Comparing the Neural Bases of Self- and Social-Reappraisal

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Abstract.
To manage life's stressors, we can self-regulate our emotions or seek social regulatory support. One commonly used strategy is reappraisal, where individuals reframe their own negative emotions (i.e. self-reappraisal) or help others reframe their negative emotions (i.e. social-reappraisal). Here, we compared the neural mechanisms underlying self- and social-reappraisal of negative autobiographical memories using standard univariate contrasts, Bayes factor and multivariate classifier approaches. Both self- and social-reappraisal recruited regions associated with control, such as dorsolateral and ventrolateral prefrontal cortex. Notably, multivariate patterns within control regions were indistinguishable, suggesting they play similar roles in self- and social-reappraisal. Second, social-reappraisal was both quantitatively and qualitatively different from self-reappraisal in its recruitment of control and mentalizing regions, such as the right lateral prefrontal cortex, medial prefrontal cortex and right temporal pole. Multivariate patterns within regions associated with mentalizing were distinguishable between self- and social-reappraisal, suggesting that they are specifically involved when reappraising for others. Finally, both self- and social-reappraisal modulated activity in regions associated with affective responding and the perceptual representation of remembered scenes, including the mid-orbital frontal cortex, left insula and parahippocampus. Taken together, these data reveal the processes supporting self and social emotion regulation with implications for both basic and clinical research.

Comparing the Neural Bases of Self- and Social-Reappraisal

If there is one constant in life, it is that it routinely presents us with affective valleys to traverse and emotional mountains to climb. Research points to two broad ways to navigate our everyday affective landscapes. One way involves 'going it alone' by choosing to deploy a variety of strategies for self-regulating one's own emotions. A second way involves turning to other people who may offer us emotion regulatory support. This second means of meeting emotional challenges has been described as either the social regulation of emotion (Coan et al., 2006; Reeck et al., 2016; Sahi et al., 2023; Digiovanni, He & Ochsner, in prep) or interpersonal emotion regulation (Zaki & Williams et al., 2013; Hofmann et al., 2014; Dixon-Gordon et al., 2015; Niven et al., 2017). Here, we use the former term – the social regulation or emotion and variants of the term, such as social emotion regulation – because it more broadly encompasses the various ways in which one (or more) persons' actions may regulate the emotions of another person (or persons) (Digiovanni, He & Ochsner, in prep), whereas the term 'interpersonal emotion regulation' largely refers to dyadic contexts that involve explicit emotional disclosures (Rimé, 2007; Zaki & Williams, 2013).

In the past few years there has been a proliferation of work on social emotion regulation, with behavioral studies showing it benefits individuals seeking support (i.e., 'targets' of regulation; cf. Uchino, 2006; Sahi et al., 2023), regulators offering support (Inagaki & Eisenberger, 2012; Cohen & Arbel, 2020) and the relationship between targets and regulators (Rauers & Riedinger, 2023). However, there has been relatively little work on the psychological and neural mechanisms underlying these beneficial effects. This paper seeks to elucidate these mechanisms using fMRI to compare and contrast the neural systems supporting attempts to socially regulate vs. self-regulate negative emotions.

We drew on two literatures to formulate hypotheses about what neural mechanisms might support social emotion regulation. The first is the study of the brain systems supporting the ability to self-regulate one's own emotions. The lion's share of this work has examined a specific cognitive strategy known as reappraisal, which involves reframing the meaning of an emotional experience in order to change its affective potency (Gross 1998, 2014; Ochsner et al, 2012). Although initial studies focused on how reappraisal can down-regulate negative emotion – in part because reappraisal was thought to embody key aspects of cognitive behavioral interventions (e.g. Beck, 2020) – reappraisal can be flexibly used to reframe the meaning of events in ways that up or down-regulate various kinds of emotions (McRae et al., 2012), depending on one's goals. Notably, reappraisal can also be used socially. In social-reappraisal, one person, the 'regulator', suggests alternative reinterpretations for the negative emotional experience(s) of another person, the 'target' (Reeck et al., 2016; Shu et al., 2020; Sahi et al., 2021). A small but growing number of behavioral studies have begun showing that social-reappraisal may be prevalent and effective for regulating emotions in daily life (e.g. Doré et al, 2017; Shu et al., 2021; Sahi et al., 2021; Liu et al., 2021; Arbel et al., 2024).

With these considerations in mind, we reasoned that social-reappraisal (Sahi et al., 2021) may have much in common with traditional self-reappraisal. Here we were interested in both the systems that implement each type of reappraisal and in the systems they might modulate to achieve their emotion regulatory effects. With respect to systems implementing reappraisals, it is possible that both involve maintaining regulatory goals, selecting context-appropriate reframes or reinterpretations of the meaning of stimuli, and monitoring progress towards this goal. Consistent with this hypothesis, behavioral results suggest that providing social-reappraisal increases the frequency of engaging in self-reappraisals (Doré et al., 2017), suggesting they depend on common underlying mechanisms (Sahi et al., 2021). Meta-analyses of fMRI studies of self-reappraisal (Buhle et al., 2014; Picó-Pérez et al., 2017; Denny et al, 2023) have shown that these processes recruit a set of prefrontal and parietal regions generally involved in cognitive control (Duncan and Owen, 2000; Miller and Cohen, 2001), including dorsolateral prefrontal cortex (dlPFC), ventrolateral prefrontal cortex (vlPFC), posterior medial prefrontal cortex (pmPFC) and inferior parietal cortex (Wager and Smith, 2003; Ridderinkhof et al., 2004; Simmonds et al., 2008; Rottschy et al., 2012). To the extent that social- and self-reappraisal engage similar cognitive control processes, we hypothesized that they may similarly depend on these domain-general control systems. However, to the extent that social-reappraisal requires greater control, it may tax these regions more strongly (cf. Silvers et al., 2015). For example, reappraising for someone else may place greater demands on working memory (associated with dlPFC and parietal regions) and on retrieval/selection processes (associated with vlPFC; Satpute, Badre & Ochsner, 2014) needed to generate and select reappraisals that are appropriate for the target.

With respect to the systems that self- and social-reappraisal might modulate, one possibility is that both would change activity in brain regions identified in prior studies of self-reappraisal to be modulated (e.g. Buhle et al., 2014; Morawetz et al., 2017; Powers & Labar, 2019; Denny et al, 2023). Here, however, it is important to note that the specific systems that reappraisal modulates can vary as a function of the nature of the affect eliciting stimulus (Ochsner et al., 2012; Buhle et al., 2014). As noted below, in this study we asked participants to bring to mind negative memories. Most studies of reappraisal have used simple perceptual stimuli, like aversive images, which tend to elicit activity in systems like the amygdala that are tuned to processing the affective value of sensory inputs. We and others have also studied reappraisal of emotional memories, showing modulation of systems associated with affective responding, such as the insula, which is associated with interoception and affective experience (Goldin et al., 2008, Uddin et al., 2017) and the orbitofrontal cortex (Silvers et al., 2016; Doré et al., 2018), thought to be important for integrating representations of context and affective value (Rolls et al., 2020; Koban et al., 2021). We have also seen modulation of posterior medial temporal regions associated with representing contextual details of an environment (e.g. a scenes; Epstein et al., 2003; Bar et al., 2008; Aminoff et al., 2013), presumably because reappraising a memory transforms one's perceptual representation of it (Doré et al., 2018). Given work suggesting that that simulating others' and bringing to mind one's own emotional memories may engage similar processes (Gilead et al., 2016), it is likely that activity in insular, orbitofrontal and parahippocampal regions may be modulated by both self- and social-reappraisal.

The second literature that informed our hypotheses concerns the fact that social- and self-reappraisal should differ in an important respect: reappraising for someone else necessitates simulating their mind to understand how they might appraise and emotionally respond to a situation. This ability to think about, mentally represent and/or draw inferences about mental states – whether those states correspond to thoughts, goals, intentions, beliefs, or emotions – is known as mentalizing (Frith & Frith, 2006). One of the most reliable findings in human neuroscience research is that mentalizing recruits a network of regions centered around the medial prefrontal cortex (mPFC), temporal pole, temporoparietal junction (TPJ) and precuneus (Frith & Frith, 2006; Zaki & Ochsner, 2012; Schurz et al., 2021). Prior work has shown that self-reappraisals may recruit parts of the mentalizing network, including mPFC, presumably because reinterpreting the meaning of an affective stimulus involves attending to and rethinking the nature of one's emotional response (Ochsner et al., 2012). That said, we reasoned that social-reappraisal may depend more than self-reappraisal on mentalizing regions because it requires the active simulation of another person's beliefs and emotions, which may tax mentalizing operations more than introspecting about one's own affective states (Denny et al., 2012; Zaki & Ochsner, 2012; Reeck et al., 2016; Tamir et al., 2016; Tamir & Thornton, 2018).

One type of mentalizing operation key to social-reappraisal may be the consideration of multiple perspectives on an episode (Gaesser, 2020), including engaging in second and third degree reasoning about mental states (e.g. 'what do I believe you're feeling?'; 'how will you react to what I say about how you're feeling?), both of which are thought to depend on mPFC, especially its dorsal and anterior portions (corresponding to Brodmann area 10). Notably these portions of mPFC may be anatomically distinct in homo sapiens' relative to other primates (Holloway, 1983; Semendeferi et al., 2001), which may belie its role in mentalizing. A second mentalizing operation essential for social-reappraisal may be the retrieval of semantic social knowledge (e.g., names, traits, scripts/schemas for social situations; Satpute, Badre & Ochsner, 2014) and associating such knowledge with specific people and contexts, both of which are important for social relationships and the motivation to engage in affiliative behaviors (Olson et al., 2007, 2013; Ross & Olson, 2010). The representation of this knowledge has been associated with the temporal pole (and adjacent lateral temporal gyri), which tend to be recruited in mentalizing-related tasks, including reading narratives and when using distancing reappraisals (Gallagher & Frith, 2003; Ross & Olson, 2010; Olson et al., 2013). Recruitment of these brain regions may thus be unique for social-reappraisal.

To address these hypotheses about the neural systems supporting social-reappraisal vs. self-reappraisal, we created a social version of a naturalistic laboratory paradigm previously used to study self-reappraisal (Kross et al., 2009; Holland & Kensinger, 2013). In prior studies (Silvers et al., 2016; Doré et al., 2018; Schneck et al., 2023), participants recalled their own negative autobiographical memories following one of two instructions: a *reframe* condition where participants were instructed to reframe reappraise the meaning of recalled events so as to feel less negative; and an *immerse* condition where participants were instructed to re-experience events as they had originally taken place (i.e. without attempts at down-regulating emotion) before rating how bad they felt. Here, we crossed this instructional manipulation with a manipulation of perspective – in the self-perspective condition participants recalled their own memories and in the social perspective condition they recalled another person's negative life events they had read. This design therefore crossed two factors – perspective (social, self) and instruction (reframe, immerse) – to produce four main task conditions. The social-reframe condition asked participants to imagine what they would say to help another person reappraise their negative life events. The social-immerse condition asked participants to simply bring to mind the other person's life event and judge how that person might feel about it. Comparison of these two conditions – i.e. social reframe vs. social immerse – would identify activity related to social-reappraisal, controlling for what the two conditions had in common – i.e. bringing to mind and simulating another person's experience. The self-reframe and self-immerse conditions were compared using a similar logic, and as in prior work using similar conditions (e.g. McRae et al., 2008; Holland & Kensinger, 2017), were used to identify processes related to self-reappraisal of negative experiences. At the end of each trial, participants either rated how bad they felt or how bad the target felt.

