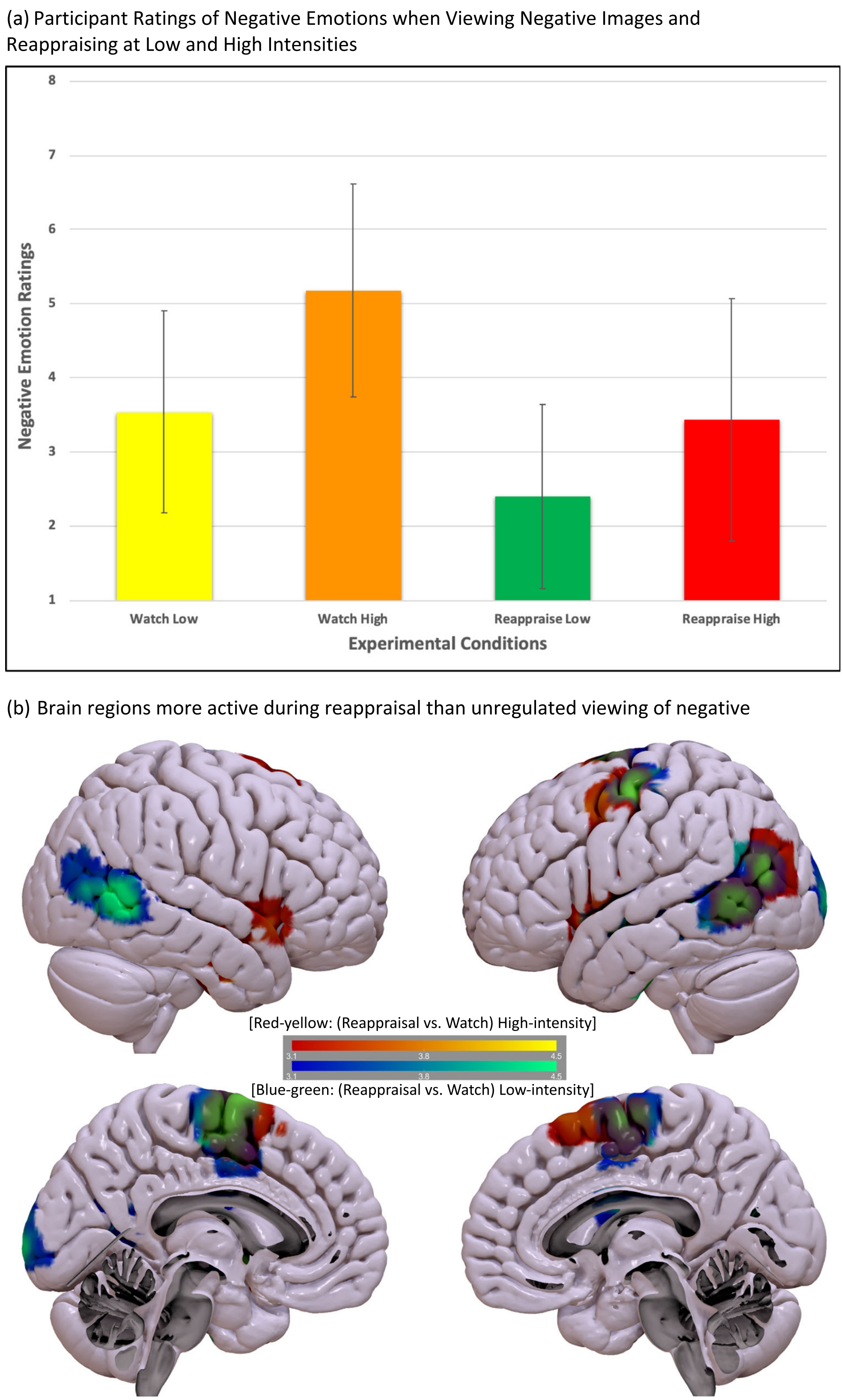
Self-Reported negative emotion ratings

For the manipulation check of negative induction, a three-strategy (reappraisal, distancing, distraction) x two intensity-level (low, high) ANOVA on the self-reported negative emotion ratings revealed a main effect of intensity ($F_{1,174}$ = 29.39, $p < 0.001$, $\eta_p^2 = 0.14$), but no main effect of strategy ($F_{2,174} = 0.22$, $p = 0.81$, $\eta_p^2 = 0.00$), or interaction of intensity and strategy ($F_{2,174} = 0.10$, $p = 0.91$, $\eta_p^2 = 0.00$).

The results of post-hoc independent samples *t*-tests revealed that viewing negatively valenced images provoked significantly more negative responses in participants than viewing neutral images ($M_{Negative}$ = 4.36, $SD_{Negative}$ = 2.14; $M_{Neutral}$ = 1.16, $SD_{Neutral}$ = 0.62) [t(88)= 9.91, $p < 0.001$] (Fig. 3a). In addition, the manipulation check for the effect of stimulus intensity showed that self-reported negative emotion increased significantly as a function of intensity across all conditions ($M_{Low\text{-}intensity} = 2.70$, $SD_{Low\text{-}intensity} = 1.70$; $M_{High\text{-}intensity} = 3.97$, $SD_{High\text{-}intensity} = 2.12$) [t(238) = 6.30, $p < 0.001$]. Negative emotion ratings also significantly increased as a function of intensity specifically in the watch condition ($M_{Watch\text{-}low} = 3.54$, $SD_{Watch\text{-}low} = 2.04$; $M_{Watch\text{-}high} = 5.18$, $SD_{Watch\text{-}high} = 2.25$) [t(58) = 4.06, $p < 0.001$].

Brain imaging results

Many brain areas were activated by viewing negatively valenced images in contrast to neutral images (Table 1). There was a large amount of overlap in the brain regions that were activated by negative viewing at both low and high intensities, for example in the bilateral associate visual and dorsomedial prefrontal cortices. However, some areas were uniquely activated by high-intensity images, such as the posterior parietal cortex and bilateral precuneus (Fig. 3b). The contrast of viewing low-intensity negative images versus neutral images produced suprathreshold local activation in the bilateral amygdala, brainstem, anterior insula, thalamus, basal ganglia, medial prefrontal cortex, and bilateral dorsolateral



prefrontal cortices. Additionally, within these activation clusters, peaks were found in the bilateral associate visual cortex, dorsomedial prefrontal cortex, bilateral ventrolateral prefrontal cortex, right dorsolateral prefrontal cortex, and bilateral inferior temporal gyrus (Table 1). The contrast of viewing high-intensity negative images versus neutral images

Fig. 4 (**a**) Participant ratings of negative emotions when viewing negative images and reappraising at low and high intensities. (**b**) Brain regions more active during reappraisal than unregulated viewing of negative images. Brain regions with more activation during reappraisal than viewing negative images at low intensities are displayed along a blue-green spectrum ($3.1 < z > 4.5$). Brain regions with more activation during reappraisal than viewing negative images at high intensities are displayed along a red-yellow spectrum ($3.1 < z > 4.5$). Brain regions activated more by reappraisal than viewing negative images at both intensities are displayed in a purple composite ($3.1 < z > 4.5$).

produced significant activations in the bilateral amygdala, brainstem, anterior insula, thalamus, basal ganglia, medial prefrontal cortex, bilateral inferior and dorsolateral prefrontal cortices, and bilateral orbitofrontal cortex. Within these activation clusters, activation peaks were observed in the associate visual cortex, dorsomedial prefrontal cortex, ventromedial prefrontal cortex, posterior cingulate cortex, right dorsolateral prefrontal cortex, and bilateral precuneus.

General effects of regulation strategies

Self-reported negative emotion

t-tests of the self-reported ratings of negative emotion showed a significant decrease in negativity ratings when employing a regulation strategy compared to the unregulated viewing of emotion-inducing images ($M_{Regulation} = 3.00$, $SD_{Regulation} = 1.83$; $M_{Watch\text{-}negative} = 4.36$, $SD_{Watch\text{-}negative} = 2.14$) [$t(238) = 5.78$, $p < 0.001$]. As expected, each regulation strategy led to reductions in negative affect ratings at each intensity level when compared to unregulated viewing of emotion-inducing images at the same intensity level ($M_{RL} = 2.40$, $SD_{RL} = 1.61$; $M_{RH} = 3.43$, $SD_{RH} = 2.05$; $M_{SL} = 2.45$, $SD_{SL} = 1.57$; $M_{SH} = 3.72$, $SD_{SH} = 2.15$; $M_{DL} = 2.40$, $SD_{DL} = 1.57$; $M_{DH} = 3.56$, $SD_{DH} = 2.03$) [RL vs. WL: $t(58) = 3.12$, $p < 0.01$]; [RH vs. WH: $t(58) = 4.37$, $p < 0.001$] (Fig. 4a); [SL vs. WL: $t(58) = 3.08$, $p < 0.01$]; [SH vs. WH: $t(58) = 3.45$, $p < 0.01$] (Fig. 5a); [DL vs. WL: $t(58) = 3.20$, $p < 0.01$]; [DH vs. WH: $t(58) = 3.89$, $p < 0.001$] (Fig. 6a).

