Regulating Negative Autobiographical Memories: An fMRI Investigation of Reappraisal and Distraction in Middle-aged and Older Adults

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Abstract

■ Cognitive reappraisal and attentional distraction constitute two core strategies for regulating emotions. Prior studies have largely focused on young adults regulating simple laboratory stimuli, with few direct comparisons of brain regions that differentiate or mutually implement these strategies. Here, we expanded the typical age range of participants, compared reappraisal and distraction within participants, and used ecologically valid autobiographical memories as regulatory targets. Sixty-two healthy adults aged 35–75 years generated cue words for negative and neutral autobiographical memories and were trained to either reappraise, distract, or let their emotions flow naturally in response to cued memories. Strategy-specific contrasts were derived from whole-brain fMRI data using univariate analyses. For reappraisal, relative to flow, we observed activity in bilateral occipital cortex, right cerebellum, and cingulate cortex and primarily left-sided frontal, temporal, and parietal cortices. Distraction, relative to flow, engaged bilateral lateral prefrontal, medial parietal, cingulate, occipital, and retrosplenial regions and left cerebellum. Common areas of activation included midline occipital and posterior cingulate cortices. Direct comparisons yielded strategy differences across multiple cortical areas: distraction engaged paralimbic areas (insula and left parahippocampal gyrus), dorsolateral and ventrolateral PFC, and right inferior frontoparietal cortex, whereas reappraisal engaged dorsomedial PFC, left ventrolateral PFC, anterior temporal cortex, and left posterolateral PFC. In-scanner valence ratings verified the efficacy of the experimental manipulation and revealed a negative impact of age on reappraisal success, which was correlated with greater visual cortical processing. These findings extend knowledge regarding the neural mechanisms of emotion regulation across the adult lifespan for autobiographical events. ■

INTRODUCTION

Emotion regulation refers broadly to the ability to modulate one's current emotional state. Emotion regulation is crucial for healthy psychological functioning as it enables individuals to adaptively cope with stress, maintain relationships, and achieve goals (Menefee, Ledoux, & Johnston, 2022). Most commonly, emotion regulation is studied in the context of the down-regulation of negative emotion (Naragon-Gainey, McMahon, & Chacko, 2017). Although multiple models of emotion regulation exist, the most widely used is the process model, in which emotion regulation strategies are delineated based on the stage of emotion generation upon which they act (Gross, 1998, 2015; Sheppes, Suri, & Gross, 2015). According to this model, the temporal unfolding of emotion is broken down into four stages: exposure to an eliciting situation, attention to the situation, appraisal of the situation, and a response. Various physical or cognitive responses may be enacted at each of these stages in the attempt to regulate a final emotional response. Regulation includes the broad categories of situation selection, situation modification, attentional deployment, cognitive change, and response modulation. Two of the most studied regulation categories of this model are attentional deployment and cognitive change. The emotion regulation strategies of distraction and reappraisal are the most commonly researched strategies at each of these stages, respectively.

Distraction is an emotion regulation technique in which attention is intentionally directed away from a negative stimulus to a more positive or neutral topic (Smoski, LaBar, & Steffens, 2014). One meta-analysis of emotion regulation strategies identified distraction as the most effective at regulating negative emotion (Webb, Miles, & Sheeran, 2012). As a less cognitively demanding strategy, distraction may be preferred over other, more complex strategies when regulating high-intensity negative emotions, particularly as one ages (Smoski et al., 2014).

Reappraisal refers to reframing or thinking differently about a stimulus to change its emotional tone (Sheppes et al., 2015). Implemented during the stimulus appraisal

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stage of emotional response formation, reappraisal has been found to reduce subjective, behavioral, and physiological indicators of negative affect (Webb et al., 2012). Reappraisal includes both distancing and reinterpretation tactics. Here, we focus specifically on reinterpretation. Reinterpretation is a relatively complicated form of reappraisal as it requires one to hold a representation of a specific stimulus or event in mind, judge its emotional tone, generate an alternative representation, compare the emotional tone of the reappraisal with that of the original appraisal, and then use executive resources to implement the chosen reappraisal.

Both distraction and reappraisal can be effectively deployed at multiple stages of the emotion-generative process, including after emotional arousal. Denny and Ochsner (2014) emphasize that reappraisal can still attenuate emotional responses even when applied after affect has been elicited, and Sheppes and Gross (2011) similarly demonstrate that distraction remains effective post-induction, supporting its use beyond the anticipatory phase. While some prior paradigms introduce regulation cues before emotional stimuli, study designs that prompt regulation after affect induction capture a complementary aspect of regulation as it often unfolds in everyday life.

Research on emotion regulation choice suggests that individuals tend to prefer distraction over reappraisal when confronted with high-intensity emotional stimuli, whereas reappraisal is more commonly used for lower-intensity emotions (Sheppes, Scheibe, Suri, & Gross, 2011). This pattern reflects the differing cognitive demands of these strategies, with distraction offering a rapid shift of attention away from distressing stimuli and reappraisal requiring effortful cognitive restructuring (Sheppes et al., 2011). Additionally, older adults tend to rely more on distraction than younger adults (Scheibe, Sheppes, & Staudinger, 2015) and are less successful in implementing reappraisal relative to distraction (e.g., Smoski et al., 2014; Tucker, Feuerstein, Mende-Siedlecki, Ochsner, & Stern, 2012), potentially due to age-related shifts in cognitive resources and emotional goals.

Neuroimaging studies of distraction and reinterpretation have typically investigated these processes in the context of viewing images of upsetting stimuli (e.g., the International Affective Picture System [IAPS]). One recent meta-analysis of such studies (consisting of Hermann, Kress, & Stark, 2017; Dörfel et al., 2014; Kanske, Heissler, Schönfelder, Bongers, & Wessa, 2011, p. 2014; McRae et al., 2010) found similar recruitment of the left dorsolateral PFC (dlPFC) for reappraisal and distraction, while the left ventrolateral PFC (vlPFC) and amygdala were more specific to reappraisal (Liu et al., 2022). It should be noted that only a small number of neuroimaging studies have directly compared these regulation types and a diverse set of distraction tasks were employed, including rehearsing nine-digit numbers (Dörfel et al., 2014), remembering six-letter strings (McRae et al., 2010), mental arithmetic (Kanske et al., 2011), and thinking about a neutral situation that occurred before the scanning session (Hermann et al., 2017). Another study also found distraction-related activation in the dlPFC when visualizing something unrelated to the negative stimulus (Moodie et al., 2020), further suggesting a domain-general role for the dlPFC in facilitating distraction across various task types. Regarding reappraisal, other meta-analyses have also identified consistent activation in vlPFC, posterior dlPFC/premotor cortex, and angular gyrus (Denny et al., 2023; Messina, Bianco, Sambin, & Viviani, 2015). Indeed, excitatory TMS applied to the right vlPFC has been shown to improve reinterpretation efficacy toward negative images by enhancing vlPFC/ventromedial PFC (vmPFC) activity and attenuating amygdala and insula activity (He et al., 2023).

While studies of distraction and reinterpretation in the context of upsetting images have provided important insights into the neural mechanisms of these strategies, the application of these strategies to more personally meaningful emotional content remains less explored. One example of stimuli that elicit such personal content is negative emotional autobiographical memories (AMs; Denkova, Dolcos, & Dolcos, 2015). AMs evoke the emotions and emotion goals associated with recollected life experiences that, in turn, potentially impact reconsolidation processes (Holland & Kensinger, 2010). Because AMs are inherently self-referential and tied to personal identity, their regulation may engage additional cognitive and affective processes distinct from those involved in regulating responses to standardized emotional stimuli. Investigating emotion regulation strategy implementation in response to distressing AMs can enhance the ecological validity and clinical translation of neuroimaging studies of emotion regulation.

Compared with laboratory-based stimuli, the regulation of AMs may recruit additional neural mechanisms related to memory reconstruction, self-referential processing, and affective meaning-making—particularly for reappraisal. Reappraisal of negative AMs has been linked to heightened activity in cognitive control regions across the PFC compared with maintaining emotional responses, with activations in dlPFC, vlPFC, and medial PFC hypothesized to relate to demands on working memory, retrieval processes, and self-referential processing/assigning affective value, respectively (Holland & Kensinger, 2013). In a partial corroboration of these findings, TMS of the dlPFC partially modulated reappraisal efficacy in one study (Doerig et al., 2021) and enhanced indices of reappraisal of negative AMs in others (Neacsiu, Beynel, Graner, et al., 2022; Neacsiu, Beynel, Powers, et al., 2022). Regarding distraction, some work has indicated that shifting attention away from the emotional elements of AMs and instead focusing on nonemotional contextual details is associated with increased activity in the vmPFC (Denkova et al., 2015), although later work also showed increased dlPFC, parahippocampal cortex, and angular gyrus activity (Iordan, Dolcos, & Dolcos, 2019).

Despite these findings, the precise neural mechanisms by which emotional responses are modified through different regulation strategies remain unclear, particularly in terms of how the engagement of prefrontal control regions might differ between distraction and reinterpretation. Many previous studies of distraction and reinterpretation are limited by the use of laboratory stimuli that lack personal relevance, and studies that have used AMs typically included small samples of younger adults (Liu et al., 2022). To address these gaps, the current study examined the neural correlates of reappraisal and distraction in an ecologically valid context by using negative AMs as stimuli and recruiting a broader age range of participants (35–75 years old). We also operationalized distraction as a turn toward positive thoughts (rather than a rote mental exercise). This was done to provide a more naturalistic representation of how individuals engage this strategy in daily life and to make the implementation more clinically relevant (Smoski et al., 2014). It also avoided distraction by numeric memorization or arithmetic calculations that may especially tax frontal lobe resources in older adults.