To provide a strong test of our hypotheses, we used a combination of univariate contrasts and multivariate pattern analyses. On the univariate side, we included two types of analyses. The first were between-condition contrasts typically used in prior studies of reappraisal. Univariate contrasts are useful for identifying regions preferentially activated by specific psychological processes. The second is a Bayes factor approach (Rounder et al., 2009; Morey & Rounder, 2011), which enables researchers to evaluate evidence both for and against hypotheses that involve patterns across multiple contrasts (e.g. Bo et al., 2024). While standard univariate contrasts can identify what is preferentially activated by a psychological process, Bayes factors can (for example) identify regions activated in one contrast but not another. This type of analysis is needed to identify regions that are specific to social-reappraisal, which requires establishing both a positive response to social-reappraisal and no difference (a null effect) for self-reappraisal.

These two univariate approaches were used to tell us which regions were (1) more active for and (2) selective for social-reappraisal compared with self-reappraisal. Multivariate pattern classification analyses were used to determine whether self- and social-reappraisal engaged these regions differently. These analyses were performed within *a priori* regions of interests to shed light on the question of *how* information was processed and represented across distributed voxels (Weaverdyck et al., 2020).

This combination of analyses allowed us to restate our hypotheses more precisely, with one behavioral hypothesis and four neural hypotheses. First, we predicted that success in downregulating negative affect for oneself and others (i.e. self- and social-reappraisal success) would be correlated (Sahi et al., 2021). Second, we predicted that self- and social-reappraisal would both recruit a set of prefrontal and parietal regions generally involved in cognitive control (Duncan and Owen, 2000; Miller and Cohen, 2001), including dorsolateral prefrontal cortex (dlPFC), ventrolateral prefrontal cortex (vlPFC), posterior medial prefrontal cortex (pmPFC) and inferior parietal cortex. We tested this prediction in two ways: (a) using a conjunction analysis of univariate maps (using standard univariate contrasts and Bayes factors) and (b) within control-related regions, low classification accuracy when attempting to differentiate multivariate patterns associated with self- vs. social-reappraisal. Third, we predicted that self- and social-reappraisal would differ quantitatively, such that social-reappraisal may tax common control regions more than self-reappraisal. This was tested using planned contrasts (Chatham, 1999; Richter, 2016) comparing regions preferentially activated for the social reframe condition specifically (i.e. vs. the average of all other conditions). Fourth, we predicted that self- and social-reappraisal would differ qualitatively, such that social-reappraisal may recruit mentalizing regions more strongly than self-reappraisal. This was tested in three ways: (a) by comparing regions preferentially and uniquely activated for the social reframe condition specifically (using standard univariate contrasts and Bayes factors) and (b) by testing for above-chance classification accuracy when attempting to differentiate the multivariate patterns within *a-priori* regions of interest associated with mentalizing (i.e. mPFC and right temporal pole). Finally, we predicted that both self- and social-reappraisal will modulate regions associated with affective and perceptual representations, including the insula, orbitofrontal cortex and parahippocampus. We tested this prediction by assessing the main effect of instruction (Immerse > Reframe) on negative autobiographical memories using standard univariate contrasts and Bayes factors.

Method

The study involved two sessions. In an initial behavioral session, participants were screened for fMRI eligibility, provided descriptions of negative and neutral autobiographical memories and read written descriptions of memories for another [unbeknownst to actual participants] fictitious participant. In a second session, eligible participants underwent fMRI scanning while using reappraisal to, on different types of trials, regulate responses to their own memories or to help a stranger regulate responses to their memories.

Participants

Participants were recruited from the Columbia University community through flyers posted on campus and screened to confirm that they were at least 18 years of age, identified as female or male, had normal or corrected to normal vision, were able to perform computer tasks, were fluent in English, had no current or past history of neurological or psychiatric illness, were not currently on psychoactive drugs, had no ferromagnetic metal devices or implants that were unremovable, had no tattoos larger than two inches or were acquired in the past six months, were not pregnant or possibly pregnant, and had not participated in a similar study at the lab involving reappraisal. From the behavioral session, participants were screened to ensure they did not exhibit high levels of depression (score > 16 on the Center for Epidemiological Studies

Depression Scale) or trait anxiety (score > 60 on the trait measure of the State and Trait Anxiety Inventory).

Sixty-two participants were recruited for the initial behavioral session to obtain sufficient participants for the second session involving fMRI scanning. This target number was determined using power analyses that would give 80% power in detecting whole-brain between-condition effects after accounting possible attrition. Of these 40 participants, four were excluded from analyses due to excessive movement during scanning. Two participants were removed from analyses as they did not make ratings for over half of the trials. Analyses were conducted on the remaining 34 participants (15 male/19 female, M_{Age} = 23.8, range = 18-38). All participants gave informed consent before participating in the study and all study procedures were approved by the Institutional Review Board at Columbia University.

Behavioral Session

Upon arriving at the lab, an experimenter explained the procedures for the study. As part of the cover story, participants were told that they would be writing about memories of negative events from their lives, and would also be providing support to another participant for their negative memories. Also, as part of the cover story, participants were told that they would be asked at the end of the study whether or not they consented to share their memories with other participants who could, in turn, think about how to provide them support. In reality, none of their memories were shared with other participants – it was simply a cover story to make the social-reappraisal manipulation more believable. It was also made clear to participants that their decision to share their memories would not impact their participation in the current study.

Participants provided written consent for the session, and then completed an fMRI safety screening form.

The experimenter then explained to the participant that they would be writing about personal events on a computer. As part of this, they would be asked to provide brief descriptions of eight negative and eight neutral events they have experienced (Figure 2). Prior to starting this task, participants were asked to practice writing one negative and one neutral memory on paper so that the experimenter could review the responses and ensure that the participant understood the instructions. Participants were instructed to write about any given event only once during this practice session and the main task (i.e. “don’t write about the same event twice or more”). For the negative memories, participants were asked to write about events that had occurred within the past five years and that still made them feel bad when recalling them. For each one, they were instructed to describe as discrete an event as possible that had occurred at a specific time and place (as opposed to recalling a habit, general event, or protracted event, e.g., a relationship that occurred over an extended period of time). They were instructed to write 2-3 sentences to describe what happened during each event and the emotions it made them feel. For each neutral memory, participants were given the same instructions, except they were told to write about events that did not make them feel strongly at the time, or when they recalled them. In their description of each memory, they were asked to describe how the event made them feel (e.g., calm), which could include stating that it did not make them feel anything in particular. To make these instructions more concrete, participants were given examples of the types of neutral events they could write about – such as when they were brushing their teeth earlier in the morning, or out for a run on a specific day. After the practice session, the experimenter checked whether the participant provided examples of memories that fulfilled these requirements.

For the main task, participants were seated in front of a computer in a soundproof booth where they completed the study on a computer via Qualtrics. During the task, participants wrote about eight negative memories in a row and eight neutral memories in a row. The order in which participants wrote about negative or neutral memories was randomized across participants. The instructions for these memories were the same as when they practiced writing them, except a word limit for each memory was set at 200-300 characters (approximately 50-60 words). After providing descriptions of the negative and neutral memories, participants were shown their descriptions. The negative memories were shown consecutively, as were the neutral memories. The order in which negative or neutral memories were displayed was randomized across participants. Participants were instructed to read each of their descriptions, make ratings about how bad each memory made them feel and how vividly they could recollect the memory (i.e., participants made emotion and vividness ratings. See Table 1 in Supplemental Materials for examples of autobiographical memories).

After rating all of their memories, participants completed individual differences measures administered through another Qualtrics survey, which included the Center for Epidemiologic Studies Depression Scale (CES-D) (Radloff, 1977) and the trait scale of the State-Trait Anxiety Inventory (STAI-T) (Spielberger, 1983). These measures were included so that the research team could screen for participants that were below clinical levels of depression and anxiety. Following this, participants were told that they would then read the memories provided by a participant they had been paired with, and for whom they would be providing support if they continued on to the second session involving fMRI scanning.

Participants were told that they were being asked to read these events so that they could get a sense of the other participant’s personality. This was also done to reduce novelty effects in the scanner (i.e. participants would not have read the target's memories for the first time). They were told that the other participant would be referred to as either Emily (if the participant identified as female) or Mark (if the participant identified as male), but that this was not the other person's real name as their identity needed to be protected (in part, this was done so that participants would not suspect their own identity would be revealed if they agreed to share their events with others). Participants only read memories from a gender-matched participant. Another Qualtrics survey was then administered in which they read the eight negative and eight neutral memories ostensibly written by the other participant (who will be referred to as the target), and rated each memory on the same scales used to rate their own memories. After reading and rating these events, participants made judgments about the target's personality by rating how similar they perceived themselves to be to the target. This was done to ensure that participants formed an impression of the target. Upon completing these ratings, participants were asked to provide consent regarding whether or not they would be willing to share their memories with other participants. This session took about 2.5 hours to complete, and participants were compensated $30.

Participants had to meet four criteria before they were invited to complete the second session involving fMRI scanning: First, they had to score below the cutoff criteria on the depression and trait anxiety measures. Second, their written responses adhered to the instructions given (e.g. neutral memories were emotionally neutral while negative memories were emotionally negative when read by the research team). Third, their memories were not deemed by the research team to be potentially traumatizing or that described acts or thoughts of self-injury.

fMRI Session

Procedure

Participants eligible for the second scanner session completed it within three weeks of the initial behavioral session. Upon arriving for this session, participants provided written consent and were screened again to ensure they could be safely scanned. Participants read the autobiographical memories they had described in the first session, as well as the target's memories, and confirmed that they could recollect (i.e. bring to mind) the events described. The experimenter then guided the participant through a practice session that instructed the participant on how to complete the task in the scanner.

For the scanner task, participants were trained to follow instruction cues that asked them to either immerse in or reframe memories. For the immerse condition, participants were instructed to imagine themselves in the event described by the retrieval cue for their memory or the target's memory. For their own memories, they were asked to imagine what they would see, hear, and feel if the events described were happening in the moment – with the emphasis being on experiencing the emotions they feel while immersing themselves in the memory. For the target's memories, participants were instructed to imagine how Emily or Mark would feel in the scene described in their event – with the emphasis being on imagining how the target would feel.