Brain imaging

Regulation conditions also produced brain activation patterns that were distinct from unregulated viewing of negative images. For reappraisal, similar activation patterns were observed at both low and high intensity in the left temporal-parietal junction/angular gyrus region, left dmPFC, and bilateral pre-SMA (Fig. 4b). At low intensity, unique activation was observed in the right temporal-parietal junction/angular gyrus region. High-intensity reappraisal also activated regions not observed in the low-intensity reappraisal map, such as the right ventrolateral prefrontal cortex (Table 2).

For self-distancing, significant activation was only observed at high intensity compared with the unregulated viewing of negative images (Table 3). This activation was observed in the right dorsolateral prefrontal cortex (Fig. 5b). For distraction, similar activation patterns were observed at both low and high intensity in the right dorsolateral prefrontal cortex (Table 4). At low intensity, distraction also produced significant activation in the left dlPFC, bilateral anterior insula, and right angular gyrus/supramarginal gyrus region (Fig. 6b).

Differential effects of regulation strategies

Self-reported negative emotion

All emotion regulation strategies were effective in decreasing negative emotion at each intensity level, but the negative emotion ratings did not differ between strategies at the same intensity level [RL vs. SL: $t(58) = -0.16$, $p = 0.87$]; [RL vs. DL: $t(58) = 0.004$, $p = 0.99$]; [SL vs. DL: $t(58) = 0.16$, $p = 0.87$]; [RH vs. SH: $t(58) = -0.71$, $p = 0.48$]; [RH vs. DH: $t(58) = -0.33$, $p = 0.74$]; [SH vs. DH: $t(58) = 0.38$, $p = 0.71$]. Hence, it is not surprising that in the ANOVA across the three regulation conditions, there was no difference across regulation strategies, nor an interaction or intensity and strategy.

Brain imaging results

In the direct comparison of reappraisal and self-distancing, brain regions were only found to be more associated with reappraisal (Table 5). These regions included the medial prefrontal cortex, left medial and right anteromedial temporal cortex, and a bilateral posterior parietal cortex/angular gyrus region (Fig. 7a). There were no regions found to be significant for the interaction of intensity within the comparison of reappraisal and self-distancing ((reappraise high > low) vs. (self-distancing high > low)) (Fig. 7b).

In the direct comparison of reappraisal and distraction, there were again many more regions associated with reappraisal (Table 6). These regions include the middle prefrontal cortex, ventrolateral prefrontal cortex, middle cingulate gyrus, and medial temporal lobe. The right angular gyrus showed activation that was more associated with distraction than reappraisal (Fig. 8a). For the interaction of intensity within the comparison of reappraisal and distraction ((reappraise high > low) vs. (distract high > low)), the primary visual cortex and right angular gyrus were more activated by distraction than reappraisal as intensity increased. There were no brain regions that were more activated by reappraisal when intensity increased (Fig. 8b).

In the direct comparison of self-distancing and distraction, there were more regions associated with self-distancing than distraction (Table 7). These brain regions include the primary and associate visual cortices, bilateral ventrolateral prefrontal

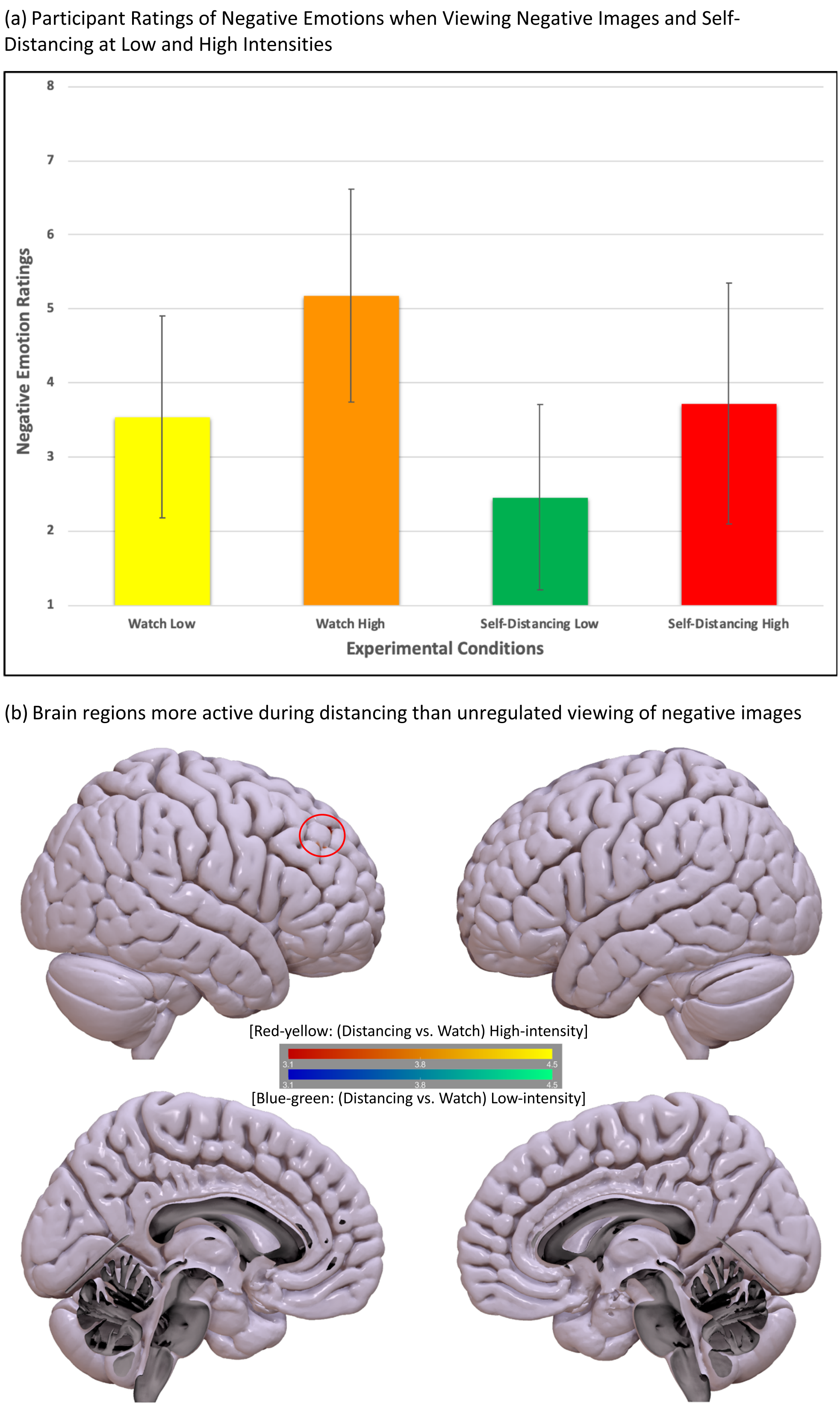


Fig. 5 **a**. Participant ratings of negative emotions when viewing negative images and selfdistancing at low and high intensities. (**b**) Brain regions more active during distancing than unregulated viewing of negative images. There were no brain regions with more activation during distancing than viewing negative images at low intensities. Brain regions with more activation during distancing than viewing negative images at high intensities are displayed in along a red-yellow spectrum (3.1 < z > 4.5)