Our first hypothesis was that the mental processes of reappraisal and distraction would be represented in partially distinct, distributed brain networks. Because reappraisal requires top–down, volitional control of a negative memory, we hypothesized it would generally recruit regions within the frontoparietal control network, which collectively support goal-oriented cognition by monitoring and manipulating information in working memory (Vincent, Kahn, Snyder, Raichle, & Buckner, 2008). Relative to distraction, we hypothesized the vlPFC to be more engaged during reappraisal, given its specialized functional role in emotion evaluation (Zhao et al., 2021) and mnemonic control (Badre & Wagner, 2007). There is also evidence for the involvement of this region during reappraisal/reinterpretation tasks (Denny et al., 2023; Liu et al., 2022). We hypothesized that reappraisal down-regulates emotional response via a vlPFC–amygdala pathway that passes through the vmPFC, and therefore, the vmPFC would also be preferentially recruited during reappraisal as part of a broader ventral affective network (Silvers et al., 2017).

For distraction, we hypothesized that orienting attention away from a negative stimulus and toward more positive thoughts would also broadly recruit frontoparietal control regions. However, relative to reappraisal, we expected distraction to place stronger demands on the dlPFC. This region guides top–down attentional processing via the dorsal ACC (dACC; Silton et al., 2010; Weissman, Gopalakrishnan, Hazlett, & Woldorff, 2005) and is often coupled with regions of the dorsal attention network (Spreng, Sepulcre, Turner, Stevens, & Schacter, 2013), which supports both external and internal shifts in attention (Lückmann, Jacobs, & Sack, 2014). The dlPFC is therefore well situated to coordinate an attentional shift away from a negative AM and toward a different, positive memory. Indeed, causal evidence has supported a functional specificity whereby stimulating the dlPFC and vlPFC specifically improves the effects of distraction and reappraisal, respectively (Zhao et al., 2021).

In summary, we hypothesized that both reappraisal and distraction would recruit prefrontal and posterior parietal regions that comprise the executive control network in service of goal-oriented regulation demands. When contrasted, we expected reappraisal to place greater demands on a ventral affective network consisting of the vlPFC and vmPFC, whereas distraction would preferentially activate a more dorsal system composed of the dlPFC, dACC, and other regions of the dorsal attention network (e.g., superior parietal lobule). To test these hypotheses, we created whole-brain activation contrast maps, across all participants, for each regulation strategy compared with an unguided "flow" condition and also directly compared the two regulation strategies against one another.

Second, we hypothesized that age, trait regulation use, and regulation success would modulate individuals' brain activation during regulation. Prior work has shown that older adults recruit prefrontal mechanisms to a greater degree than younger adults when recalling and regulating negative memories (Ford & Kensinger, 2017, 2019; Ford, Morris, & Kensinger, 2014). Moreover, individual differences in trait regulation use across ages have been found to be predictive of both neural connectivity at rest (Vitolo, Diano, Giromini, & Zennaro, 2022) and prefrontal activation when disengaging from negative content (Vanderhasselt, Baeken, Van Schuerbeek, Luypaert, & De Raedt, 2013). We tested this aim with a multiple regression analysis of these individual metrics against activation contrast maps for the whole participant group, including age, the habitual use of reappraisal and distraction, and average online ratings of strategy efficacy in regulating negative affect during the task.

As exploratory analyses, we also ran versions of these regression models including the interaction between habitual regulation use and regulation efficacy. Little is known about how neural engagement is influenced by interactions between individual differences in habitual strategy use and online regulation success. We hypothesized that individuals reporting more routine regulation use would need to recruit fewer neural resources to achieve regulation success. That is, greater reported regulation use would correspond to a decrease in the relationship between regulation success and neural activation contrast, specifically in vlPFC and dlPFC. We note that this is an exploratory analysis, as our original study was not designed to statistically power it. Results thus require confirmation from future work.

Third, we hypothesized that age would have a selective impact on reappraisal, given prior reports that older adults may find reappraisal more effortful or less effective than other regulation strategies (Martins, Florjanczyk, Jackson, Gatz, & Mather, 2018). In addition to general age-related differences in neural engagement during emotion regulation, we expected older adults to specifically report benefitting more from distraction use than reappraisal use.

METHODS

Participants

The work described here is a subset of a preregistered clinical trial investigating neurobehavioral mechanisms of emotion regulation in aging and depression (NCT03207503 at https://clinicaltrials.gov). Participants completed a battery of questionnaires, including the Response Styles Questionnaire (RSQ; Nolen-Hoeksema & Morrow, 1991) and the Emotion Regulation Questionnaire (ERQ; Gross & John, 2003); assessments of executive function; assessment of affective attentional bias to emotionally valenced pictures; and fMRI during AM recall and emotion regulation. Here, we present analysis results from the fMRI data, incorporating RSQ, ERQ, and age as covariates. While the full study participant group included participants diagnosed with major depressive disorder, the analyses described here include only results from the affectively healthy sample.

We recruited English-speaking participants from the community in Durham, North Carolina, by flyers, online advertisements, and recruitment messages through medical center communications between 2017 and 2022. Inclusion criteria were as follows: age of 35–75 years; no MRI contraindications; no known neurological conditions or history of stroke; stable (or no) use of antidepressants or other psychotropics over the past 4 weeks; no known uncorrected sensory deficits; an estimated verbal IQ greater than 85 (assessed with the National Adult Reading Test; Nelson, 1982); and no indication of dementia or mild cognitive impairment, as indicated by neuropsychological screening. The Montreal Cognitive Assessment (MoCA; Nasreddine et al., 2005), Hopkins Verbal Learning Test-Revised (HVLT-R; Brandt & Benedict, 2001), Trail Making Test (Reitan, 1992), and 1-min Animal Naming (Lezak, Howieson, & Loring, 2004) measures were used to screen out individuals who may have prodromal dementia. We used the following thresholds for participation in the study: MoCA score of 24 or above; HVLT-R, Trail Making, and Animal Naming scores of no more than 1.5 *SD* below the mean of age-corrected normative values (Heaton, Miller, Taylor, & Grant, 2004; Brandt & Benedict, 2001). Participants in the healthy control group needed to have no past or present Axis I psychopathology and a Beck Depression Inventory – II score of 8 or lower at initial screening.

After initial screening, 77 healthy control participants remained in the study. Of these, 64 completed the questionnaires and MRI session. Finally, imaging data from two participants were excluded due to excessive head motion in the scanner, leaving a final sample size of 62 (see Table 1 for demographics and Supplement 1 for detailed age distribution). All participants provided written informed consent in accordance with the Duke University Health System institutional review board and were monetarily compensated for their time ($65 for interview/assessments/questionnaires and $75 for the MRI session).

Table 1. Group Demographics

Age, years, mean (*SEM*)	55.6 (*1.5*)
Sex, *n*	
Male	26
Female	36
Ethnicity, *n*	
Hispanic or Latino	3
Not Hispanic or Latino	58
Prefer not to answer	1
Racial background, *n*	
White	51
Black	5
Native Hawaiian or Pacific Islander	1
Asian	1
More than one racial group	4

Justification of Sample Size

The initial sample size for the study was set based on the primary aims of the parent clinical trial, and justification for the trial sample size is reported in the clinical trial preregistration documentation (see NCT03207503 at https://clinicaltrials.gov). For the purposes of the present fMRI analyses in the healthy portion of the sample, previously published fMRI studies comparing reappraisal and distraction with univariate analyses have detected significantly meaningful results with sample sizes ranging from n = 18 (Sarkheil, Klasen, Schneider, Goebel, & Mathiak, 2019; McRae et al., 2010) to n = 26 (Hermann et al., 2017) to n = 30 (Kanske et al., 2011). Dörfel and colleagues (2014) used a between-group design with group sizes ranging from n = 16 to n = 22. Therefore, our sample size of n = 62 is more than double the sample sizes of prior studies conducting similar comparisons. In addition, we wanted to investigate age as a covariate of interest, given the broad age range in the present study. A G*Power 3.1 estimate of power needed to reveal a significant effect of a single regression coefficient in a linear multiple regression model is n = 55 (two-tailed test, medium effect size, alpha = .05, power = .8). Based on this evidence, we believe our sample size of n = 62 is sufficient to power our main analyses of interest.

Emotion Regulation Routine Use Measures

Participants completed several self-report measures in an online session before the imaging session, including the

RSQ and ERQ. We used the reappraisal subscale of the ERQ (ERQ_{reap}) to assess routine or trait use of reappraisal and the distraction subscale of the RSQ (RSQ_{dist}) to assess routine or trait use of distraction.

Emotion Regulation Task

During fMRI, participants performed a task in which they applied two forms of emotion regulation (distraction, reappraisal) and unguided thought (flow) to cued AMs in a counterbalanced order across the three strategies. Before the scan day, participants provided cue words and descriptions for 10 negative and four neutral AMs. Instructions for listing the negative memories were "Please briefly describe a negative experience you have had. The experience could have occurred recently or in the past. Please list your most intense negative experiences." Instructions for listing the neutral memories were "Please briefly describe a neutral experience you have had. The experience could have occurred recently or in the past." We instructed participants to use memories from the past 15 years, but not older. Cue words consisted of one or two unique words for each memory that would allow the participant to recall each memory upon seeing the associated cue during the functional task. Descriptions consisted of one or more sentences and were only used for memory review during pre-scan training.

Immediately before entering the MR scanner, study personnel trained participants on the emotion regulation task. This training consisted of an introduction to and practice with distraction, reappraisal, and flow. The complete training text for all three strategies is included in Supplement 2; here, we present the key guiding description of each. For distraction, participants were instructed to "Turn [their] thoughts to something pleasant that is unrelated to whatever is causing your negative emotion." For reappraisal, participants were instructed to "Reinterpret the memory in some way to reduce its emotional tone." For the flow condition, participants were instructed to "focus on the specific feelings that naturally flow through [their] mind as [they] think about the memory." Participants practiced these three processes on two of three generic memory prompt phrases ("Death of a Pet," "Memories of the 9/11 Attack," "Argument with a Friend or Co-Worker"). The specific phrases used for each participant were chosen so as not to overlap in content with the memories they provided. Study personnel confirmed participant understanding of the three strategies via dialogue during training, verifying that the participant was implementing each strategy as intended. Following regulation strategy training, participants were introduced to the specifics of how the task would be implemented in the MRI scanner.