For the reframe condition, participants were instructed to change the way they think about the situation described in their memory so that it caused them less distress. Towards this end, they were told they could take a distanced, more objective, and neutral perspective, or to try to think about positive aspects of the situation. These instructions are similar to those used in prior studies on reappraisal (e.g. Doré et al., 2018). For the target's memories, participants were instructed to imagine telling Emily or Mark how they could think about their memory differently. As with their own memories, participants were told they could help the target take a more distanced, or objective perspective, or to help Emily/Mark understand how aspects of the situation are not as bad as they seem. Participants were told that in the scanner, they should imagine speaking directly to the target when helping them to reappraise. To help ensure compliance with instructions, participants also were told that after the scan they would be asked to write down their thoughts about how to reframe their own and the target's memories. Importantly, in order to strengthen motivation to engage in social-reappraisal and reduce any perceived deception, participants were told that their ideas for helping the target to reframe would be provided to the other participant (See Supplemental materials Table 1 for examples of memories).

Task Design

Participants completed an experimental task consisting of two functional runs. Each run included 24 trials, which included 4 instances of each of 6 types of trials: self-reframe-negative, self-immerse-negative, self-immerse-neutral, social-reframe-negative, social-immerse-negative and social-immerse-neutral trials (Figure 2). As in prior studies of reappraisal using autobiographical memories[1] (Kross et al., 2009; Silvers et al., 2016; Doré et al., 2018), the same 8 negative self and 8 negative social memories were used in each run, and the instruction with

[1] Here we note that this design choice reflected the trade-off between quantity and quality when selecting stimuli for studies and assigning them to conditions. The present design favored collecting a smaller number of highly affectively salient memories, and having participants recollect them twice – once for each instruction type – over collecting twice as many memories so we would not need to repeat them. Based on pilot testing done for prior publications, and the tasks used in those studies (Kross et al., 2009; Silvers et al., 2016; Doré et al., 2018), the concern was that collecting more than 8 memories would result in many that were not particularly emotional.

which they were paired first was counterbalanced. For example, if a participant immersed for a given negative memory in run 1, they would reframe for that memory in run 2. Trials were grouped into blocks of 3, grouped by perspective – i.e., participants would be presented consecutively within 3 trials from either the Self or Social condition, with one each from the reframe negative, immerse negative and immerse neutral conditions. The order of these trials within each block was randomized, as was the sequence of Self/Social blocks. Random assignment determined whether participants started the task with the Self or Social condition.

Trial Structure

The experiment was programmed and presented using E-Prime 3 and back-projected to a mirror attached to the head coil. All stimuli were presented as white text on a black background. The trial event structure (see Figure 1 for trial layout) consisted of a 2 s cue at the beginning of each block of three trials that indicated whether the next three trials were in the Self or Social condition. This 2 s cue indicated "Self" for the Self condition, "Emily" for the Social condition for female participants, or "Mark" for the Social condition for male participants. Participants were then presented with the description of either their memory or the target's memory for 15 s. During this Recall period, they were instructed to read the description of the memory and recall it. Following this, participants were presented with an instruction to take either the Immerse or Reframe perspective. For trials in the Self conditions, participants were instructed to "Immerse for Self" or "Reframe for Self", whereas for the Social conditions, participants were instructed to "Immerse for Emily/Mark" or "Reframe for Emily/Mark". This screen was presented for 15 s, followed by a 1-3s jittered ISI. On the next screen, participants used a five-button response pad to rate how bad they felt after taking the Immerse or Reframe perspective for the Self condition. For trials in the Social conditions, participants were asked to rate how bad they thought the target would feel in their situation for the Immerse condition, or how the target would feel after receiving their help for reframing their memory (5-point Likert scale; 1 = Not at all, 5 = Very much) in the Reframe condition (Figure 1). This rating screen appeared for 3 s. Following this, a 2 s cue indicated that an arrow task would appear soon. The arrow task served as an active baseline task and required participants to indicate the direction that an arrow on the screen was pointing. This active baseline was used to prevent participants from engaging in autobiographical memory recall and/or mind wandering during the implicit baseline period (cf. Stark & Squire, 2001; Kross et al., 2009; Doré et al., 2018). The active baseline task was performed for 8.5 s and then followed by a jittered 3-7 s ITI.

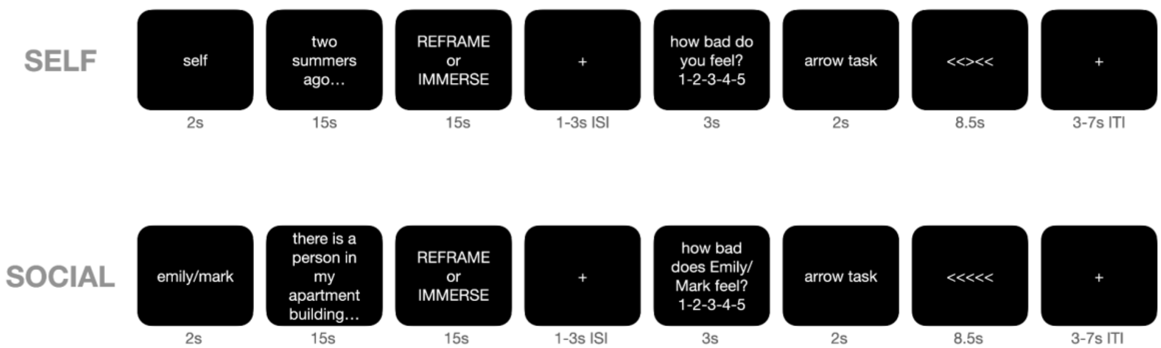


Figure 1. fMRI trial structure. Participants saw a cue indicating whether they will see their own negative memories or a stranger's negative memories for 2s. Then, participants saw a brief description of a negative memory for 15s. Next, participants were asked to either reframe or immerse in the negative memory for 15s. Participants subsequently saw a brief fixation cue for 1-3s (jittered across trials) before being asked to rate how bad they felt or how bad Emily/Mark felt. Finally, participants indicated which direction the center arrow pointed (i.e. arrows task). This task was used as an active baseline (cf. Stark & Squire, 2001; Kross et al., 2009; Doré et al., 2018) and was not of key interest.

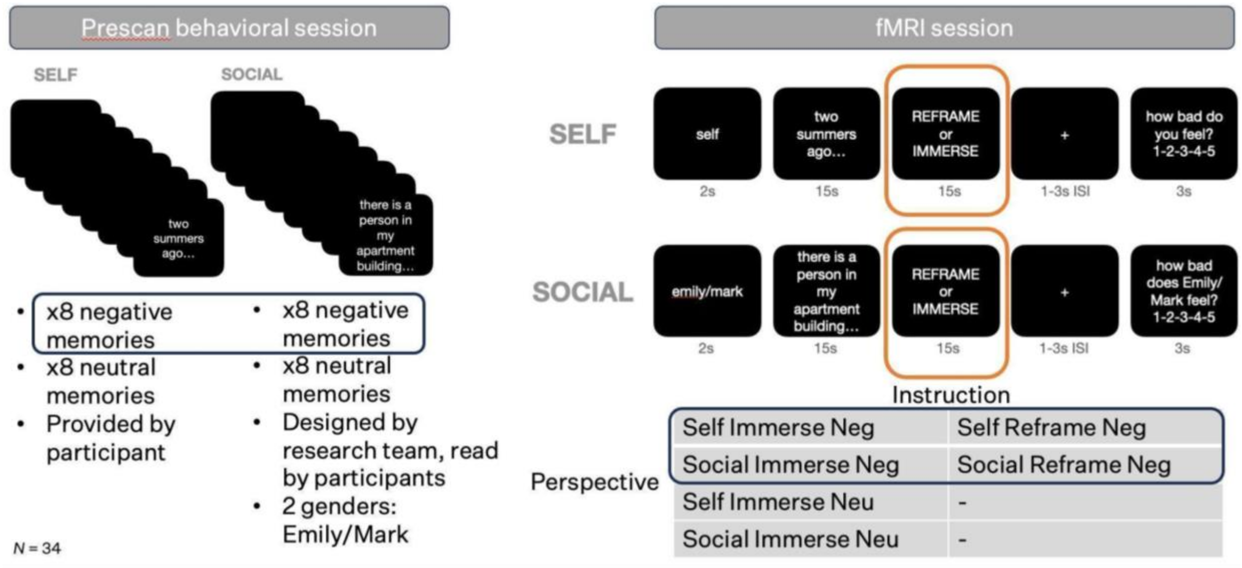


Figure 2. Overall study design. Participants first came into the lab for a behavioral session where they provided 8 negative and neutral memories. They also read 8 of a gender-matched stranger's negative and neutral memories designed by the research team. In the next fMRI session, participants were cued with their own memories and the stranger's memories. They were asked to either immerse or reframe those memories before rating how bad they felt. Note that participants were only asked to immerse in the neutral memories as per standard reappraisal paradigms. The main conditions of interest in this paper were Self-Immerse-Neg, Self-Reframe-Neg, Social-Immerse-Neg and Social-Reframe-Neg.

In total, the session at the scanner lasted 2-hours with 45 minutes in the scanner. Eye-tracking data was collected during the scan, but this data was not analyzed and is not reported here. Scout and anatomical scans were collected first. Along with the current task, participants completed another task involving similar instructions, but in response to aversive images. This task was presented in counterbalanced order with the current task and its results will be reported in a separate manuscript. A field map scan was collected in between tasks. After the scan, participants were asked to write out examples of what they had thought about when reframing their own or the target's memories for the Self and Social conditions. Participants were compensated $120 at the end of the experiment.

fMRI Image Acquisition

Imaging data were collected with a 3T Siemens Prisma MRI scanner with a 64-channel head/neck coil. The scanner is located in the MR Imaging Center of the Zuckerman Institute located in the Manhattanville campus of Columbia University. Structural volumes were acquired using a high-resolution T1-weighted sagittal 3D MPRAGE sequence yielding 1-mm^3 isotropic voxels. Functional volumes were acquired using a T2*-sensitive multiband echo-planar imaging sequence with the following parameters: repetition time = 2000 ms, echo time = 30 ms, flip angle = 77°, field of view = 204 mm and voxel dimensions of 2x2x2mm. Each volume consisted of 66 interleaved 2-mm slices with a multiband factor of 3, acquired near parallel to the anterior commissure-posterior commissure axis. Two runs of 625 volumes were collected.