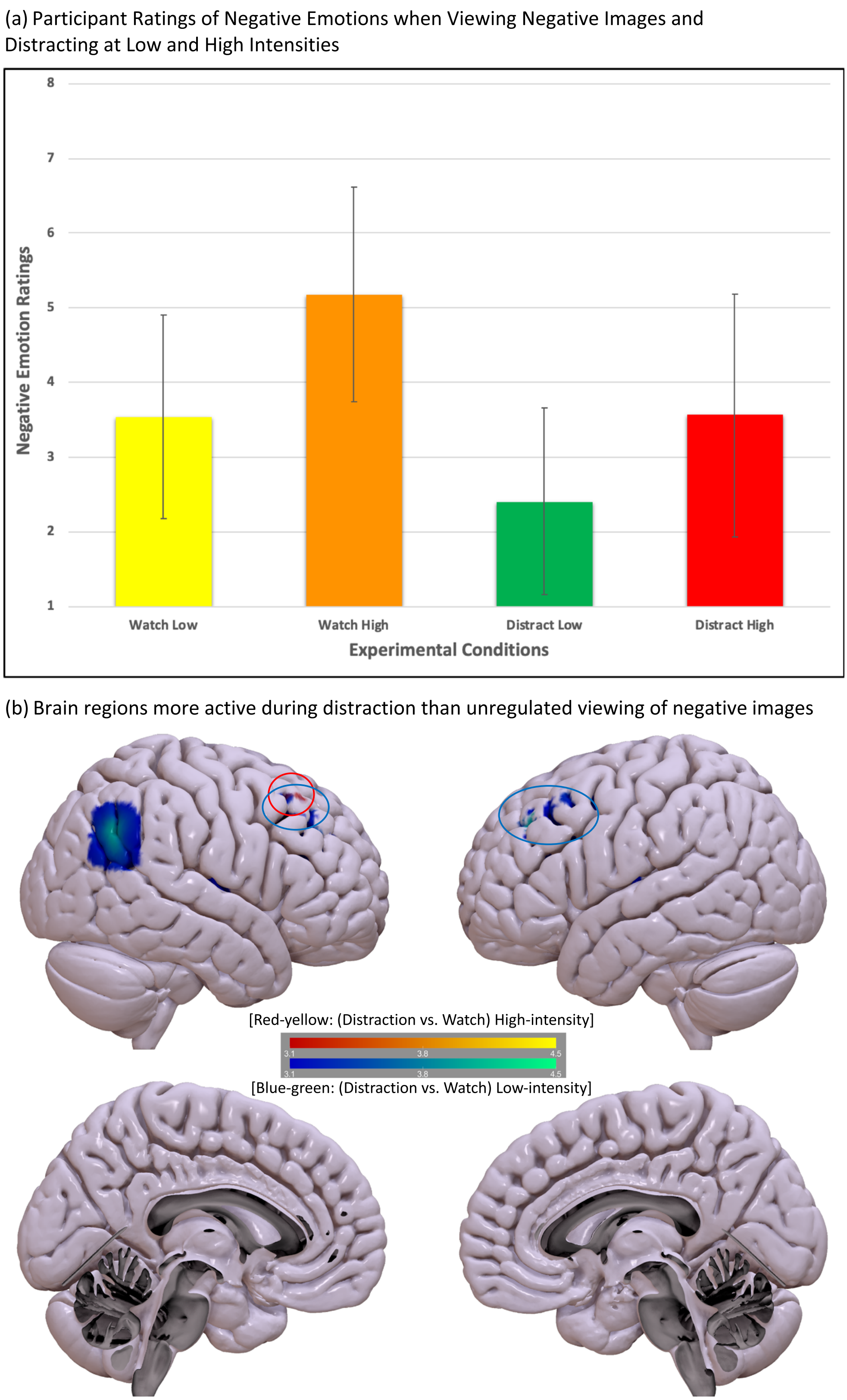


Fig. 6. **(a)** Participant ratings of negative emotions when viewing negative images and distracting at low and high intensities. (**b**) Brain regions more active during distraction than unregulated viewing of negative images. Brain regions with more activation during distraction than viewing negative images at low intensities are displayed along a blue-green spectrum (3.1 < z > 4.5). Brain regions with more activation during distraction than viewing negative images at high intensities are displayed along a red-yellow spectrum (3.1 < z > 4.5)

Table 2. Brain regions that are more activated during reappraisal vs. unregulated viewing of negative images

Contrast	Brain Region(s)	Cluster Size (voxels)	P-value (corrected)	Peak Coordinates	Max Voxel z-stat
Brain regions more active during reappraisal than unregulated viewing of negative images:					
Reappraisal LO vs. Watch LO	Left Posteromedial Temporal Cortex	1836	$p < 0.001$	[-44] [-42] [-6]	5.12
	Right Posteromedial Temporal Cortex	1650	$p < 0.001$	[66] [-38] [-4]	4.76
	Left Dorsolateral Prefrontal Cortex	976	$p < 0.001$	[-26] [4] [34]	4.5
	Left Anteromedial Temporal Cortex	919	$p < 0.001$	[-50] [-4] [-20]	4.81
	Left dmPFC / pre-SMA	845	$p < 0.001$	[-10] [6] [56]	5.28
	Left Associate Visual Cortex	730	$p < 0.001$	[-16] [-96] [16]	4.86
	Right Caudate Nucleus	464	$p < 0.01$	[26] [12] [22]	4.62
Reappraisal HI vs. Watch HI	Left Posteromedial Temporal Cortex	995	$p < 0.001$	[-56] [-60] [14]	4.9
	Left Dorsolateral Prefrontal Cortex	955	$p < 0.001$	[-44] [8] [48]	4.83
	Left Ventrolateral Prefrontal Cortex	646	$p < 0.001$	[-52] [20] [0]	4.73
	Left dmPFC / pre-SMA	590	$p < 0.001$	[-8] [16] [60]	4.95
	Right Anteromedial Temporal Cortex	581	$p < 0.001$	[46] [14] [-26]	4.28
	Right Dorsomedial Prefrontal Cortex	196	$p < 0.05$	[10] [18] [60]	4.14

All coordinates are reported based on the MNI 152 T1 average brain template coordinate space

cortices, basal ganglia, and the medial prefrontal cortex. The right dorsolateral prefrontal cortex was more associated with distraction than self-distancing (Fig. 9a). For the interaction of intensity within the comparison of self-distancing and distraction ((self-distancing high > low) vs. (distract high > low)), there were no brain regions that showed significantly more activation for self-distancing or distraction in either direction when intensity increased (Fig. 9b).

Discussion

Results from this study revealed that participants' negative emotions were decreased by all three forms of emotion regulation, but there was no difference among strategies in the relative amount of reduction, meaning that all three forms of cognitive regulation were equally effective. Increases in stimulus intensity led to concomitant increases in negative emotion, but there were no behavioral interactions of strategy and intensity. When contrasting the high versus low intensity condition (Supplementary Figures 1a and 1 b), there was a general increase in brain activity in regions that have been associated with emotion reactivity, such as the amygdala, insula, ACC, visual cortex, and precuneus (García-garcía et al., 2016). Similarly, emotion regulation recruited brain regions that have been previously shown to be involved with cognitive control of emotion (Buhle et al., 2014; Frank et al., 2014; Goldin et al., 2008; Kohn et al., 2014). The brain activation patterns showed significant interactions between intensity and strategy, which will be explored in more detail for each strategy below, suggesting that the brain engages these strategies using distinct regulatory architectures with comparable behavioral efficacy, and that these systems are engaged differently depending on emotional intensity.

The contrasts of viewing negatively valenced and neutral images revealed that the manipulation check of negative induction does induce greater activity in the expected emotion-generative brain regions. These regions include the anterior insula, basal ganglia, brainstem, and amygdala. These contrasts also revealed activity in several other regions, such as the medial prefrontal cortex, inferior and dorsolateral prefrontal cortices, and orbitofrontal cortex. While these regions have been typically associated with emotion regulation, similar control regions have been shown to be activated during reactivity before (Drabant et al., 2009; Ferri, et al., 2013; Ferri, et al., 2016).

Table 3. Brain regions that are more activated during distancing vs. unregulated viewing of negative images

Contrast	Brain Region(s)	Cluster Size (voxels)	P-value (corrected)	Peak Coordinates	Max Voxel z-stat
Brain regions more active during distancing than unregulated viewing of negative images:					
Self-distancing LO vs. Watch LO		No Significant Clusters for this Contrast			
Self-distancing HI vs. Watch HI	Right Dorsolateral Prefrontal Cortex	214	$p < 0.05$	[26] [48] [20]	4.04

All coordinates are reported based on the MNI 152 T1 average brain template coordinate space

Table 4. Brain regions that are more activated during distraction vs. unregulated viewing of negative images

Contrast	Brain Region(s)	Cluster Size (voxels)	P-value (corrected)	Peak Coordinates	Max Voxel z-stat
Brain regions more active during distraction than unregulated viewing of negative images:					
Distract LO > Watch LO	Left Dorsolateral Prefrontal Cortex	647	p < 0.001	[-32] [50] [30]	4.5
	Right Dorsolateral Prefrontal Cortex	555	p < 0.001	[32] [50] [30]	4.38
	Right Angular Gyrus	385	p < 0.01	[62] [-44] [34]	4.42
	Bilateral Anterior Insula	220	p < 0.05	[30] [20] [8]	4.15
Distract HI > Watch HI	Right Dorsolateral Prefrontal Cortex	233	p < 0.05	[28] [32] [30]	4.48

All coordinates are reported based on the MNI 152 T1 average brain template coordinate space

Implications for reappraisal

When contrasting the periods in which participants are asked to use reappraisal with unregulated viewing periods, brain regions were engaged that have classically been associated with reappraisal, such as the dlPFC, VLPFC/IFG, dorsal ACC, dmPFC, SMA and pre-SMA, and posterior parietal cortex (Buhle et al., 2014; Etkin, Büchel, & Gross, 2015; Morawetz, et al., 2017). However, reappraisal significantly activated several other areas, such as the primary visual cortex and basal ganglia, that have not typically been associated with this construct, but it is not clear why these regions in particular would be activated by reappraisal.

