

# Comparing the neural bases of self- and social-reappraisal

Zhouzhou He<sup>1,\*</sup>, Noga Cohen<sup>2</sup>, Jocelyn Shu<sup>1</sup>, Ke Bo<sup>3</sup>, Tor D. Wager<sup>3</sup>, and Kevin N. Ochsner<sup>1</sup>

<sup>1</sup>Department of Psychology, Columbia University, 1190 Amsterdam Avenue New York, New York, 10027, United States

<sup>2</sup>Department of Special Education, University of Haifa, 199 Abba Khoushy Ave, 3498838, Haifa, Israel

<sup>3</sup>Department of Psychological and Brain Sciences, Moore Hall 3 Maynard St, Dartmouth College, Hanover, NH 03755, United States

\*Corresponding author: Zhouzhou He, Department of Psychology, Columbia University, New York, NY 10027, United States. Email: zh2473@columbia.edu and ko2132@columbia.edu

To manage life's stressors, we can self-regulate our emotions or seek social regulatory support. One such strategy is reappraisal, where individuals reframe their own negative emotions (ie self-reappraisal) or help others reframe their negative emotions (ie 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 and mentalizing, such as dorsolateral and ventrolateral prefrontal cortex and dorsomedial prefrontal cortex. However, social-reappraisal was qualitatively different from self-reappraisal in its recruitment of additional control and mentalizing regions, such as the right lateral prefrontal cortex, medial prefrontal cortex, and right temporal pole. Notably, multivariate patterns within regions associated with mentalizing—but not control—were distinguishable between self- and social-reappraisal, suggesting that different kinds of information are drawn upon when reappraising for self vs. 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 posterior parahippocampal gyrus. Taken together, these data reveal the processes supporting self and social emotion regulation with implications for both basic and clinical research.

**Keywords:** autobiographical memory; control; fMRI; mentalizing; social emotion regulation.

## Introduction

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 2 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 & Ochsner 2024) or interpersonal emotion regulation (Zaki and Williams 2013; Dixon-Gordon et al. 2015; Hofmann et al. 2016; Niven 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), whereas the term “interpersonal emotion regulation” largely refers to dyadic contexts that involve explicit emotional disclosures (Rimé 2007; Zaki and 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 (ie “targets” of regulation; cf. Uchino 2006; Sahi et al. 2023), regulators offering support

(Inagaki and Eisenberger 2012; Cohen and Arbel 2020), and the relationship between targets and regulators (Rauers and Riediger 2023). However, there has been relatively little work on the psychological and neural mechanisms underlying these beneficial effects. Some research has begun to investigate the neural bases of being a target of social emotion regulation (eg Xie et al. 2016; Morawetz et al. 2021), yet very little work has examined the neural mechanisms underlying providing social regulatory support. This is surprising, given that theoretical accounts of social emotion regulation include the psychological processes engaged by regulators as well (Reeck et al. 2016). This paper seeks to elucidate these mechanisms using functional magnetic resonance imaging (fMRI) to compare and contrast the neural systems supporting attempts to socially regulate vs. self-regulate negative emotions.

We drew on 2 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, 2011; 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

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cognitive behavioral interventions (eg 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. 2021; Sahi et al. 2021a, 2021b). 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 (eg Doré et al. 2017; Shu et al. 2021; Sahi et al. 2021a, 2021b; Liu et al. 2021; Arbel et al. 2024).

With these considerations in mind, we reasoned that social-reappraisal (Sahi et al. 2021a, 2021b) 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 toward 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 may depend on common underlying mechanisms (Sahi et al. 2021a, 2021b). 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 et al. 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 (eg Buhle et al. 2014; Morawetz et al. 2017a, 2017b; Powers and 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 (Anderson and Phelps 2002). Such amygdala activity is also relatively less common in reappraisal studies that involve reframing (Denny et al. 2023), which was used in our paradigm. More generally, the amygdala is thought to serve a neuromodulatory function, and is not thought to be an “emotion” region per se (Anderson and Phelps 2001, 2002; LeDoux 2007; Inman et al. 2023). This means the amygdala

signals the presence of goal-relevant, and especially potentially threatening stimuli, and then influences how we attend to and encode them into memory (eg Phelps 2004, 2006). As such, it has a bias toward responding to novel stimuli, and in its responses tend to be transient and habituate relatively quickly (LeDoux 2007). Given that our study requires a sustaining mental representation of memories during the reframe vs. immerse period, we would not expect the amygdala to be involved. 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 (eg 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). The posterior parahippocampal gyrus has been associated with representing contextual information in episodic memory (eg Davachi 2006), and specifically with spatial contexts (Torres-Morales and Cansino 2024). Relative to the baseline immerse condition, where participants re-experience memories from a first person perspective, the reframing condition might be expected to create greater psychological distance for a given memory, and as such, may reduce activity in posterior hippocampal regions. Furthermore, 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 posterior 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 (Ferri et al. 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 (Ferri et al. 2006; Zaki and 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 and Ochsner 2012; Reeck et al. 2016; Tamir et al. 2016; Tamir and 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 (eg “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 (eg names, traits, scripts/schemas for social situations; Satpute et al. 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 and 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 and Frith 2003; Ross and 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 and Kensinger 2013a, 2013b). In prior studies (Silvers et al. 2016; Doré et al. 2018; Schneck et al. 2023), participants recalled their own negative autobiographical memories following 1 of 2 instructions: a *reframe* condition where participants were instructed to 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 (ie 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 2 factors—perspective (social and self) and instruction (reframe and immerse)—to produce 4 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 2 conditions—that is social reframe vs. social immerse—would identify activity related to social-reappraisal, controlling for what the 2 conditions had in common—that is 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 (eg McRae et al. 2008; Holland and Kensinger 2013a, 2013b), 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 2 types of analyses. The first were between conditions 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 (Rouder et al. 2009; Morey and Rouder 2011), which enables researchers to evaluate evidence both for and against hypotheses that involve patterns across multiple contrasts (eg 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

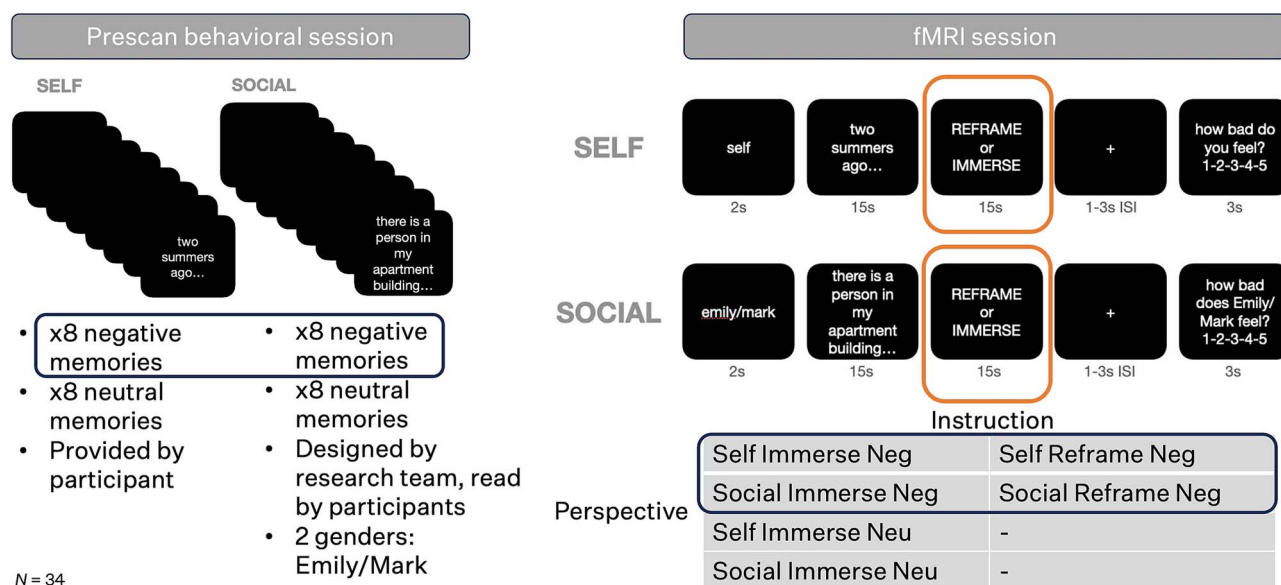
type of analysis is needed to identify regions that are specific to social-reappraisal, which requires establishing both a positive response to social-reappraisal and no difference (a null effect) for self-reappraisal.

These 2 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 4 neural hypotheses. First, we predicted that success in downregulating negative affect for oneself and others (ie self- and social-reappraisal success) would be correlated (Sahi et al. 2021a, 2021b). Second, we predicted that self- and social-reappraisal would both recruit a set of prefrontal and parietal regions generally involved in cognitive control and mentalizing (Duncan and Owen 2000; Miller and Cohen 2001; Zaki and Ochsner 2012; Dixon et al. 2017; Denny et al. 2023). We tested this prediction using conjunction analyses of univariate maps (ie standard univariate contrasts and Bayes factors) of regions engaged during self- vs. social-reappraisal, respectively. Second, we predicted that self- and social-reappraisal might differ in the extent to which they recruited control and mentalizing regions. This could manifest in 2 ways: either (a) a quantitative difference where social-reappraisal may tax common control and mentalizing regions more than self-reappraisal, as tested using an interaction contrast (ie social-reappraisal contrast > self-reappraisal contrast; cf. Silvers et al. 2016); or (b) a qualitative difference where social-reappraisal may recruit additional control and/or mentalizing regions not recruited by self-reappraisal, as tested using a Bayes factor analysis to identify regions selectively activated for the social reframe condition specifically. Third, we predicted that self- and social-reappraisal may also differ in the way they recruited control and mentalizing regions. Here, we tested whether multivoxel patterns could differentiate self vs. social-reappraisal within control and mentalizing regions that were engaged during both types of reappraisal. Finally, in keeping with prior studies of the self-reappraisal of autobiographical memories (eg Silvers et al. 2016; Doré et al. 2018), we predicted that both self- and social-reappraisal might modulate activity in regions associated with affective responding and the representation of perceptual aspects of stimuli, including the insula, orbitofrontal cortex, and posterior parahippocampal gyrus. We tested this prediction by assessing the effect of regulation instruction (Reframe vs. Immerse) on brain activity using standard univariate contrasts and Bayes factor analyses.

## Materials and methods

The study involved 2 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 yr 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 2 inches or were acquired in the past 6 mo, 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 based on effect sizes observed in ventrolateral PFC ROIs (where signal to noise ratio is poorest among reappraisal-related regions) in a representative prior fMRI study of reappraisal (Ochsner et al. 2004) that examined interactions between 2 independent variables concerning the way in which participants reappraised. This power analysis indicated that an N of 32 should provide 80% power to detect an interaction of our 2 independent variables (instruction × perspective) using a  $P < 0.05$  family wise error corrected threshold (after accounting possible attrition). Out of these 62 participants, only 40 participants participated in the fMRI session. Of these 40 participants, 4 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; 21% Black/African American; 21% White; 18% Hispanic/Latino; 24% Asian; 18% Other/Mixed).