Behavioral Analyses

Analysis of behavioral data was conducted with R version 4.1.0 and RStudio version 2022.12.0+353. We used Spearman correlation to test the relationship between self- and social-reappraisal success.

fMRI Analyses

Preprocessing

Data preprocessing was conducted with fmriprep 1.2.8_20.2.6 (Esteban et al., 2018) and consisted of motion correction, co-registration of functional and structural data that accounted for estimated susceptibility distortion from a field map, and normalization to the standard Montreal Neurological Institute (MNI) brain template. Four participants with excessive head movements were excluded from further analyses, with the criteria for exclusion being at least 20% of volumes in either run with at least a 0.5 mm change in spatial location as estimated by framewise displacement.

General Linear Model

To construct the general linear model, we modeled the self-cue, social-cue, self-memory recall, social memory recall, self-reframe negative, self-immerse negative, self-immerse neutral, social-reframe negative, social-immerse negative and social-immerse neutral, rating (collapsed across self and social) and arrow task periods of each trial as boxcar functions convolved with the canonical hemodynamic response function. We left the fixation cross unmodelled to serve as an implicit baseline, as per standard procedure in modeling task-based autobiographical memory tasks (e.g. Doré et al., 2018). The data were spatially smoothed using a 6-mm full-width half-maximum 3D Gaussian kernel. Nuisance variables included in the model consisted of 6 head motion parameters, their temporal derivatives and quadratic terms, a high-pass filter (duration 128 s), up to two powers of polynomial trends, and controlled for the runs. TRs with spikes in global signal greater than 3 SDs were included as individual regressors. We then averaged the parameter estimates across both runs to get parameter estimates for each subject for each contrast of interest. Finally, we averaged all subjects' β images for each contrast to obtain a group-level β image. All group level contrasts were FDR corrected at $p < .05$. Neuroimaging data were analyzed using NLTools and all coordinates are reported in MNI space.

What brain regions were commonly engaged during self- and social-reappraisal?

Standard univariate conjunction map. As in prior studies examining self-reappraisal of autobiographical memories (e.g. Silvers et al., 2016; Doré et al., 2018), the self-reappraisal contrast map was defined as (Self-Reframe-Neg > Self-Immerse-Neg), which controlled for engagement of regions involved in autobiographical recollection, in general. By a similar logic, the social-reappraisal contrast was defined as (Social-Reframe-Neg > Social-Immerse-Neg). To find what regions were commonly engaged by self- and social-reappraisal, we computed a conjunction of the self-reappraisal and social-reappraisal contrast maps using FSL easythresh_conj script using a standard z threshold of 3.1 and *p* value of 0.05 (Jenkinson et al.., 2012).

Bayes factor. For this analysis, we first calculated the voxel-wise t statistic values for the self- and social-reappraisal contrast beta maps. Then, we transformed these t statistic maps into Bayes factor maps, which reflect the ratio of the marginal likelihoods of alternative hypothesis (activation) or null hypothesis (no activation) given the data. Values greater than 1 indicate support for the alternative (e.g., a Bayes factor of 5 = 5:1 odds in favor of the alternative), and values less than 1 indicate support for the null (e.g., 0.2 = 5:1 odds in favor of the null). Assuming normally distributed variables, as is common in parametric statistics, allows t-values to be converted to Bayes factors in computationally efficient manner (Rounder et al., 2009), enabling tests at each voxel (Kragel et al., 2018). To establish evidence in favor of a null effect for our sample size, we required a BF ratio of 5:1 in favor of the null (Supplemental Figure 1). This corresponded to a log odds threshold of 3.2 and -3.2 using a 2*log(Bayes factor) transformation for a Bayes factor of 5 and 0.2 (1 to 5) respectively. This ratio represents moderate evidence to detect the alternative or the null hypothesis and satisfies correction for multiple comparisons (FDR $q < .05$).

To identify neural regions commonly engaged for self- and social-reappraisal, we identified voxels in the self- and social-reappraisal log-odds BF maps that (a) both had values above our positive threshold of 3.2 and (b) had positive t statistic values in the self- and social-reappraisal t statistic maps (i.e. greater activation in Self/Social Reframe-Neg > Self/Social Immerse-Neg)). We retained clusters that had at least 15 contiguous voxels as an extent threshold (Bo et al., 2024).

ROI-based multivariate pattern analyses. In addition to the whole brain analyses, we wanted to provide a strong and confirmatory test of our hypotheses by examining activity in regions known from prior work to be associated with processes of interest. As such, as a second test of our hypotheses, we performed analyses in *a-priori*, spatially distinct ROIs in lateral PFC shown in prior work to be associated with cognitive control and reappraisal (Kalish et al., 2009; Buhle et al., 2014; Powers et al., 2019; Denny et al., 2023). Here, we sought to determine whether and how self- and social-reappraisal may have differentially engaged regions commonly engaged during reappraisal, as evidenced by different multivariate patterns within these regions. To do this, we took two analytic approaches. First, we ran pairwise support vector machine classifiers on the conjunction mask derived from the standard univariate contrasts (e.g. Weaverdyck et al., 2020). Second, we similarly ran a pairwise support vector machine classifier on two control regions of *a-priori* interest because they are the prefrontal regions most commonly engaged by reappraisal (c.f meta-analyses on reappraisal: Buhle et al., 2014; Morawetz et al., 2017; Denny et al., 2023). These dorsolateral prefrontal cortex and ventrolateral prefrontal cortex ROIs were defined using the Schaefer 100 parcellations-17 Network atlas (Schaefer et al., 2018). We chose the Schaefer atlas as it comprehensively defines brain regions based on both task-based and resting-state fMRI. It is accessible, replicable and widely used and allows for different levels of resolution, allowing researchers to choose the exact region of interest and compare with other studies in the literature. In addition, all support vector machine classifiers were subjected to 6-fold cross validation with a linear kernel (Chang et al., 2021).

To correct for multiple comparisons and to test if the accuracies obtained were significantly above chance, we ran 10,000 non-parametric permutations (Stelzer et al. 2013) to obtain a null distribution for observed effects. At each permutation, a random subset of our sample had their labels for self- and social-reappraisal shuffled within each participant to gain one chance-level decoding accuracy. We then computed the probability of obtaining our classifier accuracy given the null distribution.

What brain regions were differentially engaged by self- and social-reappraisal?

Quantitative differences between self- and social-reappraisal.

Standard Univariate Contrasts**.** To examine quantitative differences between self- and social-reappraisal, we identified brain regions that (i) showed increased activity during self- and social-reappraisal (as determined by the previous conjunction analysis) and (ii) were preferentially activated during social-reappraisal, specifically – and not during other task conditions – as determined by a planned contrast (Social Reframe Neg > (Social Immerse Neg + Self Reframe Neg + Self Immerse Neg)) [2].

[2] We performed this planned contrast rather than a contrast of contrasts (i.e. (Social-Reframe-Neg >Social-Immerse-Neg) > (Self-Reframe-Neg > Self-Immerse-Neg)) as the latter analysis tests for cross-over interactions rather than regions that are preferentially and specifically activated for social-reappraisal.

Qualitative differences between self- and social-reappraisal.

Standard Univariate Contrasts. To determine what regions were involved in social-reappraisal that were not also engaged during self-reappraisal (i.e. regions qualitatively different in terms of their involvement in social vs. self-reappraisal), we identified regions in the planned social-reappraisal specific contrast that lay outside of the regions identified by the univariate conjunction analysis of regions engaged by both types of reappraisal.

Bayes factor. To use the Bayes factor approach to assess what regions were preferentially engaged by social-reappraisal, specifically, we identified voxels that (a) had values in the social-reappraisal log-odds BF map that were above the positive threshold of 3.2; (b) had values in the self-reappraisal log odds BF map that were below our negative threshold of -3.2 (i.e. not activated during self-reappraisal) and (c) had a positive t statistic value in the social-reappraisal t statistic maps (i.e. activation for Social Reframe Neg > Social Immerse Neg). We then retained clusters that had at least 15 contiguous voxels for statistical thresholding (Bo et al., 2024).

ROI-based multivariate pattern analyses. In addition to the whole brain analyses, we wanted to provide a strong confirmatory test of our hypotheses by examining activity in regions known from prior work to be associated with processes of interest. As such, as a second test of our hypotheses, we performed analyses in a-priori ROIs in mPFC and right temporal pole shown in prior work to be associated with mentalizing (e.g. Labar et al., 1995; Holloway, 1983; Semendeferi et al., 2001; Olson et al., 2007; Herlin et al., 2021; Schurz et al., 2021). To test whether and how the patterns may differ between self- and social-reappraisal in the regions that are preferentially activated for social-reappraisal, we adopted two approaches parallel to our approach in answering what self- and social-reappraisal had in common. First, we ran pairwise support vector machine classifiers on the qualitatively different regions derived from the standard univariate contrasts. Second, to assess how patterns within our hypothesized mPFC and temporal pole ROIs differentiated self- and social-reappraisal, we similarly ran a pairwise support vector machine classifier on these functional ROIs from the Schaefer parcellation (Schaefer et al., 2018). All support vector machine classifiers had 6-fold cross validation with a linear kernel (Chang et al., 2021). We picked our mPFC ROI from the 400 parcellations-17 Network atlas and the temporal pole ROI from the 100 parcellations-17 Network atlas. In parallel with the *a-priori* ROI analysis for common regions between self- and social-reappraisal, we chose the Schaefer atlas as it is accessible, replicable and widely used and allows for different levels of resolution, allowing researchers to choose the exact region of interest and compare with other studies in the literature. We chose our mPFC ROI from a more granular parcellation as we had specific hypotheses about the role of the anterior most portion of mPFC, given its involvement in perspective-taking and mental simulation (Holloway et al., 2001; Gaesser 2020). The 400 parcellation anterior mPFC region best approximated this region while no region in the 100 parcellation network covered this exact region.

To correct for multiple comparisons and to test if the accuracies obtained are significantly above chance, we ran 10,000 non-parametric permutations (Stelzer et al. 2013) to obtain a null distribution for our effect. At each permutation, a random subset of our sample had their labels for self- and social-reappraisal shuffled within each participant to gain one chance-level decoding accuracy. We then computed the probability of obtaining our classifier accuracy given the null distribution.

What brain regions were modulated by self- and social-reappraisal?

Standard Univariate Contrasts. To examine what reappraisal modulates in general, we computed a main effect contrast of Immerse > Reframe for negative autobiographical memories. We then isolated our search for mid-orbitofrontal cortex and parahippocampus as per our literature review and reported other results in the Supplemental Materials. All whole-brain maps are FDR-corrected, $q < .05$.

Bayes factor. To examine which brain regions are modulated by both self- and social-reappraisal, we identified voxels in the self- and social-react (i.e. Immerse > Reframe) log-odds BF maps that (a) both had values above our positive threshold of 3.2 and (b) had positive t statistic values in the self- and social-react t statistic maps (i.e. greater activation in Self/Social Immerse-Neg > Self/Social Reframe-Neg)). We retained clusters that had at least 15 contiguous voxels as an extent threshold (Bo et al., 2024).