The emotion regulation task was presented over the course of four functional imaging runs, each containing four blocks of stimulus trials. Each block contained two or three trials, with each trial consisting of the following: active baseline arrow task (9 sec), memory cue presentation (5 sec), strategy cue presentation (10 sec), valence self-report (5 sec), and arousal self-report (5 sec; see Figure 1). During the active baseline task, participants were presented with three arrows, one at a time. Each arrow pointed either left or right, and participants had 3 sec to press a button to indicate in which direction the arrow was pointing. Memory and strategy cue presentations consisted of a memory cue prompt and then a display of either "DISTRACT," "REAPPRAISE," or "FLOW". We instructed participants to only recall the cued memory during the 5-sec memory cue presentation without applying any of the trained strategies. For the valence and arousal self-reports, participants responded via button press to two Likert scales: "On a scale of 1 to 4, how positive or negative do you feel?" and "On a scale of 1 to 4, how excited or calm do you feel?", respectively. Response options included 1 = *very negative*, 2 = *somewhat negative*, 3 = *somewhat positive*, 4 = *very positive*, and 1 = *very excited*, 2 = *somewhat excited*, 3 = *somewhat calm*, 4 = *very calm*, respectively. Each trial was followed by an intertrial interval of 8 sec (average; jittered between 6 and 10 sec), during which a fixation cross was displayed in the center of the screen.

All the trials within a block used the same strategy cue. The neutral memory blocks were always three trials long

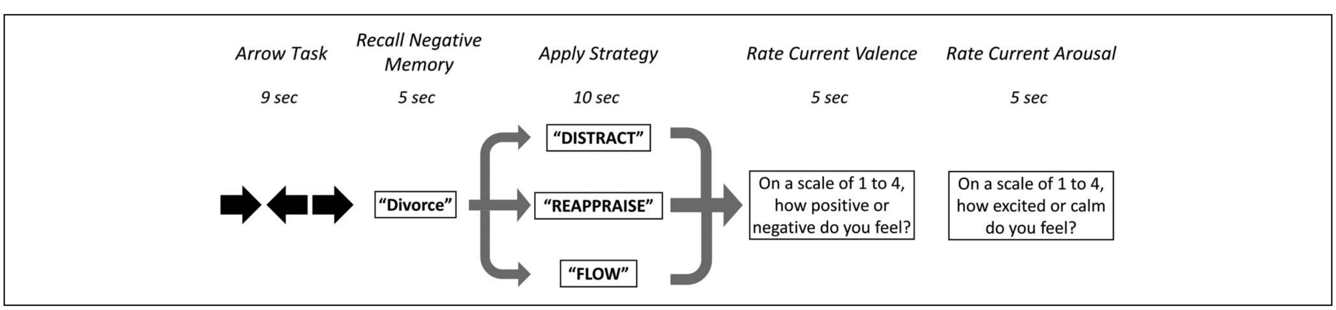

Figure 1. Each trial of the emotion regulation task consisted of button responses to presented arrows, negative memory recall, application of one of three "strategies" (attentional distraction, memory reappraisal, or a "flow" condition), and self-report of current valence and arousal. Neutral memory recall was followed by "flow" only.

and always used the "FLOW" strategy cue. Each run contained one of each type of block (negative-distract, negative-reappraise, negative-flow, and neutral-flow), randomly ordered. Each of the 10 negative memories was paired once with each of the three strategies, for a total of 30 negative memory trials and 12 neutral memory trials. The functional task runs took a total of 31 min.

MRI Acquisition Parameters

Part-way through data collection, the MR scanner used for this study underwent a significant hardware upgrade. This upgrade allowed for the acquisition of higher-resolution EPI data. Given that the upgrade happened relatively early in the data collection phase of the study, the decision was made to change the acquisition parameters of the functional images to take advantage of the new hardware. Of the 62 participants with usable fMRI data, 24 were scanned before the hardware upgrade. Previous work has shown that between-participant variance in BOLD signal is significantly greater than between-scanner variance for working memory tasks (Forsyth et al., 2014; Brown et al., 2011) as well as emotion processing (Gee et al., 2015). However, to account for any bias in activation contrasts due to scanner hardware condition and acquisition parameter set, two scanner-related explanatory variables (EVs), one representing having been scanned pre-upgrade and one representing having been scanned post-upgrade, were included in the general linear model (GLM) analyses examining individual participant differences across the population.

Before the upgrade, MR imaging was performed on a GE Medical Systems Discovery MR750 scanner. Acquisition began with a basic three-plane localizer, followed by a high-resolution T1-weighted image (FSPGR BRAVO sequence, acquisition matrix = 256 × 256, repetition time = 8.16 msec, echo time = 3.18 msec, field of view = 256 mm^2, in-plane voxel size = 1.0 × 1.0 mm, slice thickness = 1.0 mm, spacing between slices = 0 mm, 162 axial slices). After an ASSET calibration scan, four spiral EPI functional images were acquired, one for each task run (acquisition matrix = 64 × 64, repetition time = 2000 msec, echo time = 30 msec, field of view = 240 mm^2, in-plane voxel size = 3.75 × 3.75 mm, slice thickness = 3.8 mm, spacing between slices = 0 mm, 37 AC–PC-aligned slices). Runs 1 and 3 of the functional task had 240 volumes each, while Runs 2 and 4 had 219 volumes each.

After the upgrade, the scanner was upgraded to a GE Medical Systems Signa MR360. This upgrade allowed use of multiband acquisition for the functional images, increasing spatial resolution while maintaining the repetition time. Post-upgrade, high-resolution T1-weighted images were acquired using an MPRAGE sequence (acquisition matrix = 256 × 256, repetition time = 2297.27 msec, echo time = 3.2 msec, field of view = 256 mm^2, in-plane voxel size = 1.0 × 1.0 mm, slice thickness = 1.0 mm, spacing between slices = 0 mm, 162 axial slices). The functional images were collected using an echo-planar gradient-recall acquisition (acquisition matrix = 128 × 128, repetition time = 2000 msec, echo time = 30 msec, field of view = 256 mm^2, in-plane voxel size = 2.0 × 2.0 mm, slice thickness = 2.0 mm, spacing between slices = 0 mm, 68 AC–PC-aligned slices, multiband factor = 3, in-plane acceleration factor = 2). Runs 1 and 3 of the functional task comprised 240 volumes each, while Runs 2 and 4 comprised 219 volumes each.

MR Data Preprocessing

Both functional and anatomical MR data were reconstructed as DICOMs and converted to NIFTI image files. These were then put into the Brain Image Data Structure format, along with functional task event information extracted from the task script output. We used fMRIPrep (v1.5.0; Esteban et al., 2019) for initial preprocessing of the imaging data. A full description of this processing is included in Supplement 5. However, we also include a summary here. For the T1-weighted images, processing included the following: N4 bias correction, skull stripping, registration to a standard template space (MNI ICBM 152 nonlinear 6th Generation Asymmetric Average Brain Stereotaxic Registration Model, MNI152NLin6Asym, 2.0 × 2.0 × 2.0 mm voxels). For the functional images, preprocessing included the following: slice-time correction, skull stripping, motion parameter estimation, registration to the standard template space, automatic removal of motion artifacts using independent component analysis (nonaggressive ICA-AROMA; Pruim et al., 2015). Time points of the functional data identified as motion outliers by fMRIPrep were excluded from analysis via creation of a censoring model regressor (see below). After initial preprocessing with fMRIPrep, functional images also underwent the following: removal of the first four time points (8 sec) to exclude non-steady-state data, application of the brain mask created by fMRIPrep to exclude non-brain voxels from analysis, and high-pass temporal filtering (100 sec cutoff).

MR Data Analysis

We performed analysis of functional task data in three levels: run, participant, and group. First, we generated activation and contrast maps for each run (first level). These results where then combined for each participant (second level). Finally, the result for each participant was entered into group analyses (third level).

First-level analysis used a GLM in FMRIB software library (FSL; v6.0.4; Woolrich, Behrens, Beckmann, Jenkinson, & Smith, 2004; Woolrich, Ripley, Brady, & Smith, 2001). The following task conditions were included in the GLM as boxcar functions convolved with a double-gamma variate hemodynamic response function (HRF): arrow task, negative memory cue presentations, neutral memory cue presentations, reappraise cue presentations, distract cue presentations, flow cue presentations following negative memory cues, flow cue presentations following neutral memory cues, and ratings presentations. We also included several regressors associated with potential sources of noise in the GLM (not convolved with the HRF): average cerebral spinal fluid time course, derivative of root-mean-square variance over voxels (DVARS; Power, Barnes, Snyder, Schlaggar, & Petersen, 2012), and frame-wise displacement (FD; Power et al., 2012). Binary time point censoring regressors were also included to remove the influence of high-motion volumes from the GLM output. Each of these regressors had a value of 1 for the time point it was meant to censor and values of 0 for all other time points. Time points were chosen for censoring using the fMRIPrep default settings (FD > 0.5 mm or DVARS > 1.5).

The goal of the activation contrasts was to capture differences between the mental processes of reappraisal, distraction, and flow in response to negative memories. We created contrasts between the presentation of the three types of strategy cues following negative memories at the first level of analysis and carried these through to each subsequent level: Reappraisal > Flow, Distraction > Flow, Reappraisal > Distraction, and their inverses. Higher-level analysis was carried out using FSL's FLAME (FMRIB's Local Analysis of Mixed Effects) Stage 1 (Woolrich, 2008; Woolrich et al., 2004; Beckmann, Jenkinson, & Smith, 2003) with outlier de-weighting. Significant voxel clusters were identified for all third-level analyses by first applying a voxel-wise z-score threshold of 3.1 and then retaining only clusters with an alpha of <.05, using family-wise error correction to adjust for multiple comparisons. A simple conjunction analysis was also carried out between the Reappraisal > Flow and Distraction > Flow contrast maps to show overlapping regions of activation between the two conditions. This analysis was done by first binarizing each group-level corrected map and then multiplying the two binarized maps on a voxel-wise basis. Several demographic and behavioral covariates were included in group-level analyses. We mean-centered each covariate before it was entered into the analysis model as a regressor.