All participants gave informed consent before participating in the study and all study procedures were approved by the Institutional Review Board at Columbia University (IRB-AAAR8654).

## 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 (Fig. 1). Prior to starting this task, participants were asked to practice writing 1 negative and 1 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 (ie “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 5 yr 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, eg 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 (eg 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 (ie participants made emotion and vividness ratings. See [Supplementary Table S1](#) in Supplemental Materials for examples of autobiographical memories). The modal age of the memories (~32%) was between a few weeks ago to the past year. Twenty-two percent of memories were based on events that occurred within the past 1–2 days, 23% of memories were based on memories that occurred more than 2 days ago but within the past couple of weeks and 24% of memories were based on events that occurred more than a year ago.

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 (ie 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. The memory stimuli used in the present study were modeled after negative autobiographical memories collected from real participants in another study ([Shu et al. 2021](#)). In this study, a group of 103 participants recollected negative autobiographical memories and rated the level of negative and neutral emotions associated with each one. From all memories collected in this pilot study, a subset were chosen for this study based on content (eg so that they depicted relatively common negative life events) and levels of negative emotional intensity (ie so that the average level of negative emotion associated with them matched the average of the overall pilot sample). These ratings were confirmed based on ratings collected from the current study sample. 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 h to complete, and participants were compensated \$30.

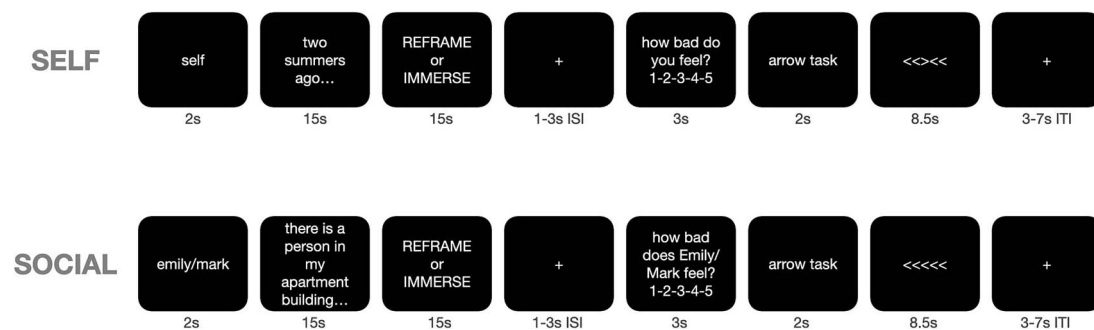
Participants had to meet 4 criteria before they were invited to complete the second session involving fMRI scanning: First, they had to score below the cutoff criteria on the depression and trait anxiety measures. Second, their written responses adhered to the instructions given (eg neutral memories 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 3 wk 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 (ie 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



**Fig. 2.** fMRI trial structure. Participants saw a cue indicating whether they will see their own negative memories or a stranger's negative memories for 2 s. then, participants saw a brief description of a negative memory for 15 s. next, participants were asked to either reframe or immerse in the negative memory for 15 s. participants subsequently saw a brief fixation cue for 1–3 s (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 (ie arrows task). This task was used as an active baseline (cf. Stark and Squire 2001; Kross et al. 2009; Doré et al. 2018) and was not of key interest.

memory so that it caused them less distress. Toward 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 (eg 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 Supplementary Table S1 for examples of memories).

### Task design

Participants completed an experimental task consisting of 2 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 (Fig. 1). As in prior studies of reappraisal using autobiographical memories (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.) (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 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—that is, 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 Fig. 2 for trial layout) consisted of a 2 s cue at the beginning of each block of 3 trials that indicated whether the next 3 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 1–3 s jittered ISI. On the next screen, participants used a 5-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 (Fig. 2). 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 and 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.

In total, the session at the scanner lasted 2 h with 45 min 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 debriefed at the end of the study that the memories in the Social condition were generated by the research team. Notably, however, no participants reported awareness of this fact. Instead, all participants reported believing that they were providing social-reappraisals to a real person during the study. Participants were compensated \$120 at the end of the experiment.

### fMRI image acquisition

Imaging data were collected with a 3 T 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<sup>3</sup> 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 2×2×2 mm. 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. 2019) 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-immense negative, self-immense neutral, social-reframe negative, social-immense negative, and social-immense 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 unmodeled to serve as an implicit baseline, as per standard procedure in modeling task-based autobiographical memory tasks (eg 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 2 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'  $\beta$  images for each contrast to obtain a group-level  $\beta$  image. All group level contrasts were FDR corrected at  $P < 0.05$ . Neuroimaging data were analyzed using NITools (version 0.5.1) and all coordinates are reported in MNI space. While the results for Immerse Neg > Immerse Neu and Social Recall > Self Recall contrasts do not directly address the questions in this paper, we report them in the [Supplemental Materials](#) to facilitate transparency and future meta-analyses.

### What is common between self- and social-reappraisal?

**Standard univariate conjunction map.** As in prior studies examining self-reappraisal of autobiographical memories (eg 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 (eg a Bayes factor of 5 = 5:1 odds in favor of the alternative), and values less than 1 indicate support for the null (eg 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 (Rouder 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 (Supplementary Fig. S1). This corresponded to a log odds threshold of 3.2 and -3.2 using a  $2 \times \log(\text{Bayes factor})$  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  $q < 0.05$ ).

To identify neural regions commonly engaged for self- and social-reappraisal, we identified voxels in the self- and social-reappraisal log-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 (ie 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).

### What is different between self- and social-reappraisal? Differences in the extent to which self- and social-reappraisal recruit common control and mentalizing regions

Quantitative differences between self- and social-reappraisal

**Standard univariate contrasts.** To examine quantitative differences between self- and social-reappraisal, we identified regions that (i) showed increased activity during self- and social-reappraisal (as determined by the previous conjunction analysis) and (ii) were activated more during social-reappraisal than self-reappraisal, as determined by an interaction contrast ([Social Reframe Neg > Social Immerse Neg] > [Self Reframe Neg + Self Immerse Neg]).

**Qualitative differences between self- and social-reappraisal Bayes factor.** To use the Bayes factor approach to assess what regions were specifically engaged by social-reappraisal, we identified voxels that (a) had values in the social-reappraisal log-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  $-3.2$  (ie not activated during self-reappraisal); and (c) had a positive t-statistic value in the social-reappraisal t-statistic maps (ie 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). To identify which regions may be unique to self-reappraisal, we identified voxels that (a) had values in the self-reappraisal log-BF map that were above the positive threshold of 3.2; (b) had values in the social-reappraisal log-BF map that were below our negative threshold of  $-3.2$  (ie not activated during self-reappraisal); and (c) had a positive t-statistic value in the self-reappraisal t-statistic maps (ie activation for Self Reframe Neg > Self Immerse Neg).

### Differences in how self- and social-reappraisal recruit control and mentalizing regions

In addition to univariate analyses that identify *where* and to *what extent* self- and social-reappraisal recruited control and mentalizing, we wanted to ask *how* self- and social-reappraisal may have differentially engaged control and mentalizing regions. This was tested by comparing the multivariate patterns within control and mentalizing regions. To do this, we took 2 analytic approaches. First, we ran pairwise support vector machine classifiers on a priori ROIs associated with cognitive control (Kalisch 2009; Buhle et al. 2014; Powers and LaBar 2019; Denny et al. 2023) as well as on control regions commonly recruited for both self- and social-reappraisal. Second, we also ran pairwise support vector machine classifiers on a priori ROIs associated with mentalizing and mentalizing regions commonly recruited for both self- and social-reappraisal. Testing multivariate patterns within a priori ROIs provides a strong and confirmatory test of our hypotheses by examining activity in regions known from prior work to be associated with processes of interest, while testing multivariate patterns within commonly recruited regions can tell us whether their computations differ despite similar magnitudes of activation. We detail these analyses separately below.

#### Multivariate pattern analyses within commonly-recruited regions

**Control processes.** We defined our commonly-recruited control regions for self- and social-reappraisal as the intersection of the conjunction mask and a Neurosynth-based meta-analysis

of regions associated with control processes. This intersection identified a region of interest within the left dorsolateral prefrontal cortex (MNI:  $[-36, 22, 50]$ , radius = 5 mm).

**Mentalizing processes.** We defined our commonly-recruited mentalizing regions for self- and social-reappraisal as the intersection of the conjunction mask and a Neurosynth-based meta-analysis of regions associated with mentalizing processes. This intersection identified 3 regions of interest: left temporal pole (MNI:  $[-50, 6, -32]$ , radius = 5 mm), dorsomedial prefrontal cortex (MNI:  $[-10, 58, 34]$ , radius = 5 mm), and left temporoparietal junction (MNI:  $[-50, -62, 34]$ , radius = 5 mm).

#### Multivariate pattern analyses within a priori ROIs

**Control processes.** We defined our a priori, spatially distinct ROIs in lateral PFC shown in prior work to be associated with cognitive control and reappraisal: dorsolateral and ventrolateral prefrontal cortex. These 2 ROIs were defined from a meta-analysis on cognitive reappraisal (MNI<sub>dLPFC</sub>: sub-peaks at  $[-34, 2, 54]$  and  $[-36, 14, 56]$ ; MNI<sub>vLPFC</sub>:  $[-50, 12, 20]$  and  $[-50, 22, 8]$ ; Buhle et al. 2014; Morawetz et al. 2017a, 2017b; Denny et al. 2023).

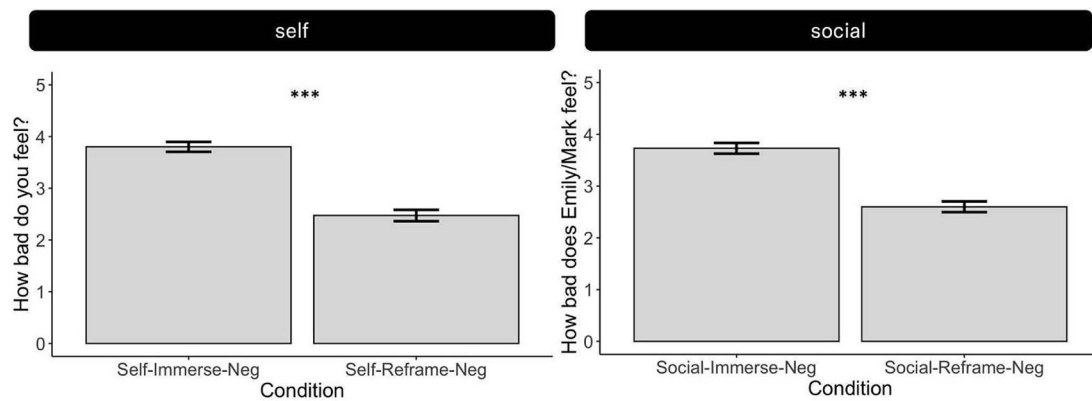
**Mentalizing processes.** We performed analyses in a priori ROIs in mPFC and right temporal pole shown in prior work to be associated with mentalizing (eg Holloway 1983; LaBar et al. 1995; Semendeferi et al. 2001; Olson et al. 2007; Herlin et al. 2021; Schurz et al. 2021). We picked our mPFC ROI from the 400 parcellations-17 Network atlas and the temporal pole ROI from the 100 parcellations-17 Network atlas. We chose the Schaefer atlas (Schaefer et al. 2018) 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 1983; Gaesser 2020). The 400 parcellation anterior mPFC region best approximated this region while no region in the 100 parcellation network covered this exact region.