Results

Behavioral results

Manipulation check

To confirm that both self- and social-reappraisal were effective in down-regulating negative affect, we examined the changes in behavioral ratings of negative affect across reappraisal conditions. As expected, in both the self- and social-reappraisal conditions, ratings of negative affect were highest in the Immerse Negative condition (Self: $M = 3.80$, $SD = .56$; Social: $M = 3.73$, $SD = .60$), lower in the Reframe Negative condition (Self: $M = 2.47$, $SD = .64$; Social: $M = 2.60$, $SD = .61$), and lowest in the Immerse Neutral condition (Self: $M = 1.21$, $SD = .29$; Social: $M = 1.60$, $SD = .32$). Paired *t*-tests indicated that for both conditions, the mean ratings in the Reframe Negative conditions were significantly lower than the mean ratings in the Immerse

Negative conditions (Self: $M_{\text{Diff}} = -1.33$, 95% CI [-1.60, -1.06], $t(33) = -9.96$, $p < .001$; Social: $M_{\text{Diff}} = -1.13$, 95% CI [-1.38, -.88], $t(33) = -9.30$, $p < .001$), indicating that participants were able to successfully use reappraisal to down-regulate their emotional responses to negative memories, and also perceived that they would successfully help the target to regulate their emotions (see Figure 3). Paired *t*-tests also indicated that, as in prior studies of reappraisal, the mean ratings in the Immerse Neutral conditions were significantly lower than the mean ratings in the Reframe Negative conditions (Self: $M_{\text{Diff}} = -1.26$, 95% CI [-1.49, -1.04], $t(33) = -11.39$, $p < .001$; Other: $M_{\text{Diff}} = -1.00$, 95% CI [-1.19, -.80], $t(33) = -10.52$, $p < .001$; see Figure 3).

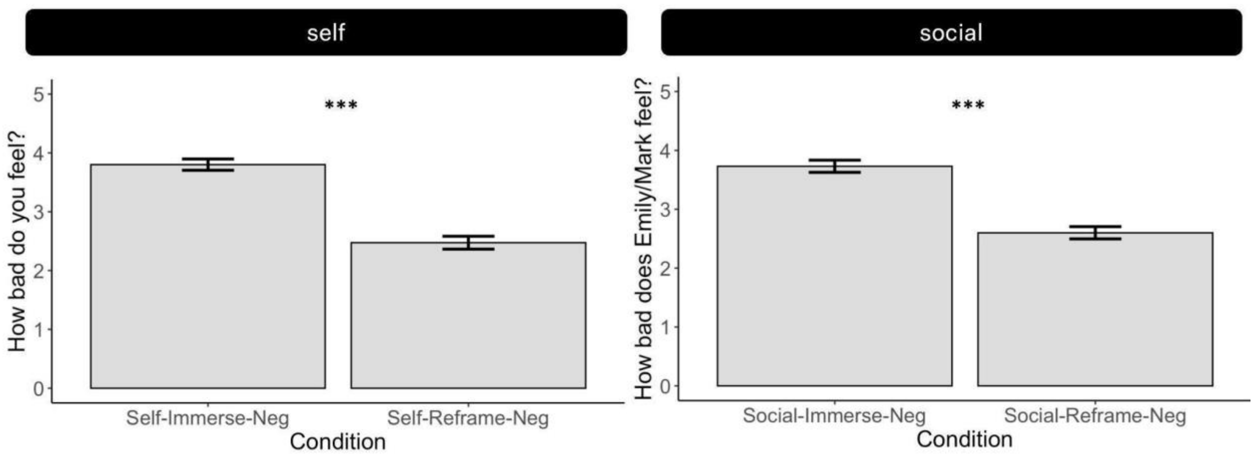


Figure 3. Behavioral ratings of negative affect after reframing and immersing in one's own negative memories and a gender-matched stranger's negative memories. Participants felt better when they reframed their own memories than when they immersed themselves in their own memories. Similarly, participants felt better when they reframed a stranger's memories than when they immersed themselves in the stranger's memories. *** indicates $p < .001$.

A paired sample *t*-test indicated that there was no significant difference between the Immerse Negative ratings for the Self and Social conditions ($M_{\text{Diff}} = .07$, 95% CI [-.084, .22], $t(33) = .93$, $p = .36$). This was expected as the set of negative memories for the target had been selected in pilot testing to approximate the average level of negative affect induced by participants' own memories. There was also no significant difference in ratings when Reframing for the Self and Social conditions (M_{Diff} = -.13, 95% CI [-.28, .027], $t(33) = -1.67$, $p = .10$). However, there was an unexpected significant difference between the Self and Social conditions for the Immerse Neutral condition (M_{Diff} = -.39, 95% CI [-.51, -.27], $t(33) = -6.56$, $p < .001$), such that Neutral memories in the Self condition were rated as less negative than neutral memories in the Social condition. These conditions were not of specific interest for the present paper.

Question 1: Relationship between self- and social-reappraisal success

Our first question was whether the capacities for self- and social-reappraisal were associated with each other. To assess this, we first calculated reappraisal success scores by subtracting the mean of the Reframe Negative Condition ratings from the mean of the Immerse Negative Condition, separately for the Self and Other conditions, and then correlated the success scores. Reappraisal success for self, and perceived success for social-reappraisal, were correlated positively ($r = .64$, $p < .001$, see Fig 4). Consistent with prior work (Doré et al., 2017), this finding indicated that, on a behavioral level, the ability to self-regulate may be associated with the perceived ability to regulate others.

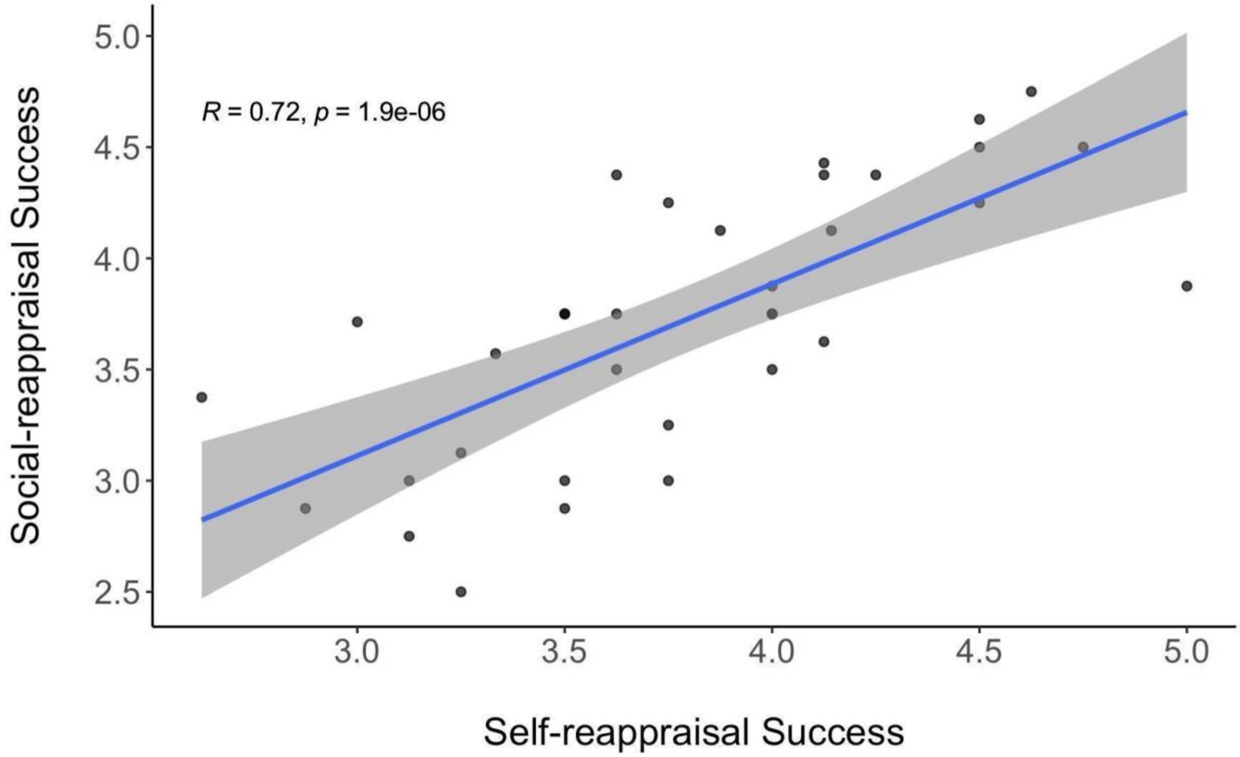


Figure 4. Correlation between self- and social-reappraisal success. Note that reappraisal success scores were calculated by subtracting the mean of the Reframe Negative Condition ratings from the mean of the Immerse Negative Condition, separately for the Self and Social conditions. Self-reappraisal success score indexes how effectively the participant downregulated one's own negative emotions, while the social-reappraisal success score indexes the participant's perceived effectiveness of their reappraisal in downregulating the target's emotions.

Question 2: What brain regions were commonly engaged by both self- and social-reappraisal?

Univariate Analyses: Self- and social-reappraisal activated common control regions

Standard univariate conjunction analysis. We found that both self- and social-reappraisal recruited the dorsolateral and ventrolateral prefrontal cortex, dorsomedial prefrontal cortex, temporoparietal junction, temporal pole, cingulate cortex and cerebellum, all localized in the left hemisphere (Fig 5A, Supplemental Materials Table 2). These are all regions previously implicated in the neural bases of self-reappraisal, in general (Buhle et al., 2014, Morawetz et al., 2017; Picó-Pérez et al., 2019; Denny et al., 2023).

Bayes factor analysis. The Bayes factor analysis also revealed that self- and social-reappraisal recruited the left dlPFC, left vlPFC, bilateral dmPFC, left TPJ, left temporal pole, cingulate cortex and cerebellum (Fig 5B, Supplemental Materials Table 2).

Multivariate Analyses: Self- and social-reappraisal showed similar multivariate patterns of activation within commonly recruited control regions

Classifier Approach.

Univariate conjunction map. If commonly engaged regions are indeed performing similar computations, then we would expect that the activity within these regions for self- and social-reappraisal would be indistinguishable. Indeed, we found that this was the case: the classifier was not able to differentiate the neural patterns for self- and social-reappraisal (Fig 5C, accuracy: 38%; p = .96, null = 51%).

A-priori ROIs. We also tested the similarity of multivariate patterns associated with self- and social-reappraisal within *a-priori* ROIs for the two PFC control regions most commonly recruited by self-reappraisal. The support vector machine classifier was unable to differentiate the neural patterns between self- and social-reappraisal in both the dorsolateral (accuracy: 56%; p = .16, null = 50%) and ventrolateral prefrontal cortex ROIs (Fig 5C, accuracy: 56%; p = .14, null = 50%).