Several regions also were found to be activated by reappraisal at different intensities. One particularly noticeable difference is the absence of dlPFC activation in the high intensity contrast. The dlPFC has been shown to be a key region associated with reappraisal (Buhle et al., 2014), and activity in this region has generally been shown to increase as the intensity of the stimulus to be reappraised increases (Silvers, Weber, Wager, & Ochsner, 2015). Apart from for the right vlPFC, activity did not increase across all of the other typical reappraisal-related brain regions as intensity increased. Similarly, a contrast of intensity within each regulation strategy showed the smallest cluster extent and voxel counts for the effect of increasing intensity within reappraisal compared with self-distancing and distraction (Supplementary Figures 1a and 1 b). Taken together, these findings suggest that reappraisal may begin to break down at higher intensity levels, a finding that is consistent with behavioral findings discussed below, which indicate that, when given the choice, participants are less likely to use reappraisal as intensity increases (Shafir et al., 2016; Sheppes, Scheibe, Suri, & Gross, 2011; Sheppes, Scheibe, Suri, Radu, Blechert, & Gross, 2014).

Implications for self-distancing

The contrast of self-distancing and negative reactivity showed activity in the right prefrontal cortex, but only for high intensity images. This brain region is typically associated with reappraisal, and in fact, reappraisal tactics often have allowed for forms of self-distancing. Hence, it is not surprising to see the similarity between these results and those in the reappraisal literature. Nevertheless, utilizing instructions that are specific to self-distancing, which should exclude reinterpretation tactics, still produced results congruent with the reappraisal literature. This lends support to the argument that self-distancing could be viewed as a form of reappraisal.

The results showing significant activation for self-distancing only at high intensities suggests that self-distancing also might not be an effective cognitive regulation strategy when applied to low intensity stimuli. This is the case

Table 5. Brain regions that are more activated at high vs. low intensity for reappraisal vs. distancing

Contrast	Brain Region(s)	Cluster Size (voxels)	P-value (corrected)	Peak Coordinates	Max Voxel z-stat
Contrast of reappraisal vs. distancing (reappraisal > distancing)	Left Medial Temporal Cortex	2703	p < 0.001	[-50] [-36] [-6]	5.58
	Right Posterior Parietal Cortex	1314	p < 0.001	[54] [-66] [12]	5.63
	Right Anteromedial Temporal Cortex	1244	p < 0.001	[54] [-14] [-18]	5.57
	Ventromedial Prefrontal Cortex	210	p < 0.05	[2] [62] [-10]	3.91
	Left dmPFC / pre-SMA	196	p < 0.05	[-6] [16] [60]	4.05
(distancing > reappraisal)		No Significant Clusters for this Interaction			
Contrast of reappraisal vs. distancing across intensity (reappraisal > distancing)		No Significant Clusters for this Interaction			
(distancing > reappraisal)		No Significant Clusters for this Interaction			

All coordinates are reported based on the MNI 152 T1 average brain template coordinate space

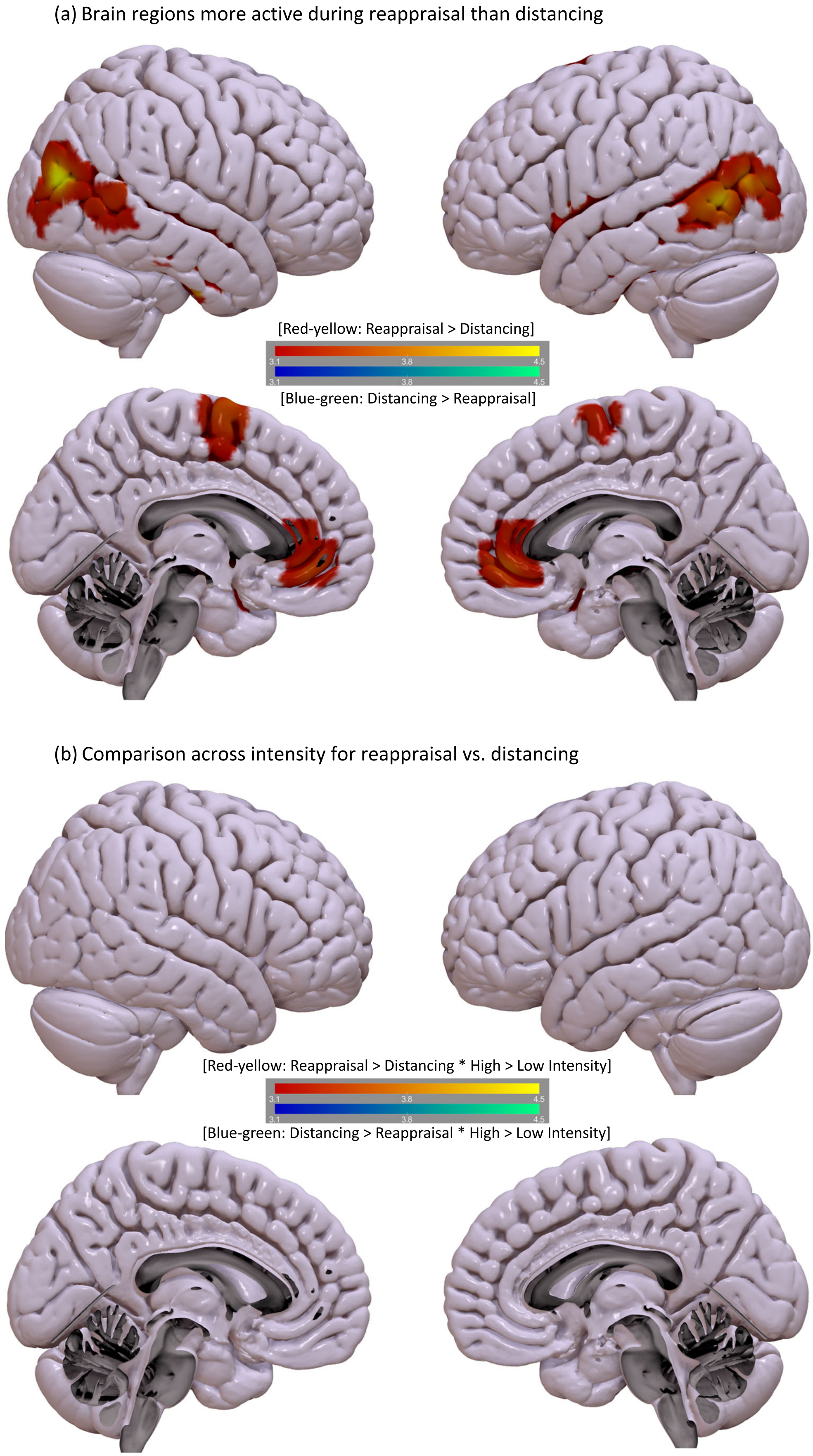

(a) Brain regions more active during reappraisal than distancing
[Red-yellow: Reappraisal > Distancing]
3.1
3.8
4.5
3.1
3.8
4.5
[Blue-green: Distancing > Reappraisal]
(b) Comparison across intensity for reappraisal vs. distancing
[Red-yellow: Reappraisal > Distancing * High > Low Intensity]
3.1
3.8
4.5
3.1
3.8
4.5
[Blue-green: Distancing > Reappraisal * High > Low Intensity]

Fig. 7. **(a)** Brain regions more active during reappraisal than distancing. Brain regions with more activation during reappraisal are displayed along a red-yellow spectrum (3.1 < z > 4.5), while the inverse contrast showing brain regions with more activation during distancing is displayed along a blue-green spectrum (3.1 < z > 4.5). (**b**) Comparison across intensity for reappraisal vs. distancing. There were no brain regions with more activation at high vs. low intensity for reappraisal than distancing. Similarly, there were no brain regions with more activation at high vs. low intensity for distancing than reappraisal

at least in this context, because there was no activity in any brain regions above and beyond recruitment for negative reactivity. One distinct possibility is that participants are already engaging in low-grade forms of cognitive regulation even in the reactivity periods, perhaps even self-distancing itself, as evidenced by regulation regions being observed in the reactivity contrast. This type of spontaneous self-distancing has previously been shown not only to occur but also to be an adaptive mechanism that arises during development (White, Kross, & Duckworth, 2015). The other possibility is that self-distancing is not possible or practical in low-intensity situations. For instance, if someone is asked to distance themselves or reduce their personal investment in a mildly annoying situation, they may have not had much engagement in the situation to begin with, thus inducing a floor effect.