All pairwise support vector machine classifiers were subjected to 6-fold cross validation with a linear kernel computed using Scikit-learn package within NLTools (version 0.5.1) in Python (Varoquaux et al. 2015; Chang 2021). We used a balanced cross-validation procedure which is less susceptible to outlier participants (Cohen 2010; Izuma et al. 2018; Vu et al. 2022). The NLTools package has also been successfully used for support vector machine analyses in other multivariate classification of neural patterns of negative affect (Chang 2021) and the bias toward self-focus (Geisler and Meyer 2023). To correct for multiple comparisons and to test if the accuracies obtained are significantly above chance, we ran 10,000 nonparametric 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 posterior parahippocampal gyrus as per our literature review and





**Fig. 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  $P < 0.001$ .

reported other results in the Supplemental Materials. All whole-brain maps are FDR-corrected,  $q < 0.05$ .

**Bayes factor.** To examine which brain regions are modulated by both self- and social-reappraisal, we identified voxels in the self- and social-react (ie Immerse > Reframe) log-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 (ie 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

### 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:  $M = 3.80$ ,  $SD = 0.56$ ; Social:  $M = 3.73$ ,  $SD = 0.60$ ), lower in the Reframe Negative condition (Self:  $M = 2.47$ ,  $SD = 0.64$ ; Social:  $M = 2.60$ ,  $SD = 0.61$ ), and lowest in the Immerse Neutral condition (Self:  $M = 1.21$ ,  $SD = 0.29$ ; Social:  $M = 1.60$ ,  $SD = 0.32$ ). 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:  $M_{Diff} = -1.33$ , 95% CI  $[-1.60, -1.06]$ ,  $t(33) = -9.96$ ,  $P < 0.001$ ; Social:  $M_{Diff} = -1.13$ , 95% CI  $[-1.38, -0.88]$ ,  $t(33) = -9.30$ ,  $P < 0.001$ ), 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 Fig. 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:  $M_{Diff} = -1.26$ , 95% CI  $[-1.49, -1.04]$ ,  $t(33) = -11.39$ ,  $P < 0.001$ ; Other:  $M_{Diff} = -1.00$ , 95% CI  $[-1.19, -0.80]$ ,  $t(33) = -10.52$ ,  $P < 0.001$ ; see Fig. 3).

A paired sample t-test indicated that there was no significant difference between the Immerse Negative ratings for the Self and Social conditions ( $M_{Diff} = 0.07$ , 95% CI  $[-0.084, 0.22]$ ,  $t(33) = 0.93$ ,  $P = 0.36$ ). 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 ( $M_{Diff} = -0.13$ , 95% CI  $[-0.28, 0.027]$ ,  $t(33) = -1.67$ ,  $P = 0.10$ ). However, there was an unexpected significant difference between the Self and Social conditions for the Immerse Neutral condition ( $M_{Diff} = -0.39$ , 95% CI  $[-0.51, -0.27]$ ,  $t(33) = -6.56$ ,  $P < 0.001$ ), 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 ( $r = 0.64$ ,  $P < 0.001$ , 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.

### Question 2: What is common between self- and social-reappraisal?

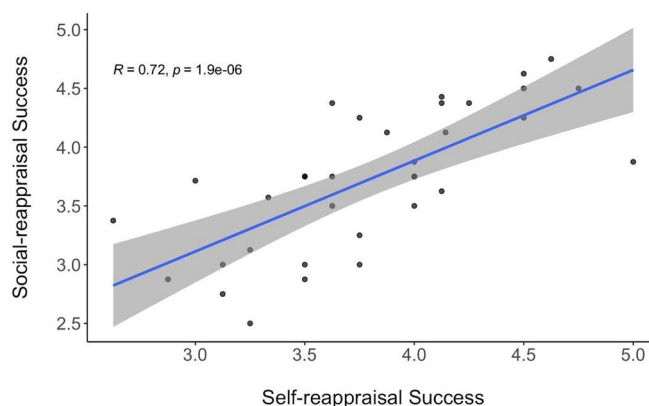
#### Self- and social-reappraisal activated common control and mentalizing regions

##### Standard univariate conjunction analysis

A conjunction of the self-reappraisal contrast (Self Reframe Neg > Self Immerse Neg) and social-reappraisal contrast (Social Reframe Neg > Social Immerse Neg) showed that both self- and social-reappraisal recruited the left dorsolateral and ventrolateral prefrontal cortex, dorsomedial prefrontal cortex, left temporoparietal junction, left temporal pole, caudate and right cerebellum (Fig. 5A, Table 1). These are all regions previously implicated in the neural bases of self-reappraisal, in general (Buhle et al. 2014, Morawetz et al. 2017a, 2017b; Picó-Pérez et al. 2019; Denny et al. 2023).

##### Bayes factor analysis

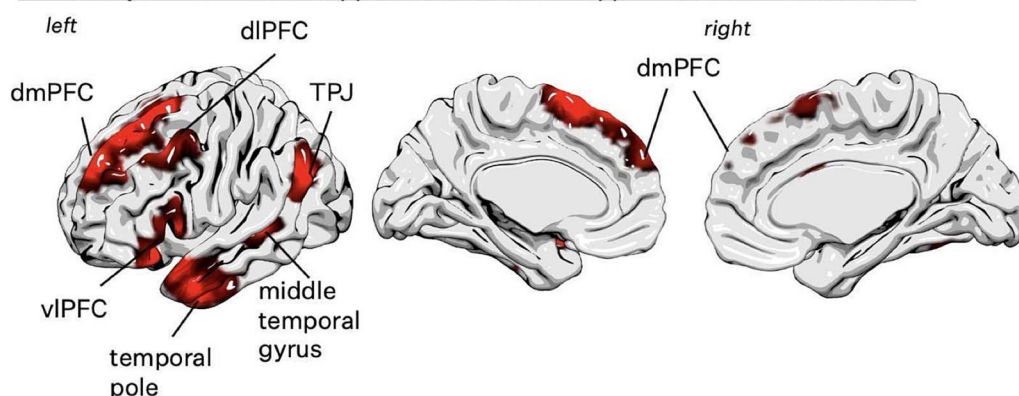
The Bayes factor analysis sought to identify regions that surpassed both log-BF and t-statistic thresholds. This analysis revealed that both self- and social-reappraisal recruited the left



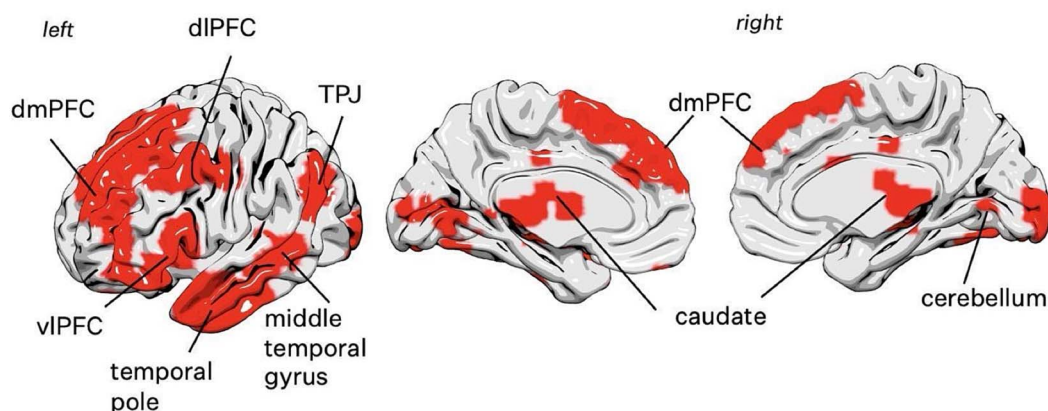
**Fig. 4.** Correlation between self- and social-reappraisal success. Note that reappraisal success scores were calculated by subtracting the mean of the reframe negative condition ratings from the mean of the immerse negative condition, separately for the self and social conditions. Self-reappraisal 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.

## What is common between self- and social-reappraisal?

### A. via conjunction of self-reappraisal and social-reappraisal univariate contrasts



### B. via Bayes factor analysis that identified voxels that were active in both self- and social-reappraisal



**Fig. 5.** What regions were commonly engaged by self- and social-reappraisal? Panel A shows regions commonly recruited as identified by a standard univariate conjunction analysis of the self-reappraisal and social-reappraisal contrasts (FDR  $q < 0.05$ ); panel B shows commonly recruited regions as identified by a Bayes factor conjunction analysis. This analysis identified voxels in the self- and social-reappraisal log-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 (ie greater activation in self/social reframe-Neg > self/social immerse-Neg). dmPFC = dorsomedial prefrontal cortex; dlPFC = dorsolateral prefrontal cortex; vlPFC = ventrolateral prefrontal cortex; TPJ = temporoparietal junction.

**Table 1.** What brain regions are commonly engaged by both self- and social-reappraisal?**Standard univariate conjunction analysis**Conjunction of (Self Reframe-Neg > Self Immerse-Neg) AND (Social Reframe-Neg > Social Immerse-Neg), standard *z* threshold of 3.1 and *P*-value of 0.05

Region	Coordinates (MNI)			Volume (mm <sup>3</sup> )	Peak <i>Z</i>
	<i>x</i>	<i>y</i>	<i>z</i>		
Left caudate	−16	6	14	2,720	4.5428
Right caudate	14	10	18	576	4.2671
Right cerebellum	30	−74	−28	4,576	4.2481
Left posterior inferior parietal cortex	−50	−64	32	2,576	4.5642
Left temporal pole	−52	2	−30	5,232	4.5468
Left superior temporal sulcus	−52	−4	−16	8	3.2047
Left orbital frontal gyrus	−48	30	−8	1,232	4.2759
Left superior temporal sulcus	−52	−36	0	920	4.0177
Left ventrolateral prefrontal cortex	−54	20	10	760	4.2004
Left superior frontal language area	−14	30	54	11,352	4.8181

**Bayes factor approach**

Voxels in the self- and social-reappraisal log-BF maps that (a) both had values above our positive threshold of 3.2 (equivalent to *BF* = 5), denoting substantial evidence in favor of the alternative hypothesis (Kass and Raftery 1995) and (b) had positive *t*-statistic values in the self- and social-reappraisal *t*-statistic maps (ie greater activation in Self/Social Reframe-Neg > Self/Social Immerse-Neg)

Region	Coordinates (MNI)			Volume (mm <sup>3</sup> )
	<i>x</i>	<i>y</i>	<i>z</i>	
Right putamen	30	−12	6	248
Left caudate	−16	6	12	5,680
Right caudate	14	8	16	2,336
Right cerebellum	32	−64	−50	1,312
Right cerebellum	4	−56	−46	232
Right cerebellum	30	−74	−30	10,904
Left temporal pole	−54	0	−28	9,456
Left inferior frontal gyrus	−52	28	0	4,856
Left superior temporal sulcus	−56	−36	0	3,544
Supplementary motor area	−14	32	52	28,608
Left ventrolateral prefrontal cortex	−38	58	0	528
Left temporoparietal junction	−50	−62	32	5,632
Right temporoparietal junction	54	−58	40	304
Right temporal pole	50	10	−36	536
Right superior temporal sulcus	54	−30	2	184
Right superior temporal sulcus	44	−36	4	152
Left anterior cingulate cortex	−8	34	30	216
Left V3	−32	−92	−10	1,184
Right V1	22	−96	−6	2,296
Left V1	−4	−68	2	400
Thalamus	20	−22	−6	312
Thalamus	−4	−30	6	336

dlPFC, left vlPFC, bilateral dmPFC, left TPJ, left temporal pole, cingulate cortex, and cerebellum (Fig. 5B, Table 1).