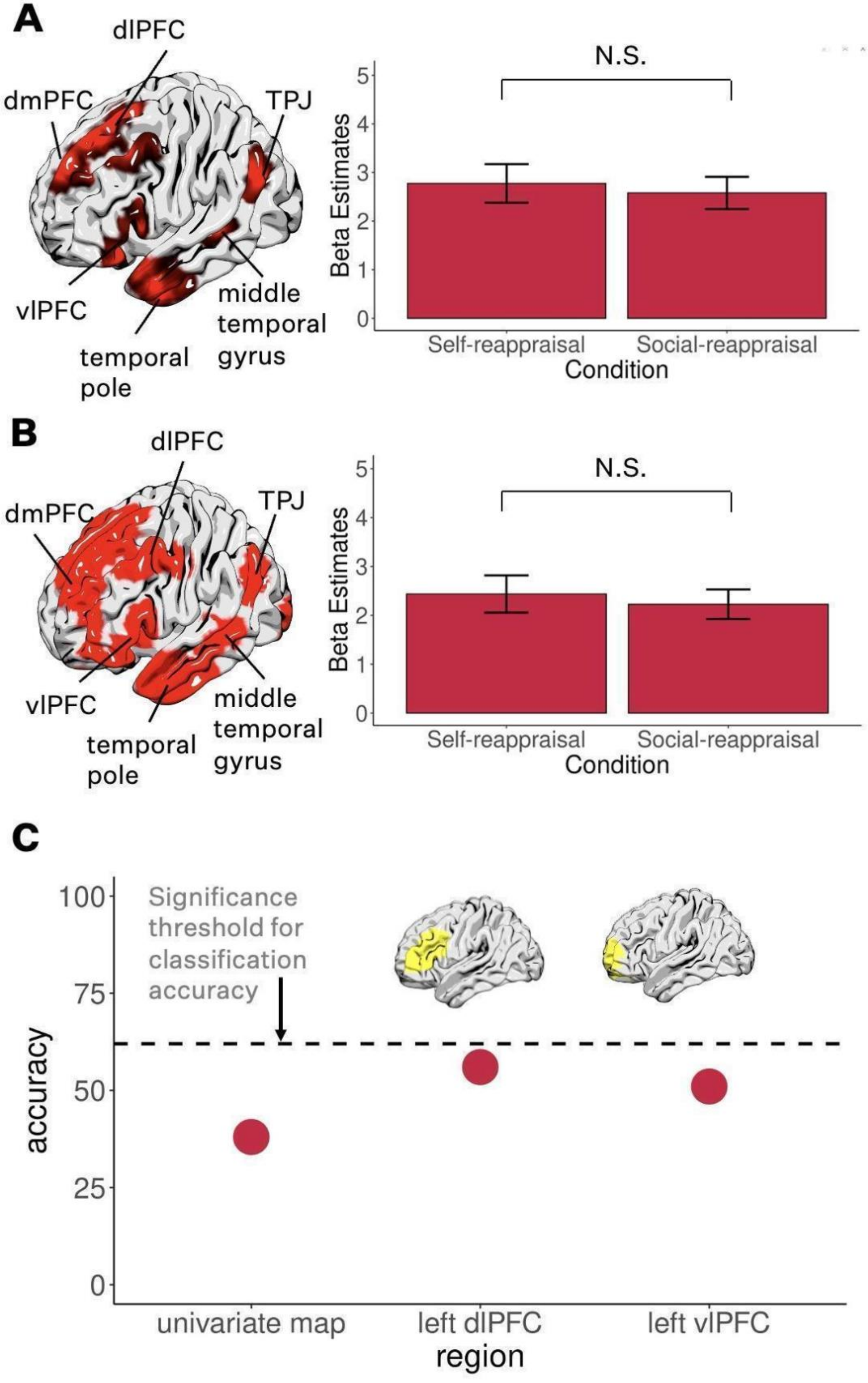

A
dlPFC
dmPFC
TPJ
vlPFC
temporal pole
middle temporal gyrus
N.S.
Beta Estimates
Self-reappraisal
Social-reappraisal
Condition
B
dlPFC
dmPFC
TPJ
vlPFC
temporal pole
middle temporal gyrus
N.S.
Beta Estimates
Self-reappraisal
Social-reappraisal
Condition
C
Significance threshold for classification accuracy
accuracy
univariate map
left dlPFC
left vlPFC
region

Figure 5. *What regions were commonly engaged by self- and social-reappraisal?* **Panel A** shows commonly recruited regions from a standard univariate conjunction analysis (FDR $q < .05$); **Panel B** shows commonly recruited regions from a Bayes factor conjunction analysis; **Panel C** shows the classification accuracy of a support vector machine classifier in distinguishing self- and social-reappraisal within the commonly recruited brain regions from panel A and *a-priori* dorsolateral and ventrolateral ROIs associated with cognitive control / reappraisal.

Question 3: What brain regions were differentially engaged by self- and social-reappraisal?

Quantitative differences: Social-reappraisal showed greater activation in commonly recruited control regions

Standard univariate contrasts. Relative to self-reappraisal, social-reappraisal showed greater activation in left dorsolateral and ventrolateral prefrontal cortex, dorsomedial prefrontal cortex, supplementary motor area, left temporoparietal junction, left temporal pole and the basal ganglia (Fig 6A, Supplemental Materials Table 3).

Qualitative differences: Social-reappraisal recruited additional control and mentalizing regions compared to self-reappraisal

Univariate analyses.

***Standard univariate contrasts*.** Social-reappraisal recruited additional control and mentalizing regions, including greater swathes of the left dorsolateral and ventrolateral prefrontal cortex, left supplementary motor cortex, left temporoparietal junction, left middle temporal gyrus, left temporal pole, left basal ganglia and left cerebellum. Additionally, social-reappraisal recruited the right ventrolateral prefrontal cortex, right temporal pole and right cerebellum (Fig 6B, Table 2 Supplemental Materials).

Bayes factor analysis**.** Social-reappraisal recruited additional control and mentalizing regions that were not engaged by self-reappraisal, including areas of the medial prefrontal cortex, right temporal pole and right ventrolateral prefrontal cortex (Fig 6C, Supplemental Materials Table 3).

Classifier Approach.

A-priori ROIs[3]. Our classifier was also able to successfully differentiate the multivariate patterns between self- and social-reappraisal within the mPFC (accuracy = 63%, p = .02, null = 52%) and right temporal pole (accuracy = 62%, p = .05, null = 52.5%) (Fig 6D) ROIs.

[3] We excluded the univariate map describing qualitative differences between self and social-reappraisal from the classifier analysis. As the univariate map already details regions that are differentially activated by self and social-reappraisal, it would be circular to run the classifier on the same regions.

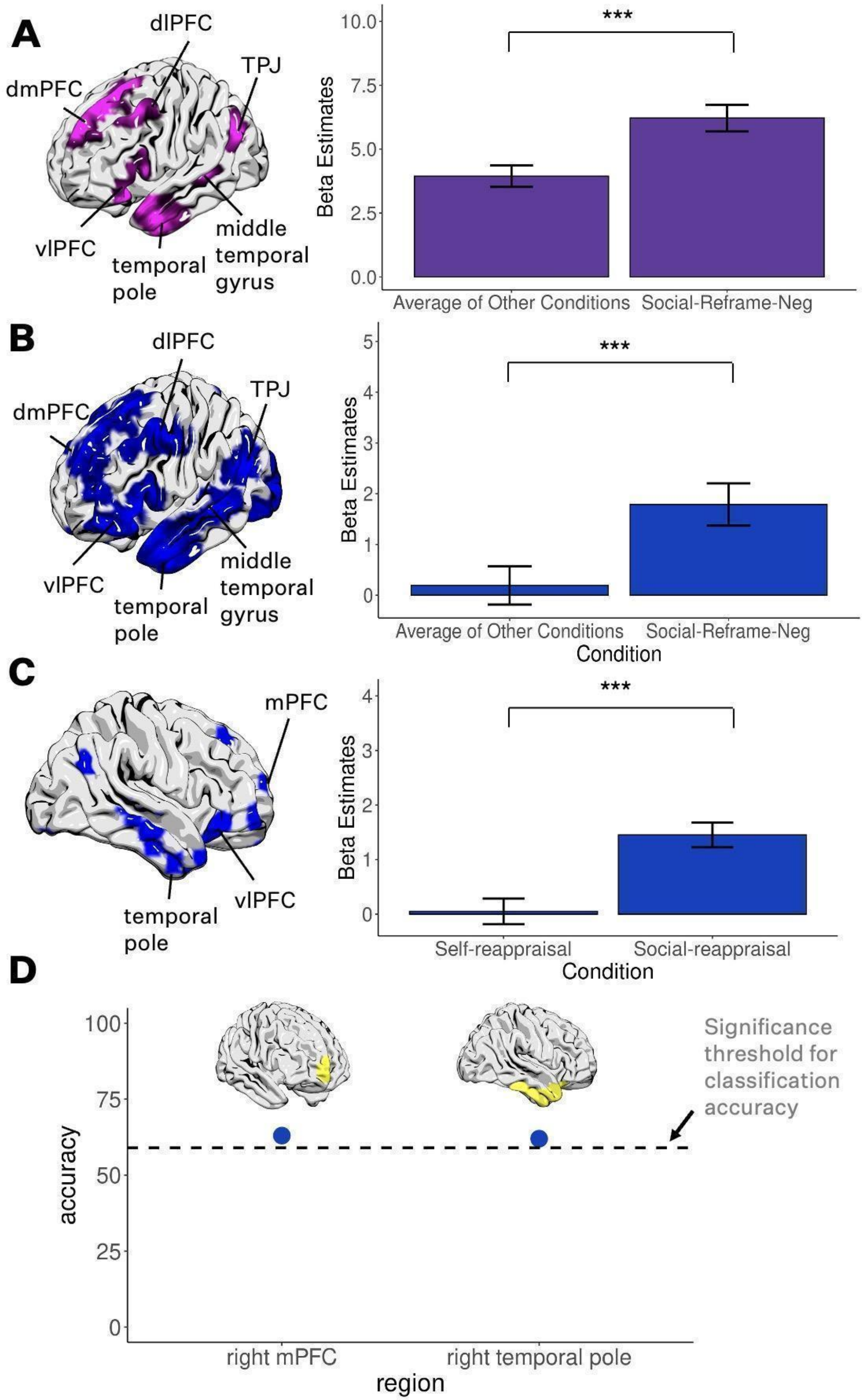

A
dlPFC
TPJ
dmPFC
vlPFC
temporal pole
middle temporal gyrus
***
Beta Estimates
10.0
7.5
5.0
2.5
0.0
Average of Other Conditions
Social-Reframe-Neg
B
dlPFC
TPJ
dmPFC
vlPFC
temporal pole
middle temporal gyrus
***
Beta Estimates
5
4
3
2
1
0
Average of Other Conditions
Social-Reframe-Neg
Condition
C
mPFC
temporal pole
vlPFC
***
Beta Estimates
4
3
2
1
0
Self-reappraisal
Social-reappraisal
Condition
D
accuracy
100
75
50
25
0
Significance threshold for classification accuracy
right mPFC
right temporal pole
region