Implications for distraction

For distraction, activation was observed in the dlPFC, anterior insula, and the angular gyrus/supramarginal gyrus region. These results are in line with previous findings, except for the lack of the previously observed vlPFC/IFG activity (Hermann, Kress, & Stark, 2017; McRae et al., 2010). Nevertheless, the observed decreases in negative self-reports, in conjunction with the observation of several other distraction-related regions, suggest that distraction was still efficacious as a cognitive emotion regulation strategy in this context.

The contrast of distraction at low and high intensities revealed the most activation was unique for high- versus low-intensity images (Supplementary Figure 1a), and this indicates that of the three strategies under consideration, distraction may be the most suitable to handle adaptively the regulation load, because it varies as a function of intensity. Given that distraction recruits prefrontal regions at both intensity levels, this suggests that the prefrontal control mechanisms required for distraction can be deployed irrespective of variation in intensity. However, the failure to produce a reduction of self-reported negativity to the same level in high intensity as low intensity could indicate that either the distraction mechanism operates within a limited range or that it is less efficacious at higher intensities. More careful titration of these effects will be necessary to distinguish between these possibilities.

Implications for emotion regulation choice

Several lines of research that have demonstrated that, in real-world and unrestricted paradigms, individuals choose different emotion regulating strategies depending on situational factors, such as emotion intensity (Doré et al., 2016; Doré et al., 2017; Martins et al., 2018; Murphy & Young, 2017; Résibois et al., 2017; Schirda et al., 2016). Thus, in contexts where participants are allowed to choose the particular strategy that they would like to implement in situations where there are presentations of both low- and high-intensity stimuli, individuals tend to prefer to use distraction at high intensity (Scheibe, Sheppes, & Staudinger, 2015; Sheppes, et al., 2014; Sheppes, Scheibe, Suri, & Gross, 2011; Silvers & Moreira; 2017). This resonates with the argument that not all regulation strategies are ideal for all contexts, and it appears that distraction might be more suited to high-intensity situations, at least compared with reappraisal. One reason that this might be the case is that there are affordances for reappraisal of low-intensity situations that are not present in high-intensity situations, where distraction is more easily applicable (Suri et al., 2018; Suri, Whittaker, & Gross, 2015). For instance, if one is asked to

Table 6 Brain regions that are more activated at high vs. low intensity for reappraisal vs. distraction

Contrast	Brain Region(s)	Cluster Size (voxels)	P-value (corrected)	Peak Coordinates	Max Voxel z-stat
Contrast of reappraisal vs. distraction (reappraisal > distraction)	Left Anteromedial Temporal Cortex	26836	$p < 0.001$	[-46] [-2] [-38]	6.41
	Left Rostromedial Prefrontal Cortex	3820	$p < 0.001$	[-4] [60] [34]	5.18
	Right Dorsolateral Prefrontal Cortex	909	$p < 0.001$	[48] [20] [42]	4.71
(distraction > reappraisal)	Right Supramarginal / Angular Gyrus	321	$p < 0.01$	[64] [-42] [34]	4.86
Contrast of reappraisal vs. distraction across intensity (reappraisal > distraction)	No Significant Clusters for this Interaction				
(distraction > reappraisal)	Right Supramarginal / Angular Gyrus	494	$p < 0.01$	[50] [-48] [16]	4.96
	Primary Visual Cortex	220	$p < 0.05$	[-4] [-96] [14]	4.21

All coordinates are reported based on the MNI 152 T1 average brain template coordinate space

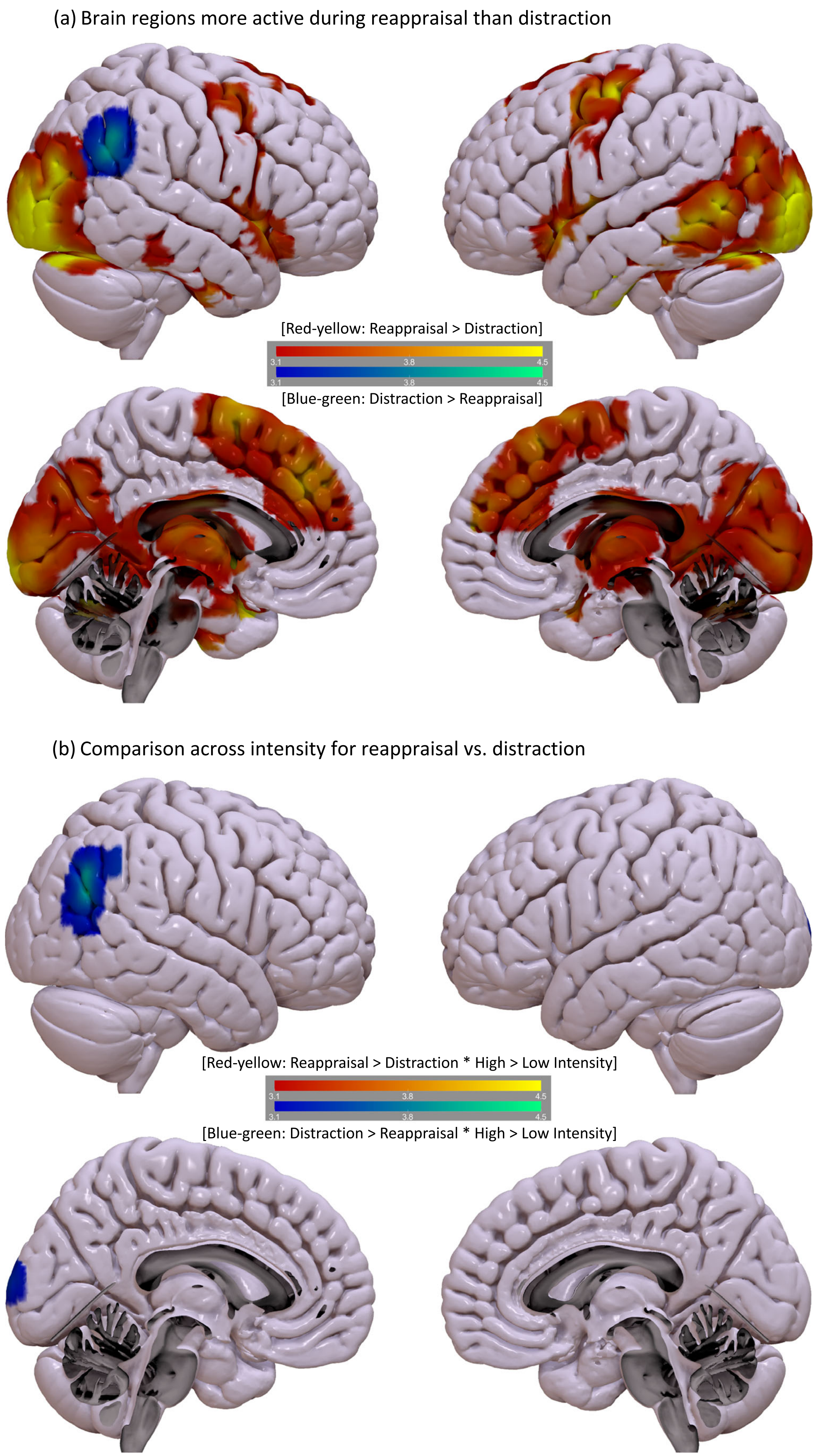

(a) Brain regions more active during reappraisal than distraction
[Red-yellow: Reappraisal > Distraction]
3.1
3.8
4.5
3.1
3.8
4.5
[Blue-green: Distraction > Reappraisal]
(b) Comparison across intensity for reappraisal vs. distraction
[Red-yellow: Reappraisal > Distraction * High > Low Intensity]
3.1
3.8
4.5
3.1
3.8
4.5
[Blue-green: Distraction > Reappraisal * High > Low Intensity]

Fig. 8. **(a)** Brain regions more active during reappraisal than distraction. Brain regions with more activation during reappraisal are displayed along a red-yellow spectrum (3.1 < z > 4.5), while the inverse contrast showing brain regions with more activation during distraction is displayed along a blue-green spectrum (3.1 < z > 4.5). (**b**) Comparison across intensity for reappraisal vs. distraction. There were no brain regions with more activation at high vs. low intensity for reappraisal. The inverse contrast showing brain regions with more activation at high vs. low intensity for distraction is displayed along a blue-green spectrum (3.1 < z > 4.5).

reappraise situations involving bodily harm, it is much easier to reappraise an injury that an individual might recover from compared with a situation in which that individual has died from severe injuries. Alternatively, differential effectiveness of regulation strategies or differences in participants' effort also could contribute to this finding, and future studies could empirically determine the relative contribution of each of these possibilities.