**Question 3: What is different between self- and social-reappraisal?**

Differences in the extent to which self- and social-reappraisal recruit common control and mentalizing regions

Quantitative differences: No differences in the amount of activation between self- and social-reappraisal within commonly recruited control and mentalizing regions

Standard univariate contrasts. An interaction contrast [Social Reframe-Neg > Social Immerse-Neg] > [Self Reframe-Neg > Self

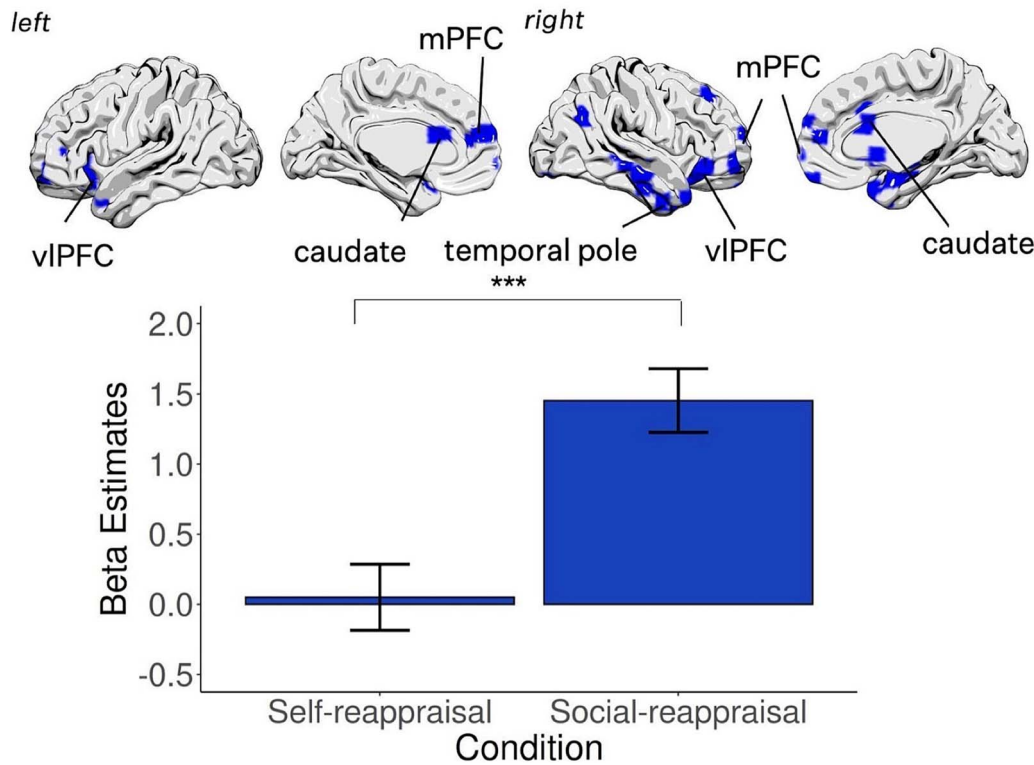
Immerse-Neg]) showed that—relative to self-reappraisal—social-reappraisal elicited a similar magnitude of activation in the left dorsolateral and ventrolateral prefrontal cortex, dorsomedial prefrontal cortex, supplementary motor area, left temporoparietal junction, left temporal pole, and the basal ganglia (Fig. 6, Table 2).

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

Bayes factor analysis. This analysis identified regions that surpassed the log-BF and *t*-statistic thresholds in the social-reappraisal contrast (Social Reframe-Neg > Social Immerse-Neg) but not in the self-reappraisal (Self Reframe-Neg > Self Immerse-Neg) contrast. Here, we found that social-reappraisal

## To what extent are self- and social-reappraisal different?

via Bayes factor analysis that identified voxels active during social-reappraisal but not during self-reappraisal



**Fig. 6.** To what extent were regions associated with control and mentalizing processes differentially engaged by self- and social-reappraisal? This figure depicts regions with qualitatively different patterns of activation during self- and social-reappraisal. Results are from a Bayes factor analysis that identified regions that were specifically engaged during social-reappraisal but not during self-reappraisal. This was operationalized as voxels that (a) had values in the social-reappraisal log-BF map that were above the positive threshold of 3.2; (b) had values in the self-reappraisal log-BF map that were below our negative threshold of  $-3.2$  (ie not activated during self-reappraisal) and (c) had a positive t-statistic value in the social-reappraisal t-statistic maps (ie activation for social reframe Neg > social immerse Neg). The bar graph depicts the activity of voxels selectively recruited for social-reappraisal. Among regions recruited during both self- and social-reappraisal (Fig. 5), none showed quantitatively greater engagement during social-reappraisal. mPFC = medial prefrontal cortex; vIPFC = ventrolateral prefrontal cortex. \*\*\* indicates  $P < 0.001$ .

**Table 2.** What brain regions were differentially engaged by self- and social-reappraisal?

**Quantitative differences between self- and social-reappraisal** (standard univariate contrast)

None found.

**Qualitative differences between self- and social-reappraisal** (Bayes Factor approach)

Voxels that (a) had values in the social-reappraisal log-BF map that were above the positive threshold of 3.2 (ie  $BF = 5$ ; substantial evidence in favor of the alternative hypothesis, Kass and Raftery 1995); (b) had values in the self-reappraisal log-BF map that were below our negative threshold of  $-3.2$  (ie  $BF = 0.2$ , substantial evidence that these voxels are not activated during self-reappraisal, Kass and Raftery 1995); and (c) had a positive t-statistic value in the social-reappraisal t-statistic maps (ie activation for Social Reframe Neg > Social Immerse Neg).

Region	Coordinates (MNI)			Volume (mm <sup>3</sup> )
	x	y	z	
Right basal ganglia	10	4	-4	144
Left caudate	-22	26	0	240
Right inferior temporal visual cortex	68	-16	-14	152
Right ventrolateral prefrontal cortex	42	30	-16	520
Right temporal pole	34	12	-38	384



recruited additional control and mentalizing regions that were not engaged by self-reappraisal, including areas of the anterior medial prefrontal cortex, right temporal pole, and right ventrolateral prefrontal cortex (Fig. 6, Table 2). We did not find any regions that were unique to self-reappraisal.

### **Differences in how self- and social-reappraisal recruit control and mentalizing regions** **Commonly-recruited regions**

**Control processes.** The classifier did not differentiate the multivariate patterns between self- and social-reappraisal within the left dorsolateral prefrontal cortex that was commonly recruited for both self- and social-reappraisal (accuracy = 47%,  $P = 0.62$ , null = 52%) (Fig. 7A).

**Mentalizing processes.** The classifier was able to differentiate the multivariate patterns between self- and social-reappraisal within the left temporal pole (accuracy = 66%,  $P = 0.007$ , null = 48%), but not within the left dorsomedial prefrontal cortex (accuracy = 56%,  $P = 0.18$ , null = 50%) and left temporoparietal junction (accuracy = 43%,  $P = 0.37$ , null = 52%) (Fig. 7A).

### **A priori regions**

**Control processes.** The classifier did not differentiate the multivariate patterns between self- and social-reappraisal within a priori ROIs for the 2 lateral prefrontal regions most commonly recruited by self-reappraisal (accuracy<sub>dipfc</sub> = 35%,  $P = 0.97$ , null = 50%; accuracy<sub>vlpfc</sub> = 51%,  $P = 0.37$ , null = 52%) (Fig. 7B).

**Mentalizing processes.** The classifier was also able to successfully differentiate the multivariate patterns between self- and social-reappraisal within the mPFC (accuracy = 63%,  $P = 0.02$ , null = 52%) and right temporal pole (accuracy = 62%,  $P = 0.05$ , null = 52.5%) ROIs (Fig. 7B).

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

### **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 in a main effect contrast of Immerse > Reframe, reframing negative autobiographical memories down-regulated activity bilaterally in the mid-orbitofrontal cortex and in the left posterior parahippocampal gyrus (Fig. 8A, Table 3). Reframing negative autobiographical memories also marginally down-regulated the left insula across self- and social-reappraisal ( $P = 0.08$ ).

#### **Bayes factor**

This analysis identified regions that surpassed the log-BF and  $t$ -statistic thresholds in the social-immersed contrast (Social Immerse-Neg > Social Reframe-Neg) and in the self-immersed contrast (Self Immerse-Neg > Self Reframe-Neg). We found that reframing negative autobiographical memories down-regulated activity in the mid-orbitofrontal cortex (Fig. 8B, Table 3).

## **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 providing self- and social-reappraisal within the same individuals using complementary univariate and multivariate approaches. 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 and mentalizing, including left dorsolateral and ventrolateral prefrontal cortex and dorsomedial prefrontal cortex. On the other hand, univariate contrasts and Bayes factor analyses showed that social-reappraisal was qualitatively—but not quantitatively—different from self-reappraisal in its recruitment of additional control regions in the ventrolateral prefrontal cortex as well as mentalizing regions such as the medial prefrontal cortex and right temporal pole.

Notably, multivariate pattern classifiers could not distinguish self- vs. social-reappraisal in control regions regardless of whether they defined using a priori prefrontal ROIs generally associated with reappraisal or were identified in this study as prefrontal regions commonly recruited during both self-reappraisal and social-reappraisal. Patterns of activity were distinct, however, in mentalizing regions, including in a priori ROIs for anterior mPFC and right temporal pole regions as well as in a region of left temporal pole commonly recruited during both self- and social-reappraisal. 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 (ie converging evidence across standard univariate contrasts and Bayes factor analyses), with moderate evidence for modulation of the posterior parahippocampal gyrus and insula (ie evidence only from standard univariate contrasts).