In addition, two models were run to investigate the ability of age, reported routine use of reappraisal or distraction, and reappraisal or distraction success to predict brain activation. Routine distraction use was operationalized as the sum of the distraction items from the RSQ. Similarly, routine reappraisal use was operationalized as the sum of the reappraisal items on the ERQ. Reappraisal success and distraction success were defined as the differences between reported valence following each regulation technique and reported valence following flow of negative memories, averaged across all trials within each participant. Scanner hardware status was also included in these models via two binary EVs (pre-upgrade, post-upgrade) to account for any bias when looking across participants. Specifically, the following two models were run with the whole-brain activation contrast maps to test our second hypothesis:

$$\begin{aligned} REAP > FLOW = {} & B_1 ScannerPre + B_2 ScannerPost \\ & + B_3 Age + B_4 ERQ_{reap} + B_5 ReapSucc \\ & + \epsilon \end{aligned}$$

$$\begin{aligned} DIST > FLOW = {} & B_1 ScannerPre + B_2 ScannerPost \\ & + B_3 Age + B_4 RSQ_{dist} + B_5 DistSucc + \epsilon \end{aligned}$$

These initial models each produced five whole-brain maps of beta weights. All results were corrected for multiple comparisons using the methods described above.

To test our exploratory hypothesis that routine regulation use and regulation success would interact when predicting neural activation, we added interaction terms to the previous models:

$$\begin{aligned} REAP > FLOW = {} & B_1 ScannerPre + B_2 ScannerPost \\ & + B_3 Age + B_4 ERQ_{reap} + B_5 ReapSucc \\ & + B_6 ReapSucc^{*} ERQ_{reap} + \epsilon \end{aligned}$$

$$\begin{aligned} DIST > FLOW = {} & B_1 ScannerPre + B_2 ScannerPost \\ & + B_3 Age + B_4 RSQ_{dist} + B_5 DistSucc \\ & + B_6 DistSucc^{*} RSQ_{dist} + \epsilon \end{aligned}$$

In brain regions where the interaction term (B_6) of either model was significant, cluster average values were extracted and visualized to verify the direction of the interaction effect.

Regression of Behavioral Variables against Age

We carried out repeated-measures GLMs of the regulation success and reported regulation use variables against age in SPSS. Regulation type was treated as the within-participant variable. The main effect of age as well as the interaction between age and regulation type were used to predict regulation success in one model and regulation use in another. Resulting p values were Holm-corrected for multiple comparisons.

Data Exclusion

We excluded functional imaging runs with more than 20% of time points marked to be censored from participant-wise analysis. Participants with two or more runs marked to be excluded were excluded from group analyses. This procedure resulted in data from two participants being excluded from group analyses due to excessive motion, leaving a final sample size of $n = 62$. One participant in the final sample had one run excluded due to motion but was still included in the group analyses. Two other participants in the final sample only had three of four runs collected due to time constraints during the MRI session but were still included in group analyses. One participant did not have responses for the ERQ and was therefore excluded from the analyses involving this metric.

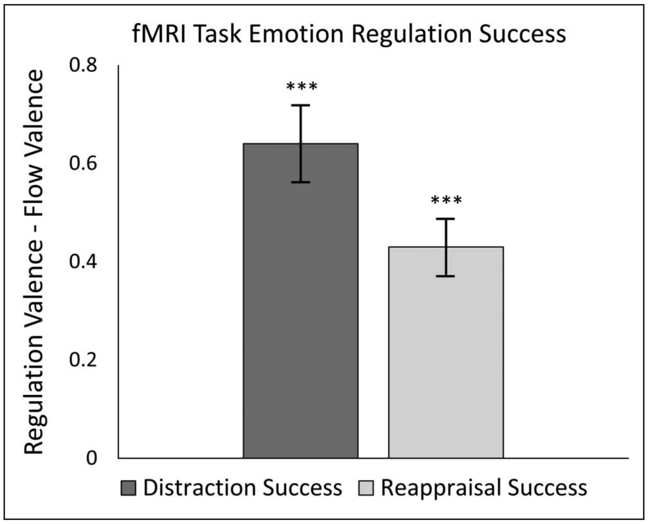

Figure 2. Both distraction from and reappraisal of negative AMs led to significant increases in reported valence relative to unguided thought (flow). Distraction and reappraisal success for each participant are defined here as the average reported valence following the associated regulation strategy minus the average reported valence following the FLOW prompt. *** indicates difference from 0 at $p < .001$.

RESULTS

Emotion Regulation Success during fMRI and Reported Regulation Use

We created metrics of emotion regulation success during the fMRI task for each participant by subtracting the average reported valence following flow trials (following negative emotional memories) from the average reported valence following distraction trials or reappraisal trials. Both distraction success and reappraisal success were significantly greater than zero (both $p < .001$ by t test), suggesting these regulation techniques did, on average, increase participants' perceived emotional valence compared with uninstructed regulation (see Figure 2). Descriptors of the regulation success and typical use metric distributions are shown in Table 2.

Relationships between Age, Regulation Success, and Reported Regulation Use

The repeated-measures GLM regressions predicting regulation success and regulation use did not have significant interaction terms (Age × Regulation Type), suggesting Regulation Type (distraction or reappraisal) did not significantly influence the relationships between either regulation success or reported regulation use and age. Model parameter estimates of the main effect of Age within each regulation type did, however, show significant negative correlations between age and both reappraisal success and reappraisal use (Holm-corrected $p = .02$ and $p = .03$, respectively; Figure 3). Correlations between age and both distraction success and distraction use were nonsignificant in the models. There was no significant correlation between ERQ_{reap} and reappraisal success ($p = .5$). Linear regressions also revealed no significant correlations between the distraction covariates (RSQ_{dist} and distraction success).

Table 2. Behavioral Covariates

	Mean	*SEM*	*Min*	*Max*
Age	55.6	1.5	35	74
ERQ_{reap}	26.9	0.75	6	36
RSQ_{dist}	12.3	0.47	6	20
Distraction success	0.64	0.076	−0.30	2.10
Reappraisal success	0.43	0.057	0.40	1.5

BOLD Signal during Distraction Relative to Flow

The voxel-wise whole-brain analysis comparing activation during distraction to activation during the flow condition revealed several regions of greater distraction-related activation throughout the brain (see Figure 4 and Supplemental Table S1). These included regions of the frontal lobe (dlPFC, anterior dorsomedial PFC [dmPFC], precentral gyrus, OFC), parietal lobe, temporal lobe (middle temporal gyrus, TPJ), midline cortices (ACC, posterior cingulate cortex [PCC], and precuneus), occipital cortex, cerebellum, and insula.

BOLD Signal during Reappraisal Relative to Flow

Similar to the whole-brain BOLD contrast results for distraction, those for the Reappraisal > Flow contrast showed greater reappraisal-related activation in regions distributed throughout the brain (see Figure 4 and Supplemental Table S2). These included regions of the frontal lobe (dlPFC, vlPFC, dmPFC), parietal lobe (angular gyrus), temporal lobe (middle temporal gyrus, superior temporal gyrus), midline cortices (ACC, PCC), occipital lobe, cerebellar vermis, and hippocampus.

BOLD Signal Contrasts between Distraction and Reappraisal

The current study design allowed a direct contrast between distraction and reappraisal within participants. The whole-brain results for the Distraction > Reappraisal contrast and the Reappraisal > Distraction contrast are shown in Figure 5 and Supplemental Tables S3 and S4. Regions where activation during distraction was greater than reappraisal included regions in the frontal lobe (clusters in dlPFC, vlPFC, OFC, some overlap with vlPFC), temporal lobe (parahippocampal gyrus, posterior temporal lobe, TPJ), posterior parietal lobe, ACC, cerebellar crus I, and insula. Regions where activation during reappraisal was greater than distraction included regions of the frontal lobe (clusters in dlPFC, dmPFC, left vlPFC, precentral gyrus), temporal lobe (anterior temporal lobe, mid-temporal lobe),

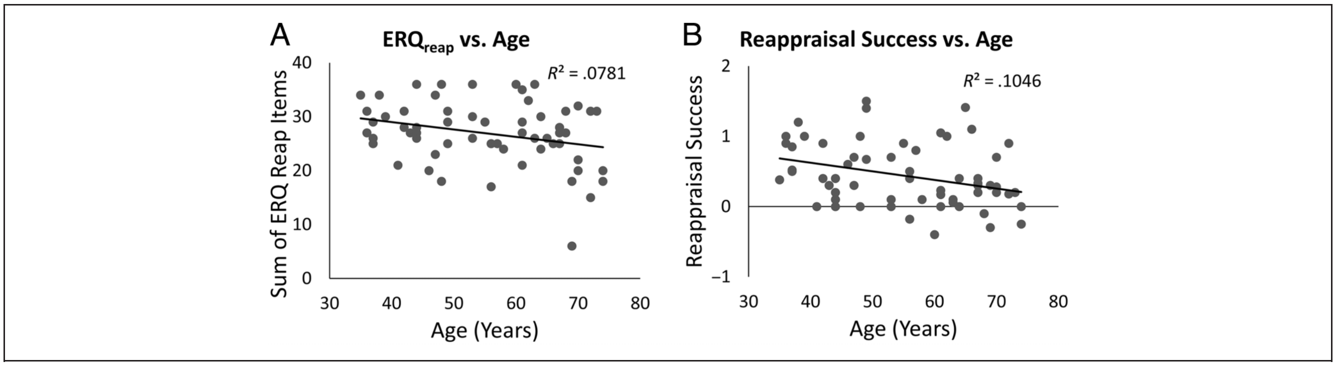

Figure 3. ERQ$_{reap}$ (A) and reappraisal success (B) were both negatively correlated with age. These results suggest that older participants routinely used reappraisal less often in everyday life and in-the-moment reappraisal during fMRI scanning was less effective for older participants.

parietal lobe (angular gyrus), occipital lobe (occipital pole, lateral occipital cortex), PCC, and cerebellar crus I.