It is within this context that the findings for the interactions between strategies and intensity will be considered. For the comparison of reappraisal and self-distancing, only reappraisal showed higher activity compared with self-distancing. These regions with more activation for reappraisal included control regions, such as the vmPFC, rostral ACC, and pre-SMA. However, when considering the interaction of reappraisal and self-distancing with intensity, no regions were preferentially activated by either strategy at higher intensities. Hence, it appears that there is much more recruitment of control regions in reappraisal overall, but significant overlap between self-distancing and reappraisal when considering intensity. When also considering the supplementary findings, which consider the effects on intensity within strategy, this work shows that both reappraisal and self-distancing engage control regions less at higher intensities. Self-distancing is associated with higher activity in integrative relay areas, such as the thalamus, and self-referential areas, such as the precuneus, as a function of intensity (Supplementary Figure 1a), but more work will need to be done to support this assertion.

For the comparison of reappraisal and distraction, the mPFC, IFG, middle cingulate gyrus, and medial temporal lobe were more associated with reappraisal overall, whereas the right angular gyrus was more associated with distraction overall. As in the previous comparison, no areas were preferentially engaged by reappraisal over distraction as intensity increased. However, the supramarginal gyrus/angular gyrus region was preferentially engaged by distraction at high intensities. These results show that some prefrontal control regions are recruited preferentially by reappraisal overall, but attention regions, such as the angular gyrus, are engaged more by distraction as intensity increases. Taken together with the observation of a much more comprehensive map of regions that increase with intensity for distraction (Supplementary Figure 1a), these comparisons suggest that distraction may be the preferred strategy at higher intensities compared with either self-distancing or distraction. However, future studies will need to address this assertion directly.

For the comparison of self-distancing and distraction, several more regions, including visual, temporal, and prefrontal regions, were preferentially activated by self-distancing overall. Conversely, the right dlPFC was preferentially engaged by distraction overall. When considering the interaction of these two strategies and intensity, no brain regions were preferentially engaged by either strategy as intensity increased. These results suggest that both of these strategies engage control regions quite similarly.

Limitations and future directions

This study is the first attempt to directly contrast three distinct cognitive emotion regulation strategies using stimuli carefully preselected to elicit low versus high levels of emotional

Table 7. Brain regions that are more activated at high vs. low intensity for distancing vs. distraction

Contrast	Brain Region(s)	Cluster Size (voxels)	P-value (corrected)	Peak Coordinates	Max Voxel z-stat
Contrast of distancing vs. distraction (distancing > distraction)	Right Associate Visual Cortex	4435	p < 0.001	[40] [-72] [-14]	5.63
	Left Associate Visual Cortex	3643	p < 0.001	[-30] [-84] [-14]	5.96
	Left Ventrolateral Prefrontal Cortex	499	p < 0.001	[-48] [32] [-16]	4.59
	Left Anteromedial Temporal Gyrus	433	p < 0.01	[-44] [14] [-38]	4.86
	Right Caudate Nuclues / Putamen	421	p < 0.01	[18] [0] [0]	4.08
	Left Dorsomedial Prefrontal Cortex	243	p < 0.05	[0] [32] [40]	3.86
	Right Ventrolateral Prefrontal Cortex	221	p < 0.05	[54] [16] [20]	3.75
(distraction < distancing)	Right Dorsolateral Prefrontal Cortex	202	p < 0.05	[28] [30] [28]	4.14
Contrast of distancing vs. distraction across intensity					
(distancing > distraction)	No Significant Clusters for this Interaction				
(distraction < distancing)	No Significant Clusters for this Interaction				

All coordinates are reported based on the MNI 152 T1 average brain template coordinate space

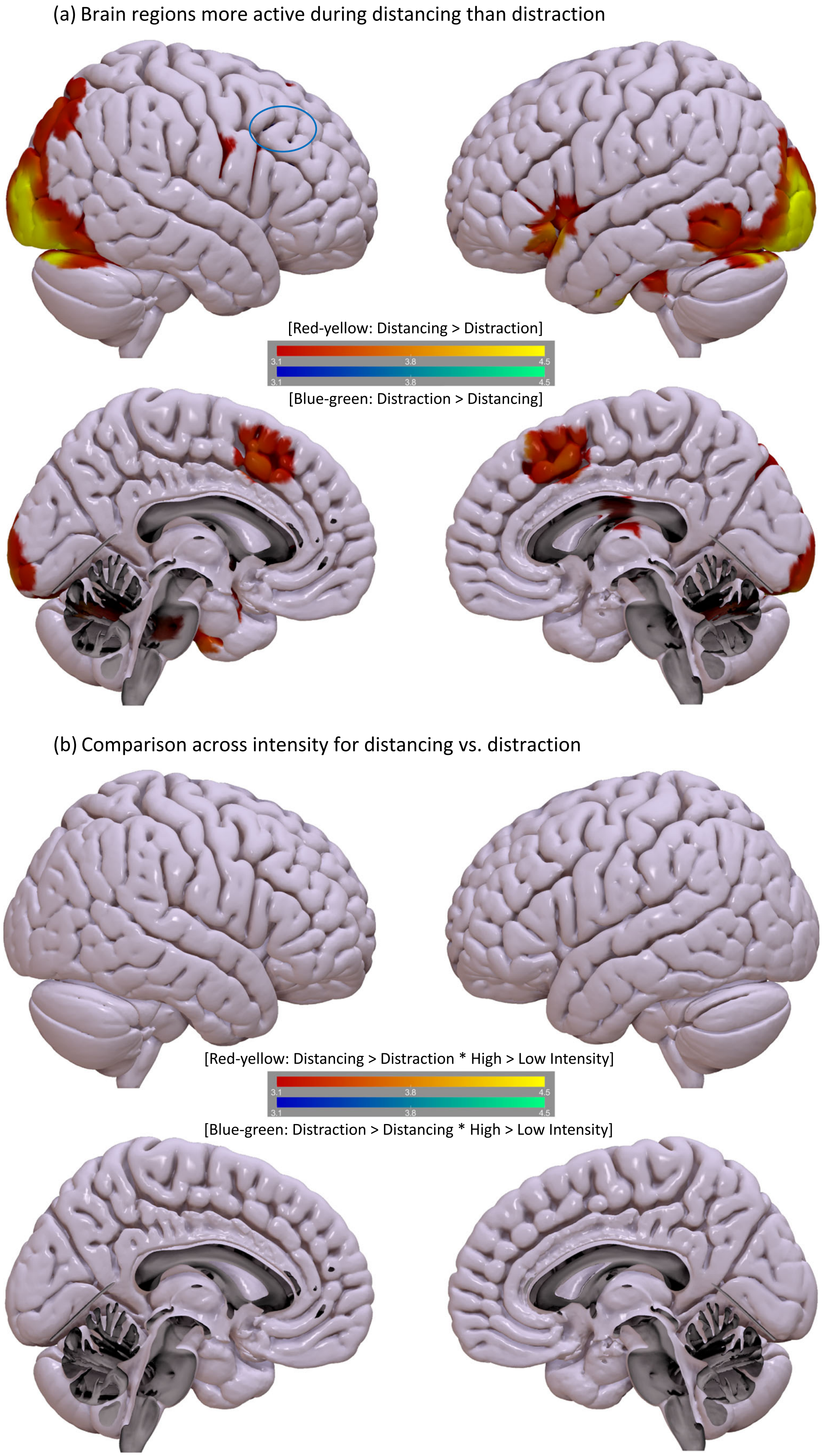

(a) Brain regions more active during distancing than distraction
[Red-yellow: Distancing > Distraction]
3.1
3.8
4.5
[Blue-green: Distraction > Distancing]
(b) Comparison across intensity for distancing vs. distraction
[Red-yellow: Distancing > Distraction * High > Low Intensity]
3.1
3.8
4.5
[Blue-green: Distraction > Distancing * High > Low Intensity]

Fig. 9 (**a**) Brain regions more active during distancing than distraction. Brain regions with more activation during distancing are displayed along a red-yellow spectrum ($3.1 < z > 4.5$), while the inverse contrast showing brain regions with more activation during distraction is displayed along a blue-green spectrum ($3.1 < z > 4.5$). (**b**) Comparison across intensity for distancing vs. distraction. There were no brain regions with more activation at high vs. low intensity for distancing than distraction. Similarly, there were no brain regions with more activation at high vs. low intensity for distraction than distancing. This contrast did not yield any significant activation in either direction

intensity in service of establishing their positions along a dimension of cognitive emotion regulation. Nevertheless, three specific regulation strategies were used, and consequently, there are several positions along this dimension where other cognitive regulation strategies may lie, and the interactions of these other strategies amongst themselves or with these three strategies are unknown (Gross, 2015b; Ochsner, Silvers, & Buhle, 2012). Similarly, this work only employs one form of negative induction through viewing negatively valenced images, and it is likely that other investigations that include other presentation formats will enrich these findings.