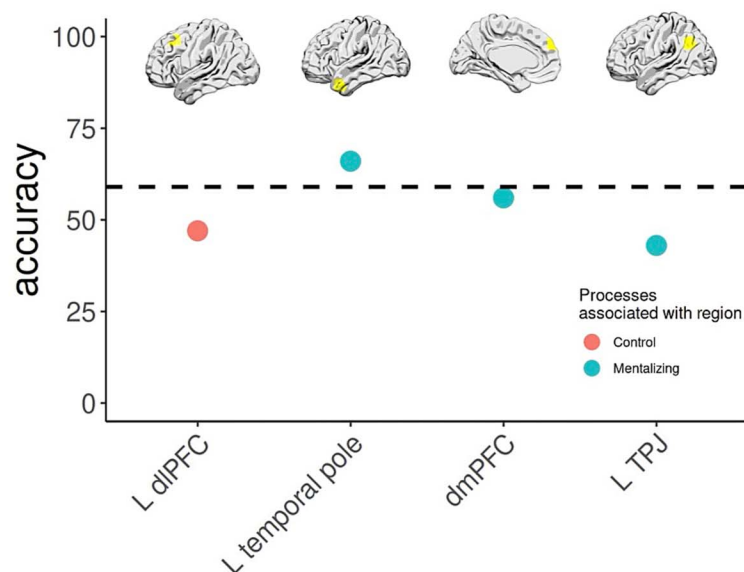
### **Implications for understanding the neural bases of self- and social-reappraisal**

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 and left 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 (eg Satpute et al. 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.

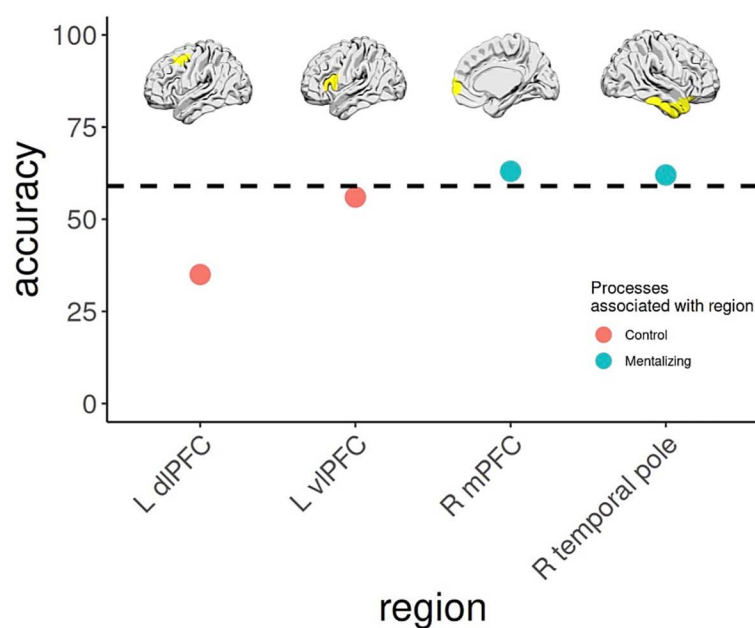
Also important and unique to social-reappraisal were the right temporal pole and medial prefrontal cortex, which might inform social-reappraisal attempts by accessing and keeping in mind representations of socioaffective knowledge that support perspective-taking (Amodio and Frith 2006; Zaki and Ochsner 2012). The temporal pole is involved in accessing social knowledge and scripts (eg Olson et al. 2007), with the right temporal pole, in

## How are self- and social-reappraisal different?

A. via ROI-based classifier analysis to differentiate multivoxel patterns within regions **commonly recruited** by self- and social-reappraisal



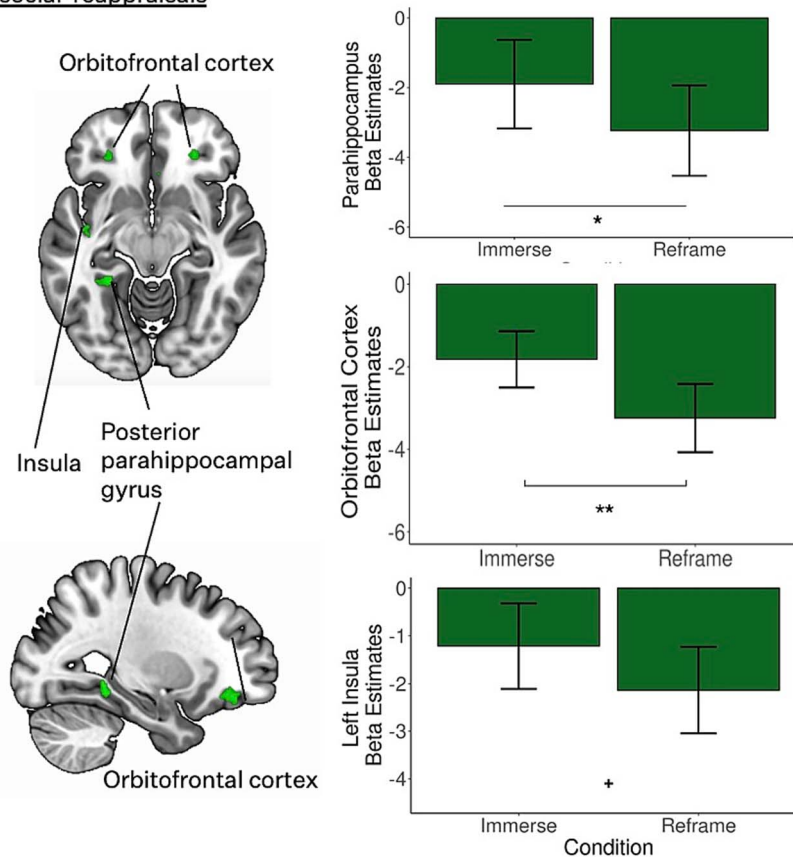
B. via ROI-based classifier analysis to differentiate multivoxel patterns within **a-priori** regions



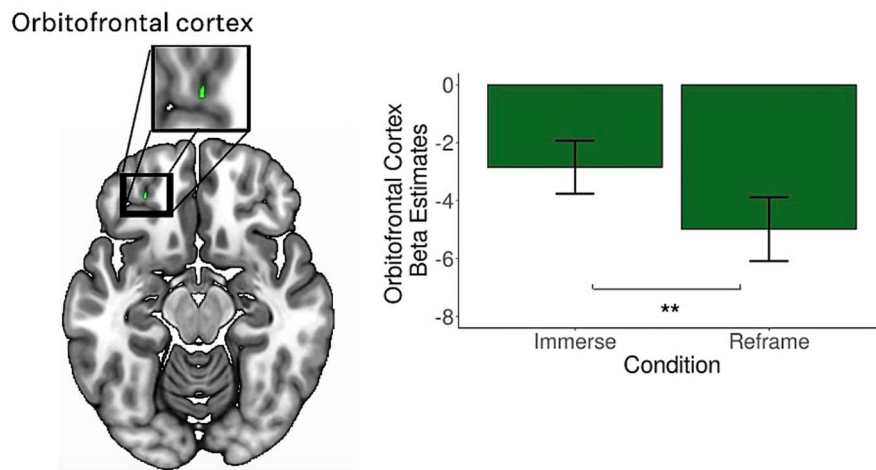
**Fig. 7.** Do self- and social-reappraisal differ in how they recruit regions associated with control and mentalizing processes? This figure depicts the classification accuracy of a pairwise support vector machine classifier in distinguishing self- and social-reappraisal within regions associated with control and mentalizing processes across a priori ROIs and regions that were commonly-recruited during both self- and social-reappraisal. Panel a shows the classifier results for commonly-recruited regions associated with control and mentalizing processes. The left dlPFC region commonly engaged by both self- and social-reappraisal was identified by intersecting the conjunction mask in Fig. 6a with a Neurosynth meta-analytic map of regions associated with “control.” To identify mentalizing regions commonly recruited during both self- and social-reappraisal, we intersected the conjunction mask in Fig. 6a with a Neurosynth meta-analytic map of regions associated with “mentalizing.” This yielded the left temporal pole, dorsomedial prefrontal cortex and left temporoparietal junction. Panel b shows the classifier results in a priori regions of interest relating to control and mentalizing processes. Left side of the figure shows results for a priori dlPFC and vlPFC ROIs shown in meta-analyses to be associated with cognitive control/reappraisal (Satpute et al. 2014; Wager and Smith 2003; Ridderinkhof et al. 2004; Simmonds et al. 2008; Rottschy et al. 2012). Right side shows results for ROIs in anterior mPFC and temporal pole that were of a priori interest, given their importance in mentalizing (Holloway 1983; Semendeferi et al. 2001; Olson et al. 2007, 2013; Ross and Olson 2010; Gaesser 2020). In both panels, the dotted line indicates the threshold for significant classification accuracy. Points that are above the dotted line indicate successful differentiation of multivariate patterns between self- and social-reappraisal. L = left; R = right. dlPFC = dorsolateral prefrontal cortex; vlPFC = ventrolateral prefrontal cortex; TPJ = temporoparietal junction; mPFC = medial prefrontal cortex.

## What is commonly modulated by self- and social-reappraisal?

A. via assessing the main effect of Immerse > Reframe conditions collapsing across self- and social-reappraisals



B. via Bayes factor analysis that identified voxels that were modulated in both self- and social-reappraisals



**Fig. 8.** What regions are modulated by self- and social-reappraisal? Panel a shows regions of interest from a standard univariate analysis assessing the main effect of immerse > reframe conditions collapsing across self- and social-reappraisals ( $FDR\ q < 0.05$ ). Panel b shows regions commonly modulated by both self- and social-reappraisal from a Bayes factor conjunction analysis. Specifically, we identified voxels in the self- and social-react (ie immerse > reframe) log-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 (ie greater activation in self/social immerse-Neg > self/social reframe-Neg). \* indicates  $P < 0.05$ , \*\* indicates  $P < 0.01$  and + indicates trending significance  $P < 0.10$ .