Canonical Network Correspondence of Distraction and Reappraisal Maps

Given the widespread nature of both the Distraction > Flow map and the Reappraisal > Flow map, we tested the correspondence of each of these maps with 17 cortical networks identified from intrinsic functional connectivity at rest (Thomas Yeo et al., 2011) using the *cbig_network_toolbox* (Kong et al., 2025). Briefly, this toolbox calculates overlap statistics (Dice scores and associated p values) between input whole-brain maps and specified atlas network masks. This network correspondence analysis showed that distraction was predominantly linked with dorsal attention network A (p = .024), visual network B (p = .022), and control network C (p = .026). In contrast, the reappraisal activation map corresponded with default network B (p = .002), otherwise referred to as the dmPFC subsystem of the default network (Andrews-Hanna, Reidler, Sepulcre, Poulin, & Buckner, 2010) and visual network A (p = .004), which

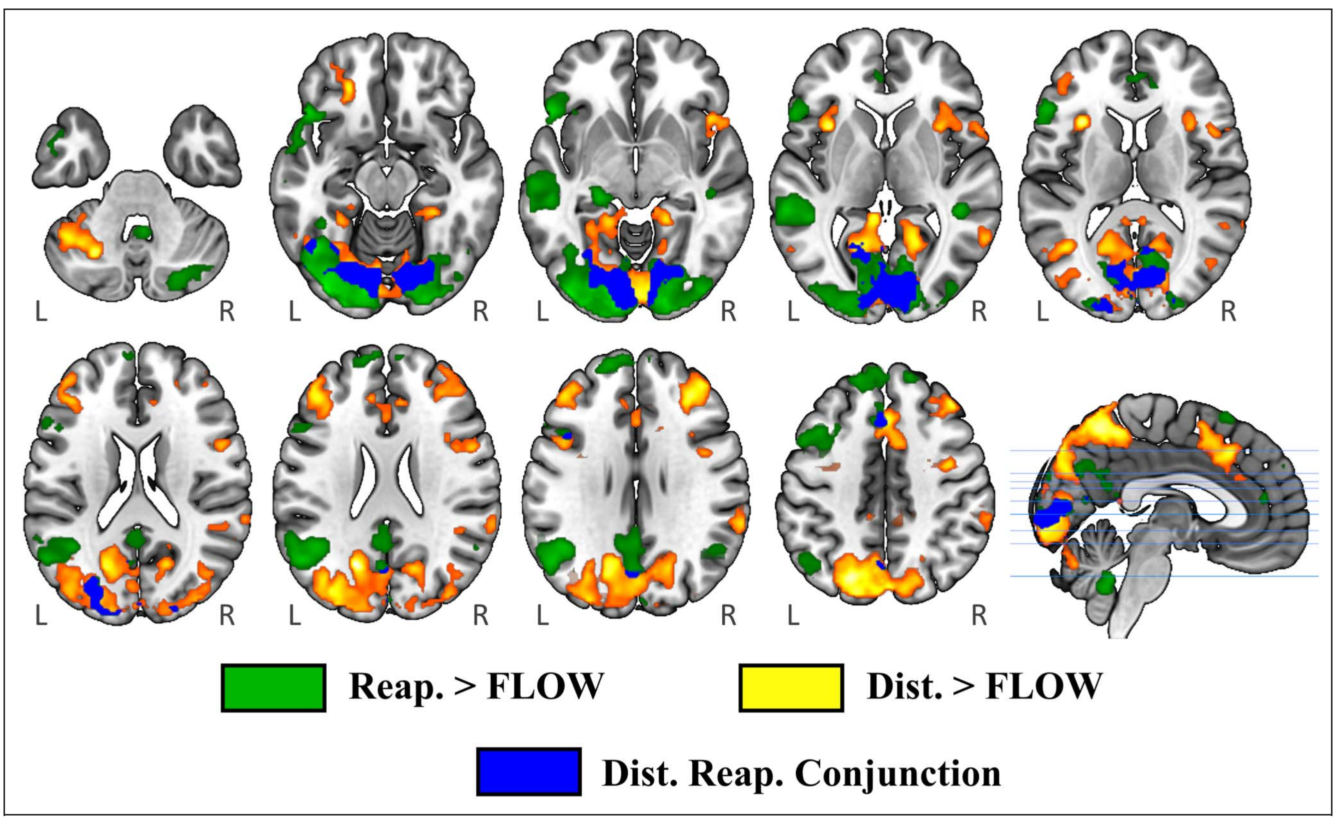

Figure 4. Both reappraisal (green) and distraction (yellow) exhibited increased neural activation across wide-spread brain networks relative to the flow condition. These regulation processes also showed a large overlapping area of activation (blue) in occipital cortex and several smaller areas in frontal and midline regions. Region coordinates are reported in Supplemental Tables S1, S2, and S5. Dist. = distraction; L = left hemisphere; R = right hemisphere; Reap. = reappraisal.

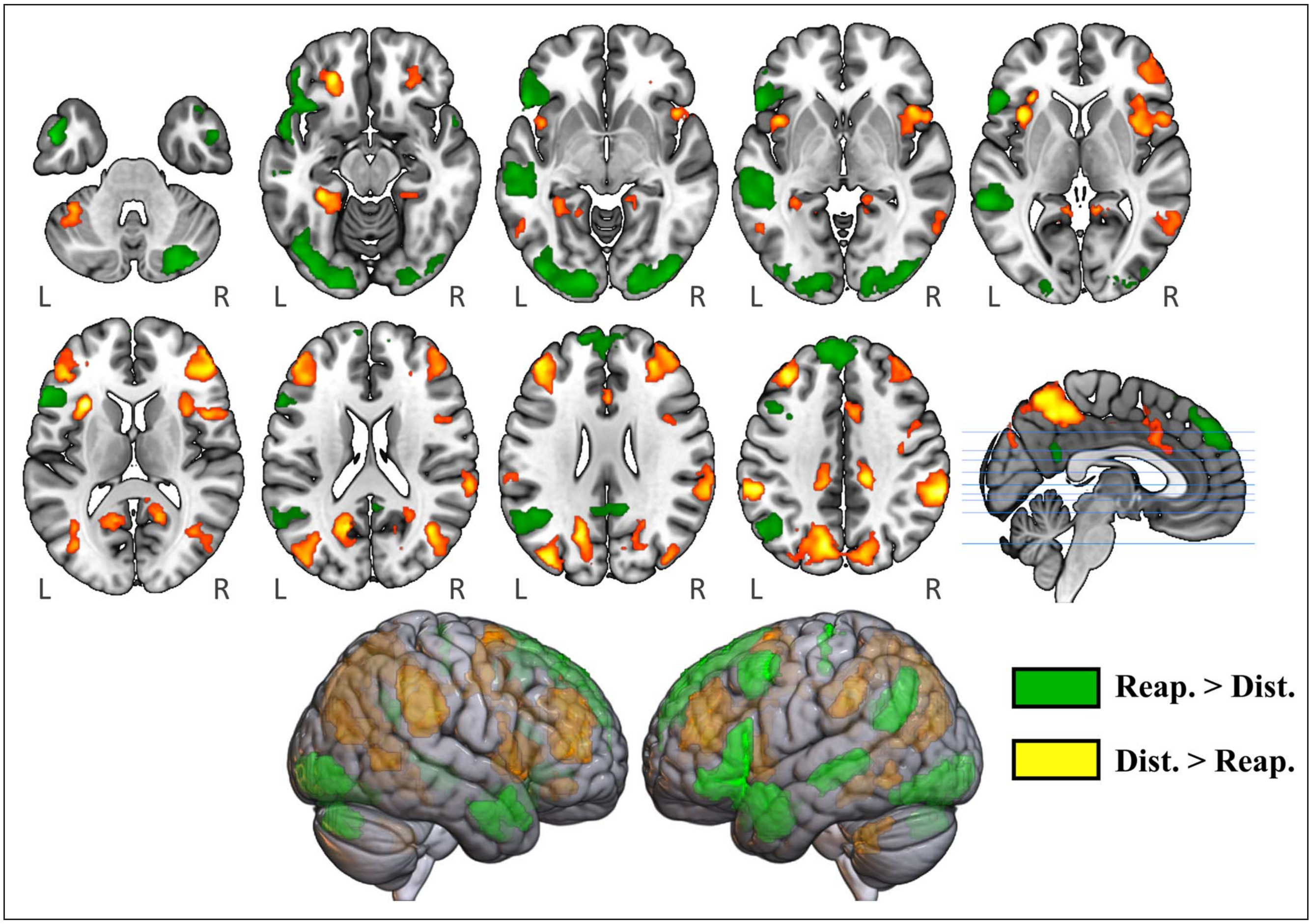

Figure 5. Whole-brain maps of direct contrasts between reappraisal of and distraction from negative AMs. Our study design allowed within-participant contrasts between these regulation methods. The contrasts show each method elicited activation in a wide network of brain regions distinct from the other. Region coordinates are reported in Supplemental Tables S3 and S4. Dist. = distraction; L = left hemisphere; R = right hemisphere; Reap. = reappraisal.

includes the primary visual cortex (network overlap shown in Supplemental Figures S2 and S3 in Supplement 4).

BOLD Signal Conjunction between Distraction and Reappraisal

Large posterior clusters and several smaller clusters in frontal and midline cortices appeared in the conjunction analysis between Distraction > Flow and Reappraisal > Flow (Figure 4, Supplemental Table S5). These include regions in the frontal lobe (posterior dlPFC, precentral gyrus), temporal lobe (lingual gyrus, fusiform gyrus, inferior temporal gyrus), midline cortices (paracingulate gyrus, precuneus, intracalcarine cortex), occipital regions (occipital pole, superior lateral occipital cortex), and cerebellar right crus I.