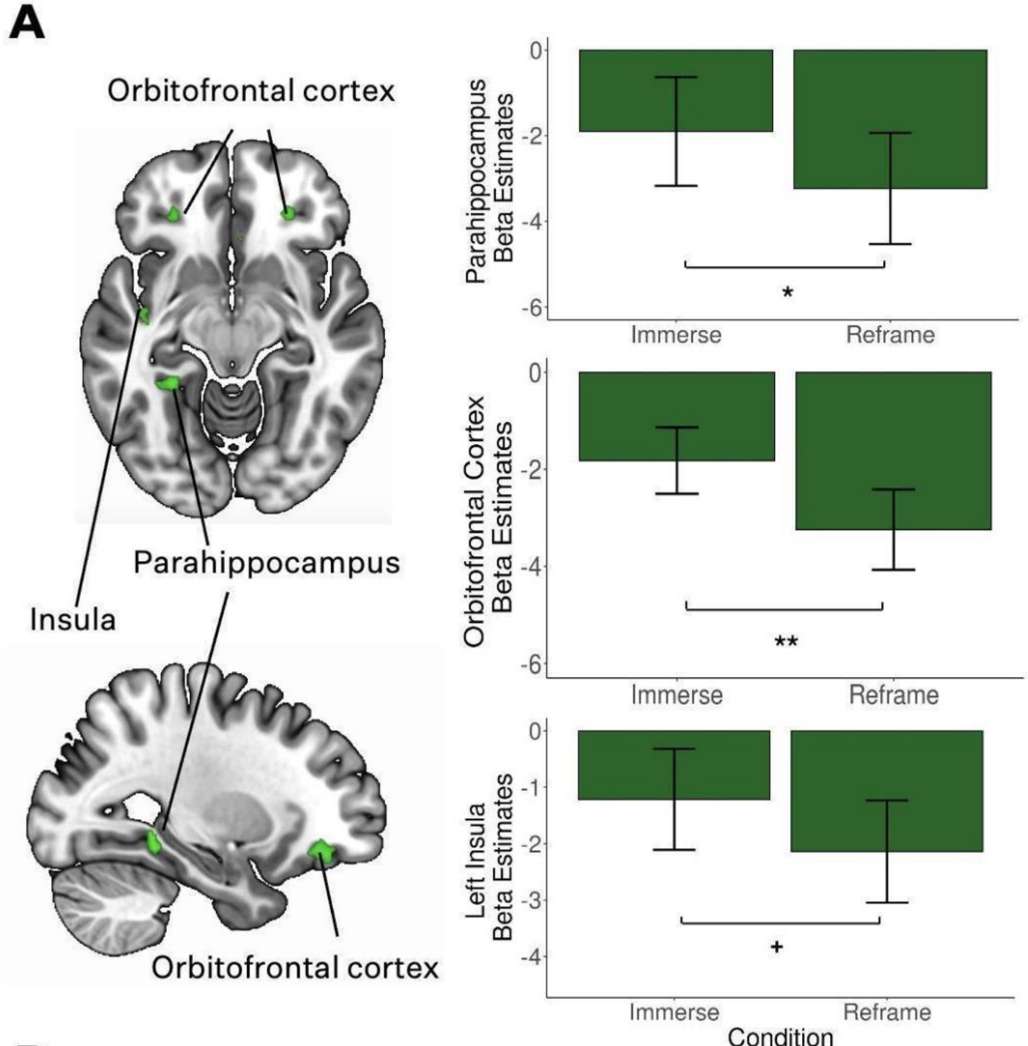
Figure 6. *What regions were differentially engaged by self- and social-reappraisal?* **Panel A** shows regions that were recruited during both self- and social-reappraisal, but whose engagement was quantitatively greater during social-reappraisal; **Panels B** and **C** show regions with qualitatively different patterns of activation during self- and social-reappraisal. **Panel B** shows results from a standard univariate contrast identifying regions that were preferentially recruited during social-reappraisal. **Panel C** shows results of a Bayes Factor analysis identifying regions that were specifically engaged during social-reappraisal. **Panel D** shows the results of a pattern classification analysis testing whether there were different profiles of cross-voxel activity for self- vs. social-reappraisal in regions from panel B and in mPFC and temporal pole ROIs that were of *a priori* interest (Schaefer et al., 2018).

Question 4: What brain regions were modulated by self- and social-reappraisal?

Univariate Analyses: Self- and social-reappraisal modulated brain regions associated with affective responding and perceptual representations

Standard univariate analysis. We found that, averaging across self- and social-reappraisal, reframing negative autobiographical memories down-regulated activity bilaterally in the mid-orbitofrontal cortex and in the left posterior parahippocampal gyrus (Fig 7A, Supplementary Materials Table 4). Reframing negative autobiographical memories also down-regulated the left insula across self- and social-reappraisal, though this effect was less robust ($p = .08$).

Bayes factor. Reframing negative autobiographical memories down-regulated activity in the mid-orbitofrontal cortex (Fig 7B, Supplementary Materials Table 4).


A
Orbitofrontal cortex
Parahippocampus
Insula
Orbitofrontal cortex
Parahippocampus Beta Estimates
Immerse
Reframe
*
Orbitofrontal Cortex Beta Estimates
**
Left Insula Beta Estimates
+
Condition

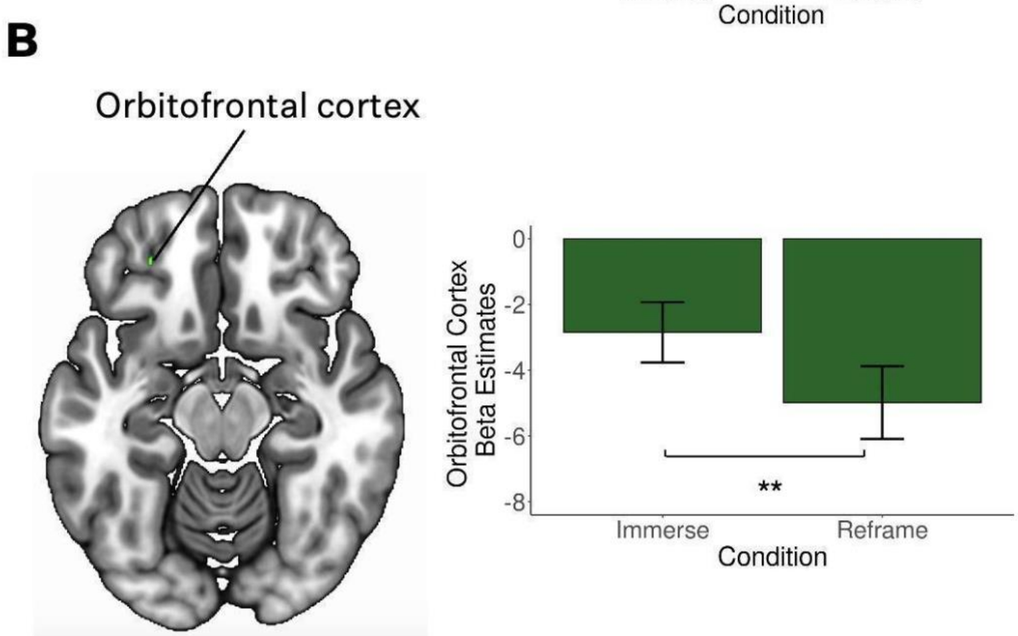

B
Orbitofrontal cortex
Orbitofrontal Cortex Beta Estimates
Immerse
Reframe
**
Condition

Figure 7. *What regions are modulated by self- and social-reappraisal?* **Panel A** shows regions of interest from a standard univariate analysis assessing main effect of Immerse > Reframe conditions (FDR $q < .05$); **Panel B** shows regions commonly modulated by both self- and social-reappraisal from a Bayes factor conjunction analysis. * indicates $p < .05$, ** indicates $p < .01$ and + indicates trending significance $p < .10$.

Discussion

Commonalities and differences between self- and social-reappraisal

Whether done for ourselves or to support others, reappraising (or reframing) the meaning of negative emotional experiences can be an effective way of boosting well-being and maintaining social relationships. Here, we provide the first comparison of the neural bases of self- and social-reappraisal. Behaviorally, we found that self- and social-reappraisal success were highly correlated. At the neural level, we obtained converging evidence for both similarities and differences between them using complementary univariate and multivariate approaches. On the one hand, univariate contrasts and Bayes factor analyses showed that self- and social-reappraisal recruited a common set of regions related to cognitive control, including left dorsolateral and ventrolateral prefrontal cortex and dorsomedial prefrontal cortex. Notably, multivariate patterns of activation within these regions and in *a-priori* dorsolateral and ventrolateral ROIs were indistinguishable for self- and social-reappraisal, suggesting that – within control regions – similar computations underlie self- and social-reappraisal. On the other hand, univariate contrasts and Bayes factor analyses showed that social-reappraisal was associated with (a) enhanced engagement of some commonly recruited control regions (i.e. a quantitative difference) as well as (b) recruitment of additional control regions in the right lateral prefrontal cortex as well as mentalizing regions such as the medial prefrontal cortex and right temporal pole (i.e. a qualitative difference). Notably, multivariate pattern classifiers could not distinguish self- and social-reappraisal in the control regions commonly recruited during self-reappraisal and social-reappraisal. However, the underlying patterns were distinct in the control and mentalizing regions engaged only by social-reappraisal, as well as in the *a priori* ROIs for mentalizing regions. Finally, we also found that self- and social-reappraisal modulated activity in a common set of brain regions associated with affective responding and the perceptual representation of (remembered) scenes. Here, the strongest evidence was for modulation of the orbitofrontal cortex, with moderate evidence for modulation of the posterior parahippocampal gyrus and insula.

Implications for understanding the neural bases of self- and social-reappraisal

Taken together, our data suggest that social-reappraisal has a lot in common with self-reappraisal, insofar as they both rely heavily on the capacity to hold and manipulate reappraisals in working memory, to select relevant information for generating reappraisals (Thompson-Schill et al., 2005; Badre and Wagner, 2007) and to monitor one's emotional state (Ochsner et al., 2004). At the same time, social-reappraisal appears to be both more cognitively taxing and draws upon different mental representations of self and other. Regions of right ventrolateral prefrontal cortex that were qualitatively more active during social-reappraisal may be involved in selecting multiple competing alternative reappraisals of another person's situation (e.g. Satpute, Badre & Ochsner, 2014). Unlike reappraising for oneself, reappraising for someone else requires choosing a reappraisal that is both socially appropriate for the target (given who they are and their emotion-eliciting situation) and helps the target feel better, thereby placing greater demands on selection processes associated with the vlPFC.