**Table 3.** What brain regions were commonly modulated by self- and social-reappraisal?

Region	Coordinates (MNI)			Volume (mm <sup>3</sup> )	Peak Z
	x	y	z		
<b>Brain regions modulated by self- and social-reappraisal</b> (standard univariate contrast)					
A standard univariate analysis assessing the main effect of Immerse > Reframe conditions collapsing across self- and social-reappraisals (FDR q < 0.05)					
Left parahippocampus	−22	−36	−14	656	4.3922
	−30	−44	−4		4.2829
Left calcerine	−16	−18	−50	312	4.3457
Left superior occipital gyrus	−16	−50	8	288	4.0949
Left superior temporal gyrus	−42	−6	−14	208	3.9358
	−40	−12	−8		3.4122
Right inferior frontal gyrus	50	40	6	648	3.9023
Left inferior frontal gyrus	−40	40	12	432	3.7963
Right calcerine	16	−56	14	304	3.7296
Right precuneus	16	−54	22		2.9856
Right mid-orbital frontal cortex	26	38	−12	400	3.6816
	20.0	38.0	−18.0		3.5968
Left mid-orbital frontal cortex	−28.0	40.0	−14.0	528	3.6635
	−24.0	32.0	−14.0		3.3764
Middle cingulate & paracingulate gyri	−6	−32	48	232	3.6310
Left middle occipital gyrus	−42	−84	32	264	3.4293
Left middle cingulum	−2	−42	52	200	3.3258
Right supramarginal gyrus	54	−38	32	200	3.2015
	62	−42	30		3.1009
<b>Brain regions modulated by self- and social-reappraisal</b> (Bayes factor)					
Voxels in the self- and social-react (ie Immerse > Reframe) log-BF maps that (a) both had values above our positive threshold of 3.2 (ie BF = 5; substantial evidence in favor of the alternative hypothesis, <a href="#">Kass and Raftery 1995</a> ) and (b) had positive t-statistic values in the self- and social-react t-statistic maps (ie greater activation in Self/Social Immerse-Neg > Self/Social Reframe-Neg)					
Right inferior frontal gyrus (mid-orbital frontal cortex)	50	40	6	192	1
Left inferior frontal gyrus (mid-orbital frontal cortex)	−40	38	14	80	1

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 and Schacter 2014). While some mentalizing processes were unique to social-reappraisal, the indistinguishability of multivariate patterns within other commonly-recruited mentalizing regions—dorsomedial prefrontal cortex and left temporoparietal junction—suggests that some mentalizing operations are shared between self- and social-reappraisal. The dorsomedial prefrontal cortex has been implicated in representing abstract mental states (Ochsner et al. 2004; Eickhoff et al. 2016; Powers et al. 2016) and emotional memory (Kensinger and Ford 2021) while the left temporoparietal junction has been implicated in representing perspectives (be itself or other) (Samson et al. 2004; Aichhorn et al. 2006, 2009; Perner et al. 2006; Quesque and Brass 2019), suggesting that these specific mentalizing processes may be common between self- and social-reappraisal. Taken together, our results are consistent with the idea that different socioaffective scripts are accessed 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 2 related studies that have compared self- and social-reappraisal (Hallam et al. 2014; Ngombe et al. 2024). Both studies found that

the lateral prefrontal cortex was recruited for both self- and social-reappraisal, while Hallam et al. 2014 additionally found that implementing social-reappraisal preferentially recruited 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. 2024 where one individual—the target—implemented a reappraisal generated by someone else—the regulator). Moreover, the present study utilized personally meaningful autobiographical stimuli (vs. normatively negative IAPS images; Lang et al. 1997) creating a relatively more naturalistic context for examining the common and distinct neural bases of self- and social-reappraisal.

In this regard, the fact that we observed modulation of orbitofrontal and posterior parahippocampal regions by both kinds of reappraisal is notable for 2 reasons. First, these results show a parallel in the social domain for the results of prior studies examining the self-reappraisal of autobiographical memories (eg Holland and Kensinger 2013a, 2013b; 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.

While the current study used Immerse-Neg trials as a comparison condition for Reframe-Neg trials (in order to isolate the



specific effects of generating reappraisals), it should be noted that the instructions used for our Social Immerse-Neg condition closely resemble the instructions used to study empathic perspective taking in other studies (eg Gilead et al. 2016; Morawetz et al. 2022). Notably, emerging research suggests that empathic perspective taking (ie Social Immerse-Neg)—a form of theory of mind—shares common neural bases with cognitive reappraisal (ie Reframe-Neg) (eg Thompson et al. 2019). Such regions include the dorsomedial prefrontal cortex—implicated in representing mental states (Denny et al. 2012; Meyer and Lieberman 2018)—as well as the bilateral ventrolateral prefrontal cortex—implicated in domain-general control processes (Satpute et al. 2014). Instead of contrasting Social Reframe-Neg and Social Immerse-Neg trials, future research could examine the extent to which the generation of social-reappraisals and empathic perspective-taking share common neural correlates and test whether the extent of overlap may predict meaningful real-world outcomes such as social regulatory efficacy.

### 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. 2024; Hallam et al. 2014; Guendelman et al. 2022; Powers et al. 2022). Yet, it is the first study that directly examines providing self vs. social-reappraisal using autobiographical memories, in a within-subjects design and employing both univariate and multivariate analytic approaches.

Notably, 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. 2021a, 2021b). While there may be many reasons why individuals are effective at both, it is possible that both forms of regulation originate with the experience of being a target of effective regulatory support from another person, and that this provides the basis for learning how to regulate others (Morris et al. 2007; Wright et al. 2024). Such experiences may be particularly important in childhood, when the experience of receiving secure care as a child (ie being a target of effective social regulation) 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. 2021a, 2021b). Yet, as behavioral studies indicate (eg Swerdlow and Johnson 2022), many other social emotion regulation strategies are used in daily life. This begs an important question for future research: do different social emotion regulation strategies depend on the same or different processes? Such work could be of interest to relationship researchers, who have studied the stress buffering effects of social presence and attachment security (eg Laurita et al. 2017), as well as developmental psychologists who study the parental buffering of fear (eg Gunnar 2017; Abramson et al. 2024). In this vein, future studies could seek to determine whether different forms

of social regulation, such as those that are more nonverbal and relatively passive (eg presence and touch) as opposed to those that are verbal and more active (eg 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 et al. (2016) as well as Cohen and Arbel (2020) posited that control, mentalizing and reward systems may be involved in providing regulatory support to others. Consistent with these models, this study found evidence that social reappraisal depends on control systems involved in manipulating and retrieving information and mentalizing systems for simulating and empathizing with others. We also found some evidence for the involvement of reward systems implicated in providing social regulatory support (eg 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 (eg family, close friends, and partners). While providing social regulatory support to close others may be expected to offer the largest potential rewards (eg Inagaki and Eisenberger 2012), it is also plausible that chronically providing support to others may dampen reward responses (ie caregiver burnout).

Crucially, we do not claim that providing social-reappraisal feels particularly demanding to the individual offering support, even though providing social-reappraisal did engage control regions. Some behavioral research has shown that providing social-reappraisal feels easier than reappraising for oneself due to the greater psychological distance from emotional events that is afforded when one socially-reappraises (eg Doré et al. 2017; Matthews et al. 2022). In keeping with this, relationship science research suggests that the difficulty of providing social-reappraisal may depend on who we are reappraising for and the nature and complexity of the emotional stressor involved (Digiovanni et al. 2024). The present study design is not able to tease these factors apart as we did not collect behavioral measures of difficulty in providing social-reappraisal. That said, these issues warrant more thorough study using measures that span 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- vs. 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 (eg 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 essentially 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. As such, the Bayes approach can complement standard univariate contrasts—as implemented in this paper—by revealing neural regions that were preferentially engaged by social-reappraisal. Future research that aims to test

hypotheses concerning multiple contrasts/conditions might consider using Bayes factor analysis, as it is particularly suited to differentiating regions associated with individual task conditions and is easily applied to existing univariate contrast maps (eg Bo et al. 2024).

## Implications for understanding 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 (ie 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 recruit left hemisphere control regions could enhance both self and social regulation ability. Indeed, depressed patients typically show reduced recruitment of left hemisphere control regions (Henriques and Davidson 1991; Fales et al. 2008; Paulus 2015), thereby raising competing hypotheses as to whether depressed patients will benefit more or less from rTMS stimulation to regions commonly recruited during both self- and social-reappraisal. Additionally, it is also possible that rTMS applied to 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 ability 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 (eg Herzog et al. 2025). For example, one proposed mechanism for the success of support groups (such as Alcoholics Anonymous) is the regulatory support of mentors (ie “sponsors”) and individuals who have gone through or are simultaneously going through similar craving-induced emotional challenges (Kassel and Wagner 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 and Arbel 2020), as close others may be motivationally salient yet emotionally complex (Zayas et al. 2017). Therefore, the present study motivates future research to examine seriously the social elements of therapy and clinical support groups as key ingredients for clinical success.

## Conclusion

There are 5 key limitations to note for this 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. During self-reappraisal, participants can directly report on how they feel after implementing a reappraisal, while judgments of hypothetical reappraisal efficacy during social-reappraisal rely on predictions or estimates of how a target stranger might feel if they had received social-reappraisals (Gilead et al. 2016; Böckler et al. 2017). While this method makes for a tractable fMRI paradigm, future work could seek to assess how a target feels in other ways, such as directly assessing a target's self-reported emotions while they engage with regulators

during scanning of real time social regulatory interactions (eg using hyperscanning, Montague 2002; Hasson et al. 2012).

Second, in everyday life, social-reappraisals are often provided for people with whom we have an existing relationship (eg a friend, partner, and family member), with the provision of social-reappraisals embedded within temporally extended patterns of dynamic interactions where verbal and nonverbal cues inform a partner's understanding of the other's interactions goals and emotional states (He et al. in prep). For example, individuals may decide whether to reappraise for a close other depending on the nature of the relationship (Digiovanni et al. 2024) and their knowledge of the close other's tendencies, such as whether they tend to use reappraisal for themselves (Reis et al. 2017). Furthermore, our cultural orientations can shape how we provide and receive social regulatory support (eg Han and Northoff 2008; Miller et al. 2017). Future work could seek to systematically unpack the role of such factors in social regulation.

Third, in the present study, we assessed social-reappraisal between participants and strangers who were not in active real-time dialog with one another, which may constrain the application of our findings to real-world situations where social regulation dynamically unfolds in real time. With the growth of portable neuroimaging devices (eg functional near infrared spectroscopy) and advanced fMRI setups (eg hyperscanning), a truly dyadic approach to studying the social regulation of emotion could strengthen our understanding of the underlying mechanisms (Liu and Pelowski 2014; Redcay and Schilbach 2019; Dikker et al. 2021).

Fourth, following prior work on the reappraisal of autobiographical memories (eg Kross et al. 2009), the reframe condition incorporated aspects of both distancing and reinterpretation tactics within the general strategy of cognitive reappraisal (McRae et al. 2012). While this approach has its advantages in terms of allowing some flexibility for participants to engage in successful regulation—and in prior work has been shown to be particularly effective for regulating negative emotions associated with autobiographical memories (Kross et al. 2009), it cannot distinguish processes that are selectively associated with tactic or another. Although this has been examined in prior work on self-reappraisal (eg Ochsner et al. 2004; Denny et al. 2023), future research could examine the shared and distinct neural bases of different social-reappraisal tactics, given that there is variability in how people generate and implement social-reappraisals in daily life (Sahi et al. 2023).