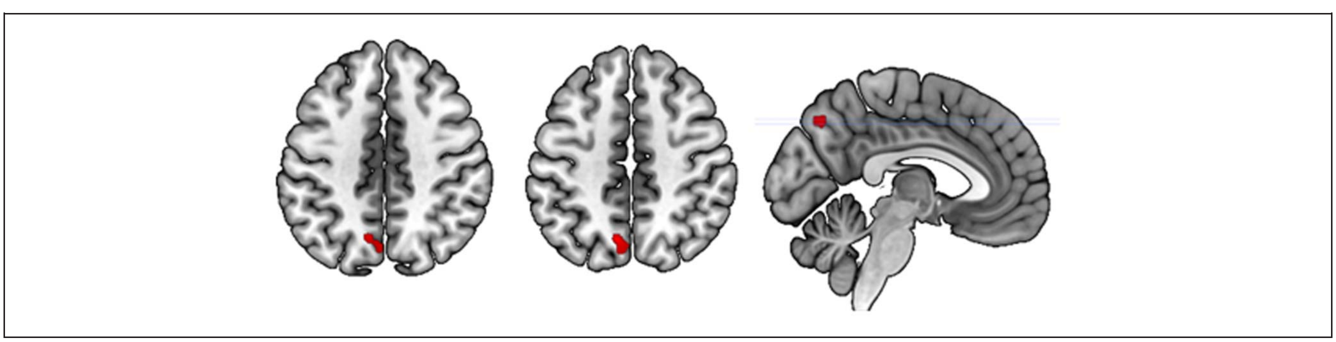

Figure 6. A region in the left precuneus cortex showed significant positive correlation between distraction success and the Distraction > Flow activation contrast. Region coordinates are reported in Supplemental Tables S6.

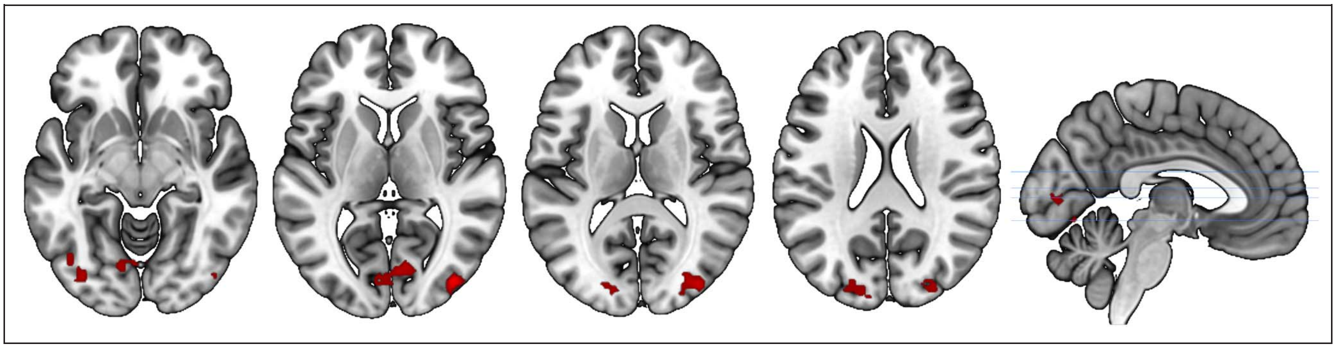

Figure 7. Two clusters showed significant positive correlations between reappraisal success and the Reappraisal > Flow activation contrast. These clusters overlapped regions of intracalcarine cortex, lateral occipital cortex, lingual gyrus, and fusiform gyrus. Region coordinates are reported in Supplemental Table S7.

Regulation BOLD Signal Predicted by Regulation Success, Routine Regulation Use, and Age

The model testing relationships among distraction success, routine distraction use (RSQ_{dist}), and age on the Distraction > Flow activation contrast showed a region in the precuneus where the main effect term for distraction success was significant (see Figure 6 and Supplemental Table S6). No significant clusters for any other model terms were found in the distraction model results.

The model testing relationships among reappraisal success, routine reappraisal use (RSQ_{dist}), and age on the Reappraisal > Flow activation contrast showed two regions where the main effect term for reappraisal success was significant. These clusters overlapped with multiple sectors along the occipitotemporal stream, including intracalcarine cortex, lateral occipital cortex, lingual gyrus, and fusiform gyrus (see Figure 7 and Supplemental Table S7).

Exploratory Analysis of Regulation BOLD Signal Predicted by the Interaction of Regulation Success and Routine Regulation Use

The exploratory distraction activation contrast model including the Success × RSQ_{dist} interaction term showed a region in lateral occipital cortex that exhibited a significant positive correlation between activation contrast and the Success × RSQ_{dist} interaction term (see Figure 8 and Supplemental Table S8). That is, as reported routine use of distraction increases, the correlation coefficient between distraction success and activation in this region increases. This finding suggests individuals who use distraction routinely in everyday life engage visual processing to a greater degree when successfully redirecting attentional focus from a negative AM to a positive one.

The exploratory reappraisal activation contrast model including the Success × ERQ_{reap} interaction term showed seven regions with significant negative correlation between activation contrast and the Success × ERQ_{reap} interaction term. These included the following: right dlPFC, left temporal lobe, frontal pole, right thalamus, left vlPFC, right cerebellum, and left dmPFC (Figure 9). As reported routine reappraisal use increases, the correlation between activation in these regions and reappraisal success decreases. Conversely, as reported reappraisal use decreases, increased activation in these regions is more coupled to reappraisal success.

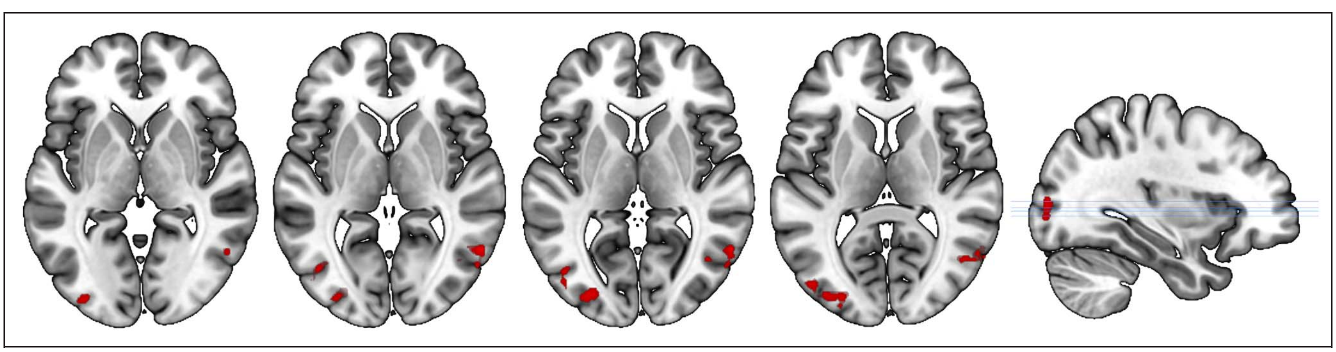

Figure 8. Exploratory results: There was significant positive correlation between the RSQdist × Distraction Success interaction term and the Distraction > Flow activation contrast in the left and right lateral occipital cortex (LOC). Region coordinates are reported in Supplemental Table S8. Greater reported routine use of distraction corresponded with a more positive relationship between the Distraction > Flow activation contrast and distraction success in these areas.

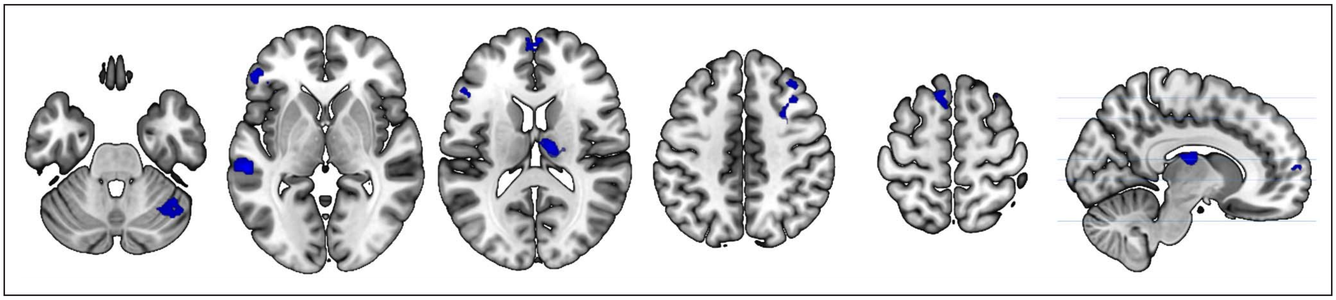

Figure 9. Exploratory results: There was a significant negative correlation between the ERQ_{reap} × Reappraisal Success interaction term and the Reappraisal > Flow activation contrast in the right dorsolateral PFC, left temporal lobe, frontal pole, right thalamus, left ventrolateral PFC, right cerebellum, and left dmPFC. Less reported routine reappraisal use corresponded to a more positive relationship between the Reappraisal > Flow activation contrast and reappraisal success in these regions. Region coordinates are reported in Supplemental Table S9.

DISCUSSION

The present study sought to further clarify the neural correlates of two emotion regulation strategies, reappraisal and distraction, by analyzing whole-brain fMRI data from a larger (n = 62) and broader-aged adult participant sample (35–74 years of age) than most prior studies. We also implemented distraction instructions (think about something pleasant) and regulatory targets (negative AMs) that are arguably more ecologically valid than prior studies, in which distraction was often a rote task (e.g., counting) and stimuli had minimal personal relevance (e.g., IAPS pictures). The study design also enabled us to directly compare, within participants, brain activation during distraction to brain activation during reappraisal. Finally, a unique contribution of our study was the integration of several moderators (age, self-reported habitual use of distraction and reappraisal, and regulation success) in our neural models. This integration was enabled by our larger sample size and broader age range.

Reappraisal Use and Effectiveness Decrease with Age Even in the Absence of Related Neural Signature

Our third hypothesis, that age has a selective impact on reappraisal, was partially supported by our results. As predicted, we found significant negative correlations between both reappraisal success and reported routine use of reappraisal (ERQ_{reap}) with age. However, neither the model predicting regulation success nor the model predicting regulation use showed a significant interaction between regulation type and age. Thus, the prediction of a selective impact of age on reappraisal, but not distraction, was not supported. As individuals age, routine use of reappraisal may decrease as it becomes less effective or more taxing of a regulation strategy due to age-associated reductions in executive functioning.