Also important and unique to social-reappraisal were the right temporal pole and medial prefrontal cortex, which might inform social-reappraisal attempts by accessing and keeping in mind representations of socioaffective knowledge that support perspective-taking (Zaki & Ochsner, 2012; Amodio & Frith, 2016). The temporal pole is involved in accessing social knowledge and scripts (e.g. Olson et al., 2007), with the right temporal pole, in particular, implicated in affective empathy (Burton et al., 2008). Additionally, the anterior medial prefrontal cortex has been implicated in episodic construction and recall of prosocial acts (Gaesser & Schacter, 2014). Building upon these studies, our results are consistent with the idea that socioaffective scripts are accessed more when reappraising for someone else as compared to reappraising for oneself. It may be that reappraising for others requires placing their experiences in the context of plausible alternative scenarios that could evoke different emotions, as well as imagining how the other person may react to the reappraisals one offers.

The findings in the present study dovetail with two related studies that have compared self- and social-reappraisal (Hallam et al., 2014; Ngombe et al., *preprint*). Both studies have found that the lateral prefrontal cortex is recruited for both self- and social-reappraisal, while Hallam et al., 2014 additionally found that implementing social-reappraisal preferentially recruits mPFC and temporal pole. These converging results are noteworthy, given that the present study used stricter statistical controls (vs. uncorrected thresholds in Hallam et al., 2014) and adopted a within-participants design where the same individual generated their own reinterpretations for both themselves and for someone else (cf. Ngombe et al., *preprint* where one individual – the target – implemented a reappraisal generated by someone else – the regulator). Moreover, the present study utilized personally meaningful autobiographical stimuli (vs. standard negative IAPS images), thereby creating a relatively more naturalistic context to understand the common and distinct neural bases of self- and social-reappraisal.

In this regard, the fact that we observed modulation of orbitofrontal and parahippocampal regions by both kinds of reappraisal is notable for two reasons. First, these results extend to the social domain similar results observed in prior studies examining only self-reappraisal of autobiographical memories (e.g. Silvers et al., 2016; Doré et al., 2018). Second, in the context of the other findings discussed in the paragraphs above, these data suggest that self- and social-reappraisal differ primarily in the systems that implement the strategies rather than the regions whose activity they modulate.

Implications for studying the social regulation of emotion

Our study sheds light on the control and mentalizing processes that are needed to implement social-reappraisal, thereby supporting a process-oriented approach to studying the ways in which individuals can regulate each other's emotions (Reeck et al., 2016). The neural bases highlighted here add to a growing collection of studies examining the neural bases of social emotion regulation more generally (Ngombe et al., *preprint*; Hallam et al., 2014). Yet, it is the first study that directly examines providing self- vs. social-reappraisal using autobiographical memories, in a within-subjects design and with both univariate and multivariate approaches. In addition, the behavioral and neural similarity between self- and social-reappraisal may shed light on why people who are good self-regulators are often good providers of social regulation as well (Sahi et al., 2021). While there may be many reasons why individuals are effective at both self and social regulation, it is possible that it begins with the experience of being a target who receives effective regulatory support, and that we learn from the experience of being regulated how to regulate others (Morris et al., 2007; Wright et al., 2024). Such experiences may be particularly important in childhood, when the experience of secure care as a child (i.e. as a target) may provide an example for learning how to regulate our own and others emotions, laying the foundation for developing into being a good self-regulator and a good social regulator in adulthood (Bowlby, 1969; Costello et al., 2024).

Beyond social-reappraisal, however, the social regulation of emotion involves a broad and varied set of phenomena, all of which are in need of further investigation. Early research on social regulation examined the neural bases of receiving comforting touch (Coan et al., 2006; Sahi et al., 2021). Yet, as behavioral studies indicate (e.g. Swerdlow & Johnson, 2022), many other social emotion regulation strategies are used in daily life. This begs the question: do different social emotion regulation strategies depend on the same or different processes? Furthermore, many relationship researchers have studied the stress buffering effects of social presence and attachment security (e.g. Laurita et al., 2017), as have developmental psychologists who study the parental buffering of fear (e.g. Gunnar et al., 2017; Abramsom et al., 2024). Future work could seek to determine whether different forms of social regulation, such as those that are more nonverbal and relatively passive (e.g. presence and touch) as opposed to those that are verbal and more active (e.g. social-reappraisal) depend upon similar vs. different mechanisms.

Our findings also support theoretical models of neural regions involved in social emotion regulation. For example, Reeck and colleagues (2016) as well as Cohen & Arbel (2020) posited that control, mentalizing and reward systems may be involved in providing regulatory support to others. Indeed, we find evidence for control systems involved in manipulating and retrieving information and mentalizing systems for simulating and empathizing with others. We also found some evidence for reward systems implicated in providing social regulatory support (e.g. the basal ganglia), although this was not a key focus in our study. Future research can test the recruitment of reward systems implicated in providing social regulatory support with close others (e.g. family, close friends, partners). While stronger evidence for providing social regulatory support has typically been found with close others (e.g. Inagaki & Eisenberger, 2012), it is also plausible that chronically providing support to others may dampen reward responses (i.e. caregiver burnout).

Crucially, we do not claim that providing social-reappraisal feels demanding, even though providing social-reappraisal did engage control regions more at a neural level. Some behavioral research has shown that providing social-reappraisal feels easier than reappraising for oneself due to the greater psychological distance implicated in social-reappraisal (e.g. Doré et al., 2017; Matthews et al., 2020), while research from relationship science suggests that the difficulty of providing social-reappraisal depends on who we are reappraising for and the complexity of the emotional stressor involved (Digiovanni, He & Ochsner, in prep). The present study design is not able to tease these relationships apart as we did not collect behavioral measures of difficulty in providing social-reappraisal. These seeming inconsistencies in the literature strongly motivate a more thorough study of social emotion regulation across multiple levels of analysis, relationship types and emotional situations.

Implications for methods used to study the neural bases of reappraisal

One strength of our study is the use of a Bayes factor approach to complement standard univariate contrasts and multivariate approaches to analyzing data. In our study, the Bayes factor approach strengthened evidence concerning the common and distinct neural bases of self- and social-reappraisal. To wit: standard univariate contrasts and Bayes factor approaches converged in identifying a set of regions commonly recruited for both self- and social-reappraisal. Although the regions identified in each analysis were not identical, they did overlap substantially (e.g. 99% of the voxels in the univariate frequentist conjunction map overlapped with the common regions from the bayes factor analyses), suggesting that the results from both analyses are qualitatively similar. This serves as a validation check for Bayes factor analyses, as the statistical power needed to detect the alternative hypotheses in Bayes factor analysis is close to the frequentist threshold. Moreover, the Bayes factor approach provided evidence for neural regions unique to social-reappraisal. This approach complements standard univariate contrasts – as implemented in this paper – which reveal neural regions that are preferentially activated for social-reappraisal. Future research that aims to test hypotheses concerning multiple contrasts/conditions might consider using Bayes factor analysis, particularly when the tools are easily available to apply to existing univariate contrast maps (e.g. Bo et al., 2024).

Implications for clinical populations

One implication of our findings is that therapeutic techniques designed to enhance engagement of neural systems commonly recruited by either self- or social-reappraisal could make one better at both. Recent transcranial magnetic stimulation (i.e. TMS) work has shown, for example, that boosting activity in ventrolateral prefrontal cortex (Li et al., 2022; He et al., 2023; Sridhar et al.,

2024) can enhance self-reappraisal ability and improve symptoms in individuals with major depressive disorder. Building on such findings, it is possible that rTMS applied to commonly recruited left hemisphere control regions could enhance both self and social regulation ability. Indeed, depressed patients typically show reduced recruitment of the left hemisphere control regions, thereby raising curious competing hypotheses on whether depressed patients will benefit more or less from rTMS stimulations to regions commonly recruited in self- and social-reappraisal. Additionally, it is also possible that rTMS applied regions specifically associated with social-reappraisal may selectively boost one's ability to offer social reappraisals for others. Existing work demonstrates that rTMS to the dmPFC – a region associated with mentalizing processes – enhances mentalizing in individuals with psychiatric disorders (Enticott et al., 2014; Marques et al., 2019). Future work could explore whether such interventions applied to the temporal pole and mPFC can selectively change the implementation of social-reappraisal.

These possibilities may be especially relevant to caregiving, parental, relationship, substance use and clinical therapeutic contexts where socially managing difficult emotions is important (e.g. Herzog et al., 2024). For example, one proposed mechanism for the success of support groups (such as Alcoholics Anonymous) is the regulatory support of mentors (i.e. "sponsors") and individuals who have gone through or are simultaneously going through similar craving-induced emotional challenges (Kassel et al., 1993; Ferri et al., 2006). Additionally, providing social regulatory support to close others may also be qualitatively different from providing regulatory support to a stranger (Cohen & Arbel, 2020), as close others may be motivationally salient yet emotionally complex (Zayas et al., 2017). Therefore, the present study motivates future research to seriously examine the social elements of therapy and clinical support groups as key ingredients for clinical success.

Limitations and Future Directions

There are two key limitations to note with our study. First, our metric of social-reappraisal success was operationalized as the social regulator's prediction of how a target would feel after receiving social-reappraisals from them. While this method makes for a tractable fMRI paradigm, future work could seek to assess how a target feels in other ways, such as attempting to image regulators and/or targets while they engage in real time social regulatory interactions (e.g. using hyperscanning, Montague et al., 2002; Hasson et al., 2012). Second, in everyday life, social-reappraisals are often provided for people with whom we have an existing relationship (e.g. a friend, partner, family member), with the provision of social-reappraisals embedded within temporally extended patterns of dynamic interactions where verbal and nonverbal cues inform both partner's understanding of the other's interactions goals and emotional states (He et al., in prep). In the present study, we assessed social-reappraisal between participants and strangers who were not in active real-time dialogue with one another. With the growth of portable neuroimaging devices (e.g. functional near infrared spectroscopy) and advanced fMRI setups (e.g. hyperscanning), a truly dyadic approach to studying the social regulation of emotion will strengthen our understanding of the underlying mechanisms (Liu & Pelowski, 2014; Redcay & Schilbach, 2019; Dikker et al., 2021).

Despite the limitations outlined, this study is the first to compare the neural bases of providing self- and social-reappraisal within the same individual using complementary univariate and multivariate approaches. We believe that our study can add to this growing field to ask many more interesting, meaningful and novel questions about how the social regulation of emotion unfolds, its relation to self-regulation and its consequences for emotional and relational well-being.

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