Finally, there was no fixation period that separated the recall and regulation phases, raising the possibility of spill-over effects of the BOLD response between phases. However, if this effect existed, we might expect it to be minimal for 2 reasons. For one, the recall and regulation periods for each trial were relatively long (ie ~15 secs), and as such, functioned more as blocks than temporally overlapping events. For another, there was a 50/50 probability of an Immerse or Distance regulation trial to follow the recall phase, which helps to probabilistically uncouple recall-related neural activity from regulation-related neural activity. In support of these arguments, variants of this paradigm have been used multiple times in prior studies from our lab (eg Kross et al. 2009)—and others (eg Holland and Kensinger 2013a, 2013b)—to detect activity related to regulation, in general, as well as individual differences in the way regulatory processes are implemented (eg Silvers et al. 2016; Doré et al. 2018; Schneck et al. 2023; Herzog et al. 2025).

Despite these potential limitations, 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 the growing study of social emotion regulation by pointing the way for future work to ask meaningful and novel questions about how social regulation unfolds, its relation to self-regulation and its consequences for emotional and relational well-being.

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## Author contributions

Zhouzhou He (Formal analysis, Investigation, Project administration, Validation, Visualization, Writing—original draft, Writing—review & editing), Noga Cohen (Conceptualization, Investigation, Methodology, Project administration, Writing—review & editing), Jocelyn Shu (Conceptualization, Data curation, Methodology, Project administration), Ke Bo (Formal analysis, Methodology, Software, Visualization, Writing—review & editing), Tor Wager (Software, Writing—review & editing), and Kevin Ochsner (Conceptualization, Investigation, Methodology, Resources, Software, Supervision, Writing—review & editing)

## Supplementary material

Supplementary material is available at *Cerebral Cortex* online.

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*Conflict of interest statement.* None declared.

## References

- Abramson L et al. 2024. The effects of parental presence on amygdala and mPFC activation during fear conditioning: an exploratory study. *Dev Sci*. 27:e13505. <https://doi.org/10.1111/desc.13505>.
- Aichhorn M, Perner J, Kronbichler M, Staffen W, Ladurner G. 2006. Do visual perspective tasks need theory of mind? *Neuroimage*. 30: 1059–1068. <https://doi.org/10.1016/j.neuroimage.2005.10.026>.
- Aichhorn M et al. 2009. Temporo-parietal junction activity in theory-of-mind tasks: falseness, beliefs, or attention. *J Cogn Neurosci*. 21: 1179–1192. <https://doi.org/10.1162/jocn.2009.21082>.
- Aminoff EM, Kveraga K, Bar M. 2013. The role of the parahippocampal cortex in cognition. *Trends Cogn Sci*. 17:379–390.
- Amodio DM, Frith CD. 2006. Meeting of minds: the medial frontal cortex and social cognition. *Nat Rev Neurosci*. 7:268–277. <https://doi.org/10.1038/nrn1884>.
- Anderson AK, Phelps EA. 2001. Lesions of the human amygdala impair enhanced perception of emotionally salient events. *Nature*. 411:305–309. <https://doi.org/10.1038/35077083>.
- Anderson AK, Phelps EA. 2002. Is the human amygdala critical for the subjective experience of emotion? Evidence of intact dispositional affect in patients with amygdala lesions. *J Cogn Neurosci*. 14:709–720. <https://doi.org/10.1162/08989290260138618>.
- Arbel R et al. 2024. Reappraising negative emotions reduces distress during the COVID-19 outbreak. *Curr Psychol*. 43:14053–14062. <https://doi.org/10.1007/s12144-022-03642-6>.
- Badre D, Wagner AD. 2007. Left ventrolateral prefrontal cortex and the cognitive control of memory. *Neuropsychologia*. 45: 2883–2901. <https://doi.org/10.1016/j.neuropsychologia.2007.06.015>.
- Bar M, Aminoff E, Schacter DL. 2008. Scenes unseen: the parahippocampal cortex intrinsically subserves contextual associations, not scenes or places per se. *J Neurosci*. 28:8539–8544. <https://doi.org/10.1523/JNEUROSCI.0987-08.2008>.
- Beck JS. 2020. *Cognitive behavior therapy*, 3rd edn. Guilford Publications, Basics and Beyond.
- Bo K et al. 2024. A systems identification approach using Bayes factors to deconstruct the brain bases of emotion regulation. *Nat Neurosci*. 27:975–987. <https://doi.org/10.1038/s41593-024-01605-7>.
- Böckler A, Herrmann L, Trautwein FM, Holmes T, Singer T. 2017. Know thy selves: learning to understand oneself increases the ability to understand others. *J Cogn Enhanc*. 1:197–209. <https://doi.org/10.1007/s41465-017-0023-6>.
- Bowlby J. 1969. *Attachment and loss*, Vol. No. 79. Random House.
- Buhle JT et al. 2014. Cognitive reappraisal of emotion: a meta-analysis of human neuroimaging studies. *Cereb Cortex*. 24: 2981–2990. <https://doi.org/10.1093/cercor/bht154>.
- Burton LA et al. 2008. Implicit and explicit memory for affective passages in temporal lobectomy patients. *Brain Cogn*. 68:22–29. <https://doi.org/10.1016/j.bandc.2008.02.120>.
- Chang L. 2021. Multivariate prediction. *Dartbrains*. [https://dartbrains.org/content/Multivariate\\_Prediction.html](https://dartbrains.org/content/Multivariate_Prediction.html).
- Coan JA, Schaefer HS, Davidson RJ. 2006. Lending a hand: social regulation of the neural response to threat. *Psychol Sci*. 17:1032–1039. <https://doi.org/10.1111/j.1467-9280.2006.01832.x>.
- Cohen JR. 2010. Decoding developmental differences and individual variability in response inhibition through predictive analyses across individuals. *Front Hum Neurosci*. 4:1287. <https://doi.org/10.3389/fnhum.2010.00047>.
- Cohen N, Arbel R. 2020. On the benefits and costs of extrinsic emotion regulation to the provider: toward a neurobehavioral model. *Cortex*. 130:1–15. <https://doi.org/10.1016/j.cortex.2020.05.011>.
- Costello MA, Bailey NA, Stern JA, Allen JP. 2024. Vulnerable self-disclosure co-develops in adolescent friendships: developmental foundations of emotional intimacy. *J Soc Pers Relat*. 41:2432–2454. <https://doi.org/10.1177/02654075241244821>.
- Davachi L. 2006. Item, context and relational episodic encoding in humans. *Curr Opin Neurobiol*. 16:693–700. <https://doi.org/10.1016/j.conb.2006.10.012>.
- Denny BT, Kober H, Wager TD, Ochsner KN. 2012. A meta-analysis of functional neuroimaging studies of self- and other judgments reveals a spatial gradient for mentalizing in medial prefrontal cortex. *J Cogn Neurosci*. 24:1742–1752. [https://doi.org/10.1162/jocn\\_a\\_00233](https://doi.org/10.1162/jocn_a_00233).
- Denny BT et al. 2023. Unpacking reappraisal: a systematic review of fMRI studies of distancing and reinterpretation. *Soc Cogn Affect Neurosci*. 18:nsad050. <https://doi.org/10.1093/scan/nsad050>.
- DiGiovanni AM, Tudder A, Peters BJ. 2024. *Reconceptualizing Co-Rumination: A Novel Theoretical and Multidisciplinary Perspective*. [https://doi.org/10.31234/osf.io/sgvx3\\_v1](https://doi.org/10.31234/osf.io/sgvx3_v1).
- Dikker S et al. 2021. Crowdsourcing neuroscience: inter-brain coupling during face-to-face interactions outside the laboratory. *NeuroImage*. 227:117436. <https://doi.org/10.1016/j.neuroimage.2020.117436>.