Contrary to our second hypothesis, the behavioral age effects were not mirrored in the fMRI analyses; age did not significantly correlate with neural activity associated with either reappraisal or distraction. We note that our age range did not include young adults in their 20s to ensure that the frontal executive systems under investigation have fully matured and to ensure that all AMs were encoded during adulthood. Nonetheless, their omission may have obscured some age-associated changes in regulatory activation in relevant neural pathways.

Attentional Distraction toward Positive Thoughts and Reappraisal of AMs Recruit Different Functional Architecture

The activation contrast maps versus flow for reappraisal and distraction, as well as the direct contrasts between these two conditions, show that each recruits a different set of distributed cortical regions with some overlap. Supporting our hypothesis, both emotion regulation techniques involved broad engagement of PFC and lateral parietal regions typically associated with cognitive control. However, there were differences in the specific functional architecture implicated in each strategy. As hypothesized, reappraisal engaged the vlPFC more than distraction, although this effect was specific to the left hemisphere and extended into the anterior temporal cortex. Distraction also preferentially engaged some regions of the vlPFC, although these clusters also strongly overlapped with insula. Reappraisal did not show stronger engagement of the vmPFC but rather elicited greater activity in the dmPFC. Recruiting a vlPFC–dmPFC system, rather than the hypothesized vlPFC–vmPFC ventral affective network, may point to the combined necessity of both vlPFC and dmPFC for mnemonic operations that underlie AM retrieval (Chapados & Petrides, 2015), as well as the specialized role of the dmPFC in guiding emotional memory retrieval to emphasize or deemphasize emotional features (Kensinger & Ford, 2021).

We further predicted that distraction would elicit greater activation in the dlPFC and dACC, which was partially supported. Activity in the dACC was indeed greater during distraction, yet greater dlPFC engagement was mostly confined to bilateral anterior dlPFC. In contrast, a left posterior dlPFC/premotor cluster was instead more active for reappraisal. Interestingly, these more posterior regions of the dlPFC tend to show stronger functional coupling with the vlPFC, whereas anterior regions of the dlPFC show stronger coupling with the dACC and lateral parietal regions (Jung, Lambon Ralph, & Jackson, 2022). Thus, this anterior/posterior distinction in dlPFC recruitment seems to reflect functional coupling with the other regions preferentially engaged for each regulation strategy. It is also worth noting that activation in PFC and temporal regions generally had strong left-lateralization during reappraisal, but were more bilaterally activated during distraction. This left lateralization follows results of previous studies (Dörfel et al., 2014; Ochsner, Bunge, Gross, & Gabrieli, 2002) and has been posited to suggest greater use of semantic or linguistic processes during reappraisal (Dörfel et al., 2014).

In summary, reappraisal activated a more left-lateralized network of cortical regions, with prefrontal clusters localized to the left vlPFC, left posterior dlPFC, and dmPFC, as well as greater engagement of lateral temporal regions. Distraction activated a more bilateral network of cortical regions, with prefrontal clusters localized to anterior dlPFC and dACC, as well as generally greater engagement of lateral and medial parietal regions.

The canonical resting-state network correspondence findings provide a more nuanced interpretation of the activation profiles for reappraisal and distraction. While we did not hypothesize reappraisal to be uniquely linked with default network activity, the involvement of the dmPFC subsystem aligns with prior evidence linking this network to self-referential processing of current emotional states (Andrews-Hanna et al., 2010) and further emphasizes the importance of the dmPFC in controlling the affective framing of personally relevant emotional memories (Kensinger & Ford, 2021). Our network analysis also suggests that reappraisal and distraction engage different visual networks, which we did not originally hypothesize but also aligns with existing literature. Primary visual regions have been causally implicated in the updating of episodic memories (Pan et al., 2025), which may explain the greater engagement of these posterior occipital regions during memory reinterpretation.

Regulation of Negative AMs Recruits Robust, Widely Distributed Brain Activity: Comparisons to Existing Literature

Distraction versus Flow

The whole-brain Distraction > Flow activation contrast results implicate a wider array of cortical regions than suggested by previous work, including the dlPFC, dACC, precuneus, TPJ, occipital cortex, cerebellar crus I, and insula. The two studies we are aware of that examined distraction from AMs, relative to a flow-like condition, found that distraction was associated only with increased activation in vmPFC and decreased activation of the amygdala (Denkova et al., 2015), or increased activation of dlPFC, parahippocampal cortex, and angular gyrus (Iordan et al., 2019). The broader neural engagement seen in our results may be explained by differences in methodology. The distraction condition used by Denkova and colleagues (2015) and Iordan and colleagues (2019) involved cueing participants to recall only the contextual elements of a memory (rather than emotional elements) before memory recall. Thus, the previous studies' implementation of distraction was a regulation of emotion during recall, akin to situation selection/modification in the Gross process model of emotion regulation, while ours was a regulation of emotion after recall. The latter may require more resources to disengage from the memory and then shift attention to a positive thought, perhaps leading to the recruitment of the additional cortical brain regions found in our results. Our study also included many more participants than the previous work (n = 62 vs. n = 18), which provided us with greater statistical power to detect more subtle changes in regional activation between conditions.

A recent meta-analysis of distraction and reappraisal (Liu et al., 2022) found activation in dlPFC to be associated with distraction from negative IAPS images. Again, the activation of additional regions in the current study may be related to the use of AMs as stimuli and our implementation of distraction. Due to their personal relevance, negative AMs may be more salient to individuals than pictures of negative items or situations. This may make it more challenging for participants to actively distract from them, requiring greater or more wide-spread use of frontoparietal control regions. Our use of a distraction process of "turning thoughts to something positive" also likely engages different neural circuitry than the distraction methods used in studies investigated by Liu et al., which included number or string retrieval, doing arithmetic, or recalling a predefined neutral situation. Anecdotally, during training on mental distraction, most participants in our study reported bringing to mind a generic positive memory (e.g., "walking along the beach") in response to the distraction cue. This process of retrieving another personally relevant and complex memory may explain the additional frontal, insular, and occipital activation seen in our whole-brain activation maps compared with some other prior studies. Our findings may better reflect the neural underpinnings of natural attentional distraction use ("setting down" negative thoughts to instead "focus on the positive").

Reappraisal versus Flow

Several of the regions implicated in our whole-brain Reappraisal > Flow results are consistent with component processes involved in AM updating, including manipulation of content in working memory (dlPFC; Curtis & D'Esposito, 2003) and memory retrieval (left vlPFC; Cabeza & St Jacques, 2007). Several of the regions, including occipital cortex, lateral PFC, and temporal cortex, were reported by a previous study (Holland & Kensinger, 2013) to be more active during reappraisal of AMs than during a flow-like condition (maintaining emotional intensity). In another AM regulation study, Kross, Davidson, Weber, and Ochsner (2009) found activation of left vlPFC, cuneus, cerebellum, middle occipital gyrus, and lingual gyrus during "both" a reappraisal condition and a feel condition. Interestingly, no brain regions in that study exhibited greater activation during reappraisal than during the flow-like condition.

Although our current study used a reappraisal task design very similar to those of both Kross and colleagues (2009) and Holland and Kensinger (2013), our reappraisal activation map more closely aligns with that of Holland and Kensinger (2013). One possible explanation is the difference in reappraisal trial length among the three studies. Our study design and that of Holland and Kensinger (2013) use similar reappraisal durations, 10 sec and up to 12 sec, respectively. Kross and colleagues (2009) used a much longer reappraisal time of 30 sec. It only takes participants a few seconds to recall an AM from a recently generated personal cue (Greenberg et al., 2005), followed by several more seconds of active reappraisal. Later time periods in a 30-sec window would reflect the maintenance of information in the reappraised memory (see also Daselaar et al., 2008) that more closely resembles flow. These considerations could explain some of the commonalities and discrepancies among the reappraisal maps of the three studies and be tested in future work.

Most previous fMRI studies investigating reappraisal have used negative images as stimuli. Comparison between our Reappraisal > Flow results and those from pictorial studies suggests the use of AMs and a relatively larger participant group allowed us to more robustly detect the full extent of the reappraisal network. Many regions in our activation results, including vlPFC, posterior dlPFC, posterior dmPFC, PCC, temporal cortex, parietal lobe, and ACC, have been reported by at least one negative image reappraisal study (see Qu & Telzer, 2017; Silvers, Weber, Wager, & Ochsner, 2015; Burklund, Creswell, Irwin, & Lieberman, 2014; Gianaros et al., 2014; Townsend et al., 2013; Ziv, Goldin, Jazaieri, Hahn, & Gross, 2013; Modinos, Ormel, & Aleman, 2010; Ochsner et al., 2002), but not consistently across these studies. A recent meta-analysis by Denny and colleagues (2023) combining results of 17 negative image reappraisal studies only found three left frontal foci (vlPFC, posterior dlPFC, posterior dmPFC) where reappraisal activation was greater than that of null conditions. In a larger meta-analysis, including 48 reappraisal studies with a range of negative stimulus types (although mostly negative images), Buhle and colleagues (2014) found a reappraisal > emotional baseline map that more closely resembles our results, including activation in dmPFC, vlPFC, ACC, parietal lobe, and temporal cortex. This suggests reappraisal of AMs and pictures may both rely on the same cognitive control network (although see discussion of visual cortex below) but recruit this network to differing degrees. However, another possibility is that our relatively larger participant sample allowed us the statistical power to better detect this network than previous individual studies.

Distraction versus Reappraisal

The widespread nature of our distraction and reappraisal contrast maps stands in contrast to the recent meta-analysis by Liu and colleagues (2022). Their analysis found no brain regions activated more strongly during distraction compared with reappraisal and only the left amygdala, inferior frontal gyrus, and vlPFC to be more strongly activated during reappraisal than during distraction. However, the studies included in this meta-analysis used negative IAPS pictures as stimuli, rather than AMs, and the distraction tasks used in three of the four studies consisted of memorizing letters or performing arithmetic problems. As previously mentioned, these differences in methods may account for differences with our results.