Given that in this paradigm, participants were not allowed to choose the strategy that they used, this work contributes only indirectly to the emotion regulation choice literature. Nevertheless, these findings converge nicely with prior behavioral findings showing that participants tend to prefer to use distraction rather than reappraisal at high-intensity levels. In future work, it will be useful to extend the present findings by integrating emotion regulation choice tasks that permit the selection among a wider range of strategies. Such studies also may inform future cognitive and clinical domains that involve emotion regulation.

Conclusions

The findings from this study show that the three strategies do indeed share quite a bit of overlap as cognitive emotion regulation strategies. More importantly, the overlap between self-distancing and reappraisal, but also distraction, show that self-distancing cannot be simply considered to be subsumed by reappraisal, due to its overlap with regions related to attentional deployment. Self-distancing elicited activity in brain regions that are classically associated with reappraisal, but also showed significant overlap in activation in self-referential regions associated with distraction. These findings are consistent with the proposal that the three cognitive strategies lie along a single cognitive emotion regulation dimension, as argued by Ochsner and Gross (2005). However, these strategies not only share characteristics along this axis, but they also have differential engagement according to intensity, with distraction exhibiting a much more robust response to increasing intensity and, hence, likelihood to be chosen at high intensities. This conclusion is in line with an information processing view of emotion regulation (Sheppes et al., 2014), and consequently, both theoretical frameworks in question received support from the findings in this study.

Acknowledgements Funding for this research was provided by the National Institute of Mental Health. An R21 grant (MH094545) was awarded to James J. Gross.

References

American Psychiatric Association (1994). Diagnostic and statistical manual of mental disorders (4th). Washington, DC: American Psychiatric Press Inc.

Andersson, J. L. R., Jenkinson, M., & Smith, S. (2007). Non-linear registration, aka spatial normalisation. *Oxford Centre for Functional MRI of the Brain Technical Report TR07*.

Beauregard, M., Lévesque, J., & Bourgouin, P. (2001). Neural correlates of conscious self-regulation of emotion. *The Journal of Neuroscience: The Official Journal of the Society for Neuroscience*, *21*(18), RC165. https://doi.org/20015619

Buhle, J. T., Silvers, J. A., Wage, T. D., Lopez, R., Onyemekwu, C., Kober, H., Weber, J., Ochsner, K. N. (2014). Cognitive reappraisal of emotion: A meta-analysis of human neuroimaging studies. *Cerebral Cortex*, *24*(11), 2981–2990. https://doi.org/10.1093/cercor/bht154

Doré, B. P., Silvers, J. A., & Ochsner, K. N. (2016). Toward a Personalized Science of Emotion Regulation. *Social and Personality Psychology Compass*, *10*(4), 171–187. https://doi.org/10.1111/spc3.12240

Doré, B. P., Weber, J., & Ochsner, K. N. (2017). Neural Predictors of Decisions to Cognitively Control Emotion. *The Journal of Neuroscience*, *37*(10), 2580–2588. https://doi.org/10.1523/JNEUROSCI.2526-16.2016

Dörfel, D., Lamke, J. P., Hummel, F., Wagner, U., Erk, S., & Walter, H. (2014). Common and differential neural networks of emotion regulation by detachment, reinterpretation, distraction, and expressive suppression: A comparative fMRI investigation. *NeuroImage*, *101*, 298–309. https://doi.org/10.1016/j.neuroimage.2014.06.051

Drabant, E. M., Mcrae, K., Manuck, S. B., Hariri, A. R., & Gross, J. J. (2009). Individual Differences in Typical Reappraisal Use Predict Amygdala and Prefrontal Responses. *Biological Psychiatry*, *65*(5), 367–373. https://doi.org/10.1016/j.biopsych.2008.09.007

Eklund, A., Nichols, T. E., & Knutsson, H. (2016). Cluster failure: Why fMRI inferences for spatial extent have inflated false-positive rates. *Proceedings of the National Academy of Sciences*, *113*(28), 7900–7905. https://doi.org/10.1073/pnas.1602413113

Etkin, A., Büchel, C., & Gross, J. J. (2015). The neural bases of emotion regulation. *Nature Reviews Neuroscience*, *16*(11), 693–700. https://doi.org/10.1038/nrn4044

Ferri, J., Schmidt, J., Hajcak, G., & Canli, T. (2016). Emotion regulation and amygdala-precuneus connectivity: Focusing on attentional deployment. *Cognitive, Affective and Behavioral Neuroscience*, *16*(6), 991–1002. https://doi.org/10.3758/s13415-016-0447-y

Ferri, J., Schmidt, J., Hajcak, G., & Canli, T. (2013). Neural correlates of attentional deployment within unpleasant pictures. *NeuroImage*, *70*, 268–277. https://doi.org/10.1016/j.neuroimage.2012.12.030

Frank, D. W., Dewitt, M., Hudgens-Haney, M., Schaeffer, D. J., Ball, B. H., Schwarz, N. F., Hussein, A. A., Smart, L. M., & Sabatinelli, D. (2014). Emotion regulation: Quantitative meta-analysis of functional activation and deactivation. *Neuroscience and*

Biobehavioral Reviews, *45*, 202–211. https://doi.org/10.1016/j.neubiorev.2014.06.010

García-garcía, I., Kube, J., Gaebler, M., Horstmann, A., & Villringer, A. (2016). Neural processing of negative emotional stimuli and the influence of age, sex and task-related characteristics. *Neuroscience and Biobehavioral Reviews*, *68*, 773–793. https://doi.org/10.1016/j.neubiorev.2016.04.020

Goldin, P. R., McRae, K., Ramel, W., & Gross, J. J. (2008). The Neural Bases of Emotion Regulation: Reappraisal and Suppression of Negative Emotion. *Biological Psychiatry*, *63*(6), 577–586. https://doi.org/10.1016/j.biopsych.2007.05.031

Gross, J. J. (1998a). Antecedent and response focused emotion regulation: Diverge consequences for experience, expression, and physiology. *Journal of Personality and Social Psychology*, *74*(1), 224–237.

Gross, J. J. (2002). Emotion regulation: affective, cognitive, and social consequences. *Psychophysiology*, *39*(3), 281–291. 10.1017.S0048577201393198

Gross, J. J. (2015a). Emotion Regulation: Current Status and Future Prospects. *Psychological Inquiry*, *26*(1), 1–26. https://doi.org/10.1080/1047840X.2014.940781

Gross, J. J. (1998b). The Emerging Field of Emotion Regulation: An Integrative Review. *Review of General Psychology*, *2*(5), 271–299. https://doi.org/10.1037/1089-2680.2.3.271

Gross, J. J. (2015b). The Extended Process Model of Emotion Regulation: Elaborations, Applications, and Future Directions. *Psychological Inquiry*, *26*(1), 130–137. https://doi.org/10.1080/1047840X.2015.989751

Hermann, A., Kress, L., & Stark, R. (2017). Neural correlates of immediate and prolonged effects of cognitive reappraisal and distraction on emotional experience. *Brain Imaging and Behavior*, *11*(5), 1227–1237. https://doi.org/10.1007/s11682-016-9603-9

Kalisch, R., Wiech, K., Herrmann, K., & Dolan, R. J. (2006). Neural Correlates of Self-distraction from Anxiety and a Process Model of Cognitive Emotion Regulation. *Journal of Cognitive Neuroscience*, *18*(8), 1266–1276. https://doi.org/10.1162/jocn.2006.18.8.1266

Kanske, P., Heissler, J., Schönfelder, S., Bongers, A., & Wessa, M. (2011). How to regulate emotion? Neural networks for reappraisal and distraction. *Cerebral Cortex*, *21*(6), 1379–1388. https://doi.org/10.1093/cercor/bhq216

Koenigsberg, H. W., Fan, J., Ochsner, K. N., Liu, X., Guise, K. G., Pizzarello, S., Dorantes, C., Guerreri, S., Tecuta, L., Goodman, M., New, A., & Siever, L. J. (2009). Neural Correlates of the Use of Psychological Distancing to Regulate Responses to Negative Social Cues: A Study of Patients with Borderline Personality Disorder. *Biological Psychiatry*, *66*(9), 854–863. https://doi.org/10.1016/j.biopsych.2009.06.010

Kohn, N., Eickhoff, S. B., Scheller, M., Laird, A. R., Fox, P. T., & Habel, U. (2014). Neural network of cognitive emotion regulation - An ALE meta-analysis and MACM analysis. *NeuroImage*, *87*, 345–355. https://doi.org/10.1016/j.neuroimage.2013.11.001

Jenkinson, M., Bannister, P., Brady, M., & Smith, S. (2002). Improved optimization for the robust and accurate linear registration and motion correction of brain images. *Neuroimage*, *17*(2), 825–841.

Lang, P. J., Bradley, M. M., & Cuthbert, B. N. (2008). International affective picture system (IAPS): affective ratings of pictures and instruction manual. *Technical Report A7*, *University.*

Martins, B., Sheppes, G., Gross, J. J., & Mather, M. (2018). Age Differences in Emotion Regulation Choice: Older Adults Use Distraction Less Than Younger Adults in High-Intensity Positive Contexts. *Journals of Gerontology - Series B Psychological Sciences and Social Sciences*, *73*(4), 603–611. https://doi.org/10.1093/geronb/gbw028

McRae, K., Ciesielski, B., & Gross, J. J. (2012). Unpacking cognitive reappraisal: goals, tactics, and outcomes. *Emotion (Washington, D.C.)*, *12*(2), 250–255. https://doi.org/10.1037/a0026351

McRae, K., Hughes, B., Chopra, S., Gabrieli, J., Gross, J., & Ochsner, K. N. (2010). The neural bases of distraction and reappraisal: An fMRI study of emotion regulation. *Journal of Cognitive Neuroscience*, *22*, 248–262.

Morawetz, C., Bode, S., Baudewig, J., Kirilina, E., & Heekeren, H. R. (2016). Changes in Effective Connectivity Between Dorsal and Ventral Prefrontal Regions Moderate Emotion Regulation. *Cerebral Cortex*, *26*(5), 1923–1937. https://doi.org/10.1093/cercor/bhv005

Morawetz, C., Bode, S., Derntl, B., & Heekeren, H. R. (2017). The effect of strategies, goals and stimulus material on the neural mechanisms of emotion regulation: A meta-analysis of fMRI studies. *Neuroscience and Biobehavioral Reviews*, *72*, 111–128. https://doi.org/10.1016/j.neubiorev.2016.11.014

Murphy, J. W., & Young, M. A. (2017). Dynamic processes in emotion regulation choice. *Cognition and Emotion*, *9931*(December), 1–9. https://doi.org/10.1080/02699931.2017.1419935

Naragon-Gainey, K., McMahon, T. P., & Chacko, T. P. (2017). The structure of common emotion regulation strategies: A meta-analytic examination. *Psychological Bulletin*, *143*(4), 384–427. https://doi.org/10.1037/bul0000093

Ochsner, K. N., Bunge, S. A., Gross, J. J., & Gabrieli, J. D. E. (2002). Rethinking Feelings: An fMRI Study of the Cognitive Regulation of Emotion. *Journal of Cognitive Neuroscience*, *14*(8), 1215–1229. https://doi.org/10.1162/089892902760807212

Ochsner, K. N., Ray, R. D., Cooper, J. C., Robertson, E. R., Chopra, S., Gabrieli, J. D. E., & Gross, J. J. (2004). For better or for worse: neural systems supporting the cognitive down- and up-regulation of negative emotion. *Neuroimage, 23*, 483–499. https://doi.org/10.1016/j.neuroimage.2004.06.030

Ochsner, K. N., & Gross, J. J. (2005). The cognitive control of emotion. *Trends in Cognitive Sciences*, *9*(5), 242–249. https://doi.org/10.1016/j.tics.2005.03.010

Ochsner, K. N., Silvers, J. A., & Buhle, J. T. (2012). Functional imaging studies of emotion regulation: a synthetic review and evolving model of the cognitive control of emotion. *Annals of the New York Academy of Sciences*, *1251*(1), E1–E24. https://doi.org/10.1111/j.1749-6632.2012.06751.x

Résibois, M., Verduyn, P., Delaveau, P., Rotgé, J. Y., Kuppens, P., Mechelen, I. Van, & Fossati, P. (2017). The neural basis of emotions varies over time: Different regions go with onset- and offset-bound processes underlying emotion intensity. *Social Cognitive and Affective Neuroscience*, *12*(8), 1261–1271. https://doi.org/10.1093/scan/nsx051

Scheibe, S., Sheoppes, G., & Staudinger, U. M. (2015). Distract or Rappraise? Age-Related Differences in Emotion-Regulation Choice. *Emotion*, *15*(1393), 677–681. https://doi.org/10.1037/a0039246

Schirda, B., Valentine, T. R., Aldao, A., & Prakash, R. S. (2016). Age-Related Differences in Emotion Regulation Strategies: Examining the Role of Contextual Factors. *Developmental Psychology, 52*(9), 1370–1380. https://doi.org/10.1037/dev0000194.supp

Schönfelder, S., Kanske, P., Heissler, J., & Wessa, M. (2014). Time course of emotion-related responding during distraction and reappraisal. *Social Cognitive and Affective Neuroscience*, *9*(9), 1310–1319. https://doi.org/10.1093/scan/nst116

Shafir, R., Thiruchselvam, R., Suri, G., Gross, J. J., & Sheppes, G. (2016). Neural processing of emotional-intensity predicts emotion regulation choice. *Social Cognitive and Affective Neuroscience, 11*(12): 1863-1871. https://doi.org/10.1093/scan/nsw114

Sheppes, G., Scheibe, S., Suri, G., & Gross, J. J. (2011). Emotion-regulation choice. *Psychological Science*, *22*(11), 1391–1396. https://doi.org/10.1177/0956797611418350

Sheppes, G., Scheibe, S., Suri, G., Radu, P., Blechert, J., & Gross, J. J. (2014). Emotion regulation choice: A conceptual framework and supporting evidence. *Journal of Experimental Psychology: General*, *143*(1), 163–181. https://doi.org/10.1037/a0030831

Silvers, J. A., & Guassi Moreira, J. F. (2017). Capacity and tendency: A neuroscientific framework for the study of emotion regulation. *Neuroscience Letters*, 693:35-39. https://doi.org/10.1016/j.neulet.2017.09.017

Silvers, J. A., Weber, J., Wager, T. D., & Ochsner, K. N. (2015). Bad and worse: Neural systems underlying reappraisal of high-and low-intensity negative emotions. *Social Cognitive and Affective Neuroscience*, *10*(2), 172–179. https://doi.org/10.1093/scan/nsu043

Suri, G., Sheppes, G., Young, G., Abraham, D., McRae, K., & Gross, J. J. (2018). Emotion regulation choice: the role of environmental affordances. *Cognition and Emotion*, *32*(5), 963–971. https://doi.org/10.1080/02699931.2017.1371003

Suri, G., Whittaker, K., & Gross, J. J. (2015). Launching reappraisal: It's less common than you might think. *Emotion*, *15*(1), 73–77. https://doi.org/10.1037/emo0000011

Uusberg, A., Thiruchselvam, R., & Gross, J. J. (2014). Using distraction to regulate emotion: Insights from EEG theta dynamics. *International Journal of Psychophysiology*, *91*(3), 254–260. https://doi.org/10.1016/j.ijpsycho.2014.01.006

Webb, T. L., Miles, E., & Sheeran, P. (2012). Dealing with feeling: A meta-analysis of the effectiveness of strategies derived from the process model of emotion regulation. *Psychological Bulletin*, *138*(4), 775–808. https://doi.org/10.1037/a0027600

White, R. E., Kross, E., & Duckworth, A. L. (2015). Spontaneous Self-Distancing and Adaptive Self-Reflection Across Adolescence. *Child Development*, *86*(4), 1272–1281. https://doi.org/10.1111/cdev.12370