The distraction and reappraisal conjunction map highlights the strong involvement of visual cortex in both regulation techniques. Several smaller clusters of conjunction were found in frontal and midline brain regions, including the left superior frontal gyrus, precuneus, left precentral gyrus, and left posterior dlPFC. The left dlPFC has regularly been reported in conjunction maps of distraction and reappraisal and is believed to play an integral part in the cognitive control used in each (Liu et al., 2022; Kanske et al., 2011; McRae et al., 2010). Our regions found in the left precentral gyrus and left precuneus are also in proximity to regions found by Kanske and colleagues (2011) to be involved both with distraction and reappraisal. Involvement of the precuneus may reflect the engagement of episodic memory during distraction and the additional use of self-reflective thinking during reappraisal.

The conjunction map cluster in the left superior frontal gyrus was not found in previous studies comparing distraction and reappraisal. This brain region has been associated with accurate memory retrieval (e.g., Chen, Gilmore, Nelson, & McDermott, 2017; Erk, von Kalckreuth, & Walter, 2010). In general, regions along the midline of the PFC have also been associated with self-referential processes (Kalenzaga et al., 2015; Martinelli et al., 2013; Denny, Kober, Wager, & Ochsner, 2012; Northoff & Bermpohl, 2004). Thus, activity in this region may reflect common processes associated with recollection and manipulation of AMs used while distracting and reappraising.

Precuneus Activity Predicts Success in Distracting from AMs

We found a positive correlation between distraction success and the Distraction > Flow activation in the left precuneus. The precuneus has been implicated in mental processes including episodic memory and self-reflection (e.g., Cabanis et al., 2013; Trimble & Cavanna, 2008). Here, increased activation in this region may reflect more effective retrieval of positive AMs and, thus, more effective distraction. Previous work by Dörfel and colleagues (2014) using a nine-digit number rehearsal as a distraction strategy found no significant correlations between regulation success and brain activation. The use of AMs and the specific implementation of our distraction instructions to shift attention to positive thoughts most likely led to greater involvement of the precuneus in successful distraction.

Visual Cortex Is Involved in Both Positive Distraction from and Reappraisal of AMs

The distraction and reappraisal activation conjunction map includes large portions of occipital cortex, and reappraisal activation in visual cortex significantly predicted reappraisal success. Although a few previous studies have found evidence of visual cortex involvement in the reappraisal of negative image stimuli (Moodie et al., 2020; Sripada et al., 2014), many primary reappraisal studies (Hermann et al., 2017; Qu & Telzer, 2017; Silvers et al., 2015; Burklund et al., 2014; Ziv et al., 2013; Kanske et al., 2011; McRae et al., 2010; Modinos et al., 2010) and reappraisal meta-analyses (Denny et al., 2023; Buhle et al., 2014) have not. Studies involving reappraisal of AMs, however, have seen related activity in this region. Denkova and colleagues (2015) reported activation of visual cortex during retrieval of both emotional and contextual characteristics of AMs. Occipital activation was also found by Kross and colleagues (2009) during application of three different mental strategies to cued AMs. These findings suggest greater visual engagement when regulating complex memories than when regulating simpler stimuli.

Our finding that reappraisal activity in portions of visual cortex predicted reappraisal success further supports the region's involvement in regulation of negative memories. This effect was not reported in several previous studies using negative image stimuli (McRae et al., 2010; Modinos et al., 2010; Ochsner et al., 2002). The specific involvement of visual cortex in the reappraisal of AMs may reflect the replaying of memory events within the participant's mind or a manipulation of visual aspects of the memory, consistent with prior fMRI studies that relate visual cortex activity to the extent of the subjective experience of reliving the autobiographical event during recall (e.g., Daselaar et al., 2008). This pattern across studies suggests some stimulus dependence in terms of how regulatory control regions interact with supporting perceptual processes during reappraisal (see also Ziv et al., 2013, who compared reappraisal across emotional faces, spoken criticism, and negative self-beliefs).

To our knowledge, visual cortex activation has not previously been associated with emotion regulation via distraction. Given that many participants in this study reported bringing to mind positive memories during distraction, it is likely that the activation in visual cortex seen here represents visual imagery associated with positive AM retrieval (Cabeza & St Jacques, 2007), a process that would not be reflected in other distraction techniques like mental arithmetic.

Routine Regulation Use May Influence Relationships between Neural Activation and Regulation Success

The neural analysis models including the interaction terms between regulation success and reported routine regulation use were not part of the initial study design and are exploratory in nature. Therefore, results need to be verified by robust future work, and we refrain from detailed interpretation here. In our exploratory analyses, we found several regions in which reported routine regulation use influenced the relationship between regulation success and activation. Activity in lateral occipital cortex positively correlated with the Distraction Success × RSQ_{dist} model interaction term; participants with higher routine distraction use have a more positive correlation between distraction success and activation in this occipital region (Figure 6). These findings dovetail with those discussed above suggesting visual engagement may play a particularly important role in our distraction task. The direction of this interaction is opposite than that predicted by our exploratory hypothesis. However, it is also in a region not associated with executive or attentional control.

The model investigating relationships between reappraisal success and routine reappraisal use showed a different interaction effect in the right dlPFC, left temporal lobe, frontal pole, right thalamus, left vlPFC, right cerebellum, and left dmPFC (Figure 8). Here, the correlation coefficient between reappraisal success and activation decreased as trait reappraisal use increased. This suggests participants who do not routinely use reappraisal may have needed to recruit these regions to a greater extent for successful emotion regulation. Although this is just a correlational finding, one interpretation is that it may reflect efficiency as a result of practice; participants who have practiced emotion regulation through reappraisal in daily life may need to recruit fewer resources to enact successful regulatory control. The findings in the dlPFC, vlPFC, and dmPFC support our exploratory hypothesis regarding increased efficiency in executive control regions with increased routine use. This finding in the dlPFC follows recent work showing the efficacy of augmenting cognitive-behavioral therapy skills training with TMS to the dlPFC in individuals with transdiagnostic emotion dysregulation (Neacsiu, Beynel, Graner, et al., 2022; Neacsiu, Beynel, Powers, et al., 2022). These studies included a condition in which participants actively reappraised negative AMs; notably, individuals with low-to-moderate ERQ scores benefitted more from the intervention on some behavioral and physiological metrics associated with recalling these autobiographical events (Neacsiu, Beynel, Graner, et al., 2022). The regions found in the left temporal lobe, frontal pole, and cerebellum have overlap with the Reappraise > Flow activation contrast map, suggesting their importance in implementing reappraisal. The thalamus has been implicated in cognitive control and working memory performance (Shine, Lewis, Garrett, & Hwang, 2023) and may also benefit from increased efficiency during reappraisal with more routine use. Alternatively, thalamic activation may reflect processing and transfer of sensory information related to emotional arousal (Frank et al., 2014); habitual reappraisers may experience less intense emotional arousal when successfully implementing reappraisal.

Limitations and Future Directions

Our study has several limitations. As noted above, the exclusion of the youngest segment of the adult lifespan, which was done to ensure maturation in the frontal circuits of interest, may have obscured some age-associated effects. Although the larger parent clinical trial was preregistered and powered for those analyses, many of the results reported here were secondary analyses and thus exploratory in nature. The analyses conducted were univariate in nature; it is possible that additional brain regions and/or brain–behavior relationships would be obtained with more sensitive multivariate approaches. Because only one tactic was used for each strategy, results may not generalize across other forms of reappraisal or distraction. Future work could also include analyses of functional connectivity across strategies and as a function of aging.

Finally, the repeated use of each negative memory across the three strategy conditions, while allowing us to more directly contrast these conditions without unintended stimulus confounds, may have led to habituation or modification of the memories across repeated trials. We note that negative autobiographical events are often rehearsed in real life, and we found more extensive attentional/executive control network engagement than in prior pictorial regulation studies that did not repeat stimuli. Nonetheless future studies should strive to explicitly assess the role of habituation for better alignment with other regulation paradigms.

Conclusions

This study aimed to expand on prior examinations of reappraisal and distraction in emotion regulation by maximizing the personal relevance and ecological validity of emotion cues and strategy implementation. Furthermore, the focus on adults in middle to late adulthood extends prior studies that have focused more narrowly on either early or later life periods. Perhaps specific to use of emotional AMs to induce negative affect, visual cortex was associated with both reappraisal and distraction strategy use, and there was robust detection of widespread networks associated with these strategies. While we replicate many past studies, our wider age range and use of more complex AMs provide more support for a model in which distraction and reappraisal recruit separable neural networks with some points of overlap. Finally, we show additional behavioral support for reduced reappraisal efficacy with older age, although older adults in our sample tended to recruit similar brain networks.

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Data Availability Statement

The findings reported in this article are part of preregistered clinical trial NCT03207503 at https://clinicaltrials.gov. The data are available in the NIMH Data Archive at https://nda.nih.gov/edit_collection.html?id=2663. Supplemental Material can be accessed on this article's homepage: https://doi.org/10.1162/JOCN.a.88.

Author Contributions

John L. Graner: Data curation; Formal analysis; Investigation; Methodology; Software; Visualization; Writing—Original draft; Writing—Review & editing. Leonard Faul: Data curation; Investigation; Writing—Review & editing. Joseph M. Diehl: Data curation; Writing—Original draft; Writing—Review & editing. David J. Madden: Conceptualization; Project administration; Supervision; Writing—Review & editing. Moria J. Smoski: Conceptualization; Funding acquisition; Methodology; Project administration; Supervision; Writing—Review & editing. Kevin S. LaBar: Conceptualization; Funding acquisition; Methodology; Project administration; Supervision; Writing—Review & editing.

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Diversity in Citation Practices

Retrospective analysis of the citations in every article published in this journal from 2010 to 2021 reveals a persistent pattern of gender imbalance: Although the proportions of authorship teams (categorized by estimated gender identification of first author/last author) publishing in the *Journal of Cognitive Neuroscience* (*JoCN*) during this period were M(an)/M = .407, W(oman)/M = .32, M/W = .115, and W/W = .159, the comparable proportions for the articles that these authorship teams cited were M/M = .549, W/M = .257, M/W = .109, and W/W = .085 (Postle and Fulvio, *JoCN*, 34:1, pp. 1–3). Consequently, *JoCN* encourages all authors to consider gender balance explicitly when selecting which articles to cite and gives them the opportunity to report their article's gender citation balance.

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