- Dixon ML, Thiruchselvam R, Todd R, Christoff K. 2017. Emotion and the prefrontal cortex: an integrative review. *Psychol Bull.* 143:1033. <https://doi.org/10.1037/bul0000096>.
- Dixon-Gordon KL, Bernecker SL, Christensen K. 2015. Recent innovations in the field of interpersonal emotion regulation. *Curr Opin Psychol.* 3:36–42. <https://doi.org/10.1016/j.copsyc.2015.02.001>.
- Doré BP, Morris RR, Burr DA, Picard RW, Ochsner KN. 2017. Helping others regulate emotion predicts increased regulation of one's own emotions and decreased symptoms of depression. *Personal Soc Psychol Bull.* 43:729–739. <https://doi.org/10.1177/0146167217695558>.
- Doré BP et al. 2018. Negative autobiographical memory in depression reflects elevated amygdala-hippocampal reactivity and hippocampally associated emotion regulation. *Biol Psychiatry Cogn Neurosci Neuroimaging.* 3:358–366. <https://doi.org/10.1016/j.bpsc.2018.01.002>.
- Duncan J, Owen AM. 2000. Common regions of the human frontal lobe recruited by diverse cognitive demands. *Trends Neurosci.* 23: 475–483. [https://doi.org/10.1016/S0166-2236\(00\)01633-7](https://doi.org/10.1016/S0166-2236(00)01633-7).
- Eickhoff SB, Laird AR, Fox PT, Bzdok D, Hensel L. 2016. Functional segregation of the human dorsomedial prefrontal cortex. *Cereb Cortex.* 26:304–321. <https://doi.org/10.1093/cercor/bhu250>.
- Enticott PG et al. 2014. A double-blind, randomized trial of deep repetitive transcranial magnetic stimulation (rTMS) for autism spectrum disorder. *Brain Stimul.* 7:206–211. <https://doi.org/10.1016/j.brs.2013.10.004>.
- Epstein R, Graham KS, Downing PE. 2003. Specific scene representations in human parahippocampal cortex. *Neuron.* 37:865–876.
- Esteban O et al. 2019. fMRIPrep: a robust preprocessing pipeline for functional MRI. *Nat Methods.* 16:111–116. <https://doi.org/10.1038/s41592-018-0235-4>.
- Fales CL et al. 2008. Altered emotional interference processing in affective and cognitive-control brain circuitry in major depression. *Biol Psychiatry.* 63:377–384. <https://doi.org/10.1016/j.biopsych.2007.06.012>.
- Ferri M, Amato L, Davoli M. 2006. Alcoholics anonymous and other 12-step programmes for alcohol dependence. *Cochrane Database Syst Rev.* 3:CD005032. <https://doi.org/10.1002/14651858.CD005032.pub2>.
- Gaesser B. 2020. Episodic mindreading: mentalizing guided by scene construction of imagined and remembered events. *Cognition.* 203:104325. <https://doi.org/10.1016/j.cognition.2020.104325>.
- Gaesser B, Schacter DL. 2014. Episodic simulation and episodic memory can increase intentions to help others. *Proc Natl Acad Sci.* 111: 4415–4420. <https://doi.org/10.1073/pnas.1402461111>.
- Gallagher HL, Frith CD. 2003. Functional imaging of 'theory of mind'. *Trends Cogn Sci.* 7:77–83. [https://doi.org/10.1016/S1364-6613\(02\)00025-6](https://doi.org/10.1016/S1364-6613(02)00025-6).
- Geisler D, Meyer ML. 2023. Identifying a neural signature that predicts self-focus [preprint]. *bioRxiv.* <https://doi.org/10.1101/2024February1.578262>.
- Gilead M et al. 2016. Self-regulation via neural simulation. *Proc Natl Acad Sci.* 113:10037–10042. <https://www.pnas.org/doi/full/10.1073/pnas.1600159113>.
- Goldin PR, McRae K, Ramel W, Gross JJ. 2008. The neural bases of emotion regulation: reappraisal and suppression of negative emotion. *Biol Psychiatry.* 63:577–586. <https://doi.org/10.1016/j.biopsych.2007.05.031>.
- Gross JJ. 1998. The emerging field of emotion regulation: an integrative review. *Rev Gen Psychol.* 2:271–299. <https://doi.org/10.1037/1089-2680.2.3.271>.
- Gross JJ. 2011. *Handbook of emotion regulation*, 1st edn. Guilford Press.
- Guendelman S, Bayer M, Prehn K, Dziobek I. 2022. Regulating negative emotions of others reduces own stress: neurobiological correlates and the role of individual differences in empathy. *NeuroImage.* 254:119134. <https://doi.org/10.1016/j.neuroimage.2022.119134>.
- Gunnar MR. 2017. Social buffering of stress in development: a career perspective. *Perspect Psychol Sci.* 12:355–373. <https://doi.org/10.1177/1745691616680612>.
- Hallam GP et al. 2014. The neural correlates of regulating another person's emotions: an exploratory fMRI study. *Front Hum Neurosci.* 8:376. <https://doi.org/10.3389/fnhum.2014.00376>.
- Han S, Northoff G. 2008. Culture-sensitive neural substrates of human cognition: a transcultural neuroimaging approach. *Nat Rev Neurosci.* 9:646–654. <https://doi.org/10.1038/nrn2456>.
- Hasson U, Ghazanfar AA, Galantucci B, Garrod S, Keysers C. 2012. Brain-to-brain coupling: a mechanism for creating and sharing a social world. *Trends Cogn Sci.* 16:114–121. <https://doi.org/10.1016/j.tics.2011.12.007>.
- He Z et al. 2023. The VLPFC-engaged voluntary emotion regulation: combined TMS-fMRI evidence for the neural circuit of cognitive reappraisal. *J Neurosci.* 43:6046–6060. <https://doi.org/10.1523/JNEUROSCI.1337-22.2023>.
- Henriques JB, Davidson RJ. 1991. Left frontal hypoactivation in depression. *J Abnorm Psychol.* 100:535. <https://doi.org/10.1037/0021-843X.100.4.535>.
- Herlin B, Navarro V, Dupont S. 2021. The temporal pole: from anatomy to function—a literature appraisal. *J Chem Neuroanat.* 113:101925. <https://doi.org/10.1016/j.jchemneu.2021.101925>.
- Herzog S et al. 2025. A neural signature for reappraisal as an emotion regulation strategy: relationship to stress-related suicidal ideation and negative affect in major depression. *Biol Psychiatry Cogn Neurosci Neuroimaging.* 10:94–102. <https://doi.org/10.1016/j.bpsc.2024.08.011>.
- Hofmann SG, Carpenter JK, Curtiss J. 2016. Interpersonal emotion regulation questionnaire (IERQ): scale development and psychometric characteristics. *Cogn Ther Res.* 40:341–356. <https://doi.org/10.1007/s10608-016-9756-2>.
- Holland AC, Kensinger EA. 2013a. The neural correlates of cognitive reappraisal during emotional autobiographical memory recall. *J Cogn Neurosci.* 25:87–108. [https://doi.org/10.1162/jocn\\_a\\_00289](https://doi.org/10.1162/jocn_a_00289).
- Holland AC, Kensinger EA. 2013b. An fMRI investigation of the cognitive reappraisal of negative memories. *Neuropsychologia.* 51:2389–2400. <https://doi.org/10.1016/j.neuropsychologia.2013.02.012>.
- Holloway RL. 1983. Cerebral brain endocast pattern of *Australopithecus afarensis* hominid. *Nature.* 303:420–422. <https://doi.org/10.1038/303420a0>.
- Inagaki TK, Eisenberger NI. 2012. Neural correlates of giving support to a loved one. *Psychosom Med.* 74:3. <https://doi.org/10.1097/PSY.0b013e3182359335>.
- Inman CS et al. 2023. Discovering how the amygdala shapes human behavior: from lesion studies to neuromodulation. *Neuron.* 111: 3906–3910. <https://doi.org/10.1016/j.neuron.2023.09.040>.
- Izuma K, Kennedy K, Fitzjohn A, Sedikides C, Shibata K. 2018. Neural activity in the reward-related brain regions predicts implicit self-esteem: a novel validity test of psychological measures using neuroimaging. *J Pers Soc Psychol.* 114:343. <https://doi.org/10.1037/pspa0000114>.
- Jenkinson M, Beckmann CF, Behrens TEJ, Woolrich MW, Smith SM. 2012. FSL. *NeuroImage.* 62:782–790. <https://doi.org/10.1016/j.neuroimage.2011.09.015>.
- Kalisch R. 2009. The functional neuroanatomy of reappraisal: time matters. *Neurosci Biobehav Rev.* 33:1215–1226. <https://doi.org/10.1016/j.neubiorev.2009.06.003>.



- Kass RE, Raftery AE. 1995. Bayes factors. *J Am Stat Assoc.* 90:773–795. <https://doi.org/10.1080/01621459.1995.10476572>.
- Kassel JD, Wagner EF. 1993. Processes of change in alcoholics anonymous: a review of possible mechanisms. *Psychother Theory Res Pract Train.* 30:222–234. <https://doi.org/10.1037/0033-3204.30.2.222>.
- Kensinger EA, Ford JH. 2021. Guiding the emotion in emotional memories: the role of the dorsomedial prefrontal cortex. *Curr Dir Psychol Sci.* 30:111–119. <https://doi.org/10.1177/0963721421990081>.
- Koban L, Gianaros PJ, Kober H, Wager TD. 2021. The self in context: brain systems linking mental and physical health. *Nat Rev Neurosci.* 22:309–322. <https://doi.org/10.1038/s41583-021-00446-8>.
- Kragel PA, Koban L, Barrett LF, Wager TD. 2018. Representation, pattern information, and brain signatures: from neurons to neuroimaging. *Neuron.* 99:257–273. <https://doi.org/10.1016/j.neuron.2018.06.009>.
- Kross E, Davidson M, Weber J, Ochsner K. 2009. Coping with emotions past: the neural bases of regulating affect associated with negative autobiographical memories. *Biol Psychiatry.* 65:361–366. <https://doi.org/10.1016/j.biopsych.2008.10.019>.
- LaBar K, LeDoux J, Spencer D, Phelps E. 1995. Impaired fear conditioning following unilateral temporal lobectomy in humans. *J Neurosci.* 15:6846–6855. <https://doi.org/10.1523/JNEUROSCI.15-10-06846.1995>.
- Lang PJ, Bradley MM, Cuthbert BN. 1997. *International affective picture system (IAPS): technical manual and affective ratings.* NIMH Center for the Study of Emotion and Attention. Vol. 1. p. 3. <https://doi.org/10.1037/t66667-000>.
- Laurita AC, Hazan C, Spreng RN. 2017. Dissociable patterns of brain activity for mentalizing about known others: a role for attachment. *Soc Cogn Affect Neurosci.* 12:1072–1082. <https://doi.org/10.1093/scan/nsx040>.
- LeDoux J. 2007. The amygdala. *Curr Biol.* 17:R868–R874.
- Li S et al. 2022. The causal role of the bilateral ventrolateral prefrontal cortices on emotion regulation of social feedback. *Hum Brain Mapp.* 43:2898–2910. <https://doi.org/10.1002/hbm.25824>.
- Liu T, Pelowski M. 2014. Clarifying the interaction types in two-person neuroscience research. *Front Hum Neurosci.* 8:276. <https://doi.org/10.3389/fnhum.2014.00276>.
- Liu DY, Strube MJ, Thompson RJ. 2021. Interpersonal emotion regulation: an experience sampling study. *Affect Sci.* 2:273–288. <https://doi.org/10.1007/s42761-021-00044-y>.
- Marques RC, Vieira L, Marques D, Cantilino A. 2019. Transcranial magnetic stimulation of the medial prefrontal cortex for psychiatric disorders: a systematic review. *Braz J Psychiatr.* 41:447–457. <https://doi.org/10.1590/1516-4446-2019-0344>.
- Matthews M, Webb TL, Sheppes G. 2022. Do people choose the same strategies to regulate other people's emotions as they choose to regulate their own? *Emotion.* 22(8):1723. <https://psycnet.apa.org/doi/10.1037/emo0001008>.
- McRae K, Ochsner KN, Mauss IB, Gabrieli JJ, Gross JJ. 2008. Gender differences in emotion regulation: an fMRI study of cognitive reappraisal. *Group Process Intergr Relat.* 11:143–162. <https://doi.org/10.1177/1368430207088035>.
- McRae K, Ciesielski B, Gross JJ. 2012. Unpacking cognitive reappraisal: goals, tactics, and outcomes. *Emotion.* 12:250. <https://doi.org/10.1037/a0026351>.
- Meyer ML, Lieberman MD. 2018. Why people are always thinking about themselves: medial prefrontal cortex activity during rest primes self-referential processing. *J Cogn Neurosci.* 30:714–721. [https://doi.org/10.1162/jocn\\_a\\_01232](https://doi.org/10.1162/jocn_a_01232).
- Miller EK, Cohen JD. 2001. An integrative theory of prefrontal cortex function. *Annu Rev Neurosci.* 24:167–202. <https://doi.org/10.1146/annurev.neuro.24.1.167>.
- Miller JG, Akiyama H, Kapadia S. 2017. Cultural variation in communal versus exchange norms: implications for social support. *J Pers Soc Psychol.* 113:81. <https://doi.org/10.1037/pspi0000091>.
- Montague P. 2002. Hyperscanning: simultaneous fMRI during linked social interactions. *NeuroImage.* 16:1159–1164. <https://doi.org/10.1006/nimg.2002.1150>.
- Morawetz C, Bode S, Baudewig J, Heekeren HR. 2017a. Effective amygdala-prefrontal connectivity predicts individual differences in successful emotion regulation. *Soc Cogn Affect Neurosci.* 12:569–585. <https://doi.org/10.1093/scan/nsw169>.
- Morawetz C, Bode S, Derntl B, Heekeren HR. 2017b. The effect of strategies, goals and stimulus material on the neural mechanisms of emotion regulation: a meta-analysis of fMRI studies. *Neurosci Biobehav Rev.* 72:111–128. <https://doi.org/10.1016/j.neubiorev.2016.11.014>.
- Morawetz C, Berboth S, Bode S. 2021. With a little help from my friends: the effect of social proximity on emotion regulation-related brain activity. *NeuroImage.* 230:117817. <https://doi.org/10.1016/j.neuroimage.2021.117817>.
- Morawetz C, Berboth S, Kohn N, Jackson PL, Jauniaux J. 2022. Reappraisal and empathic perspective-taking—more alike than meets the eyes. *NeuroImage.* 255:119194. <https://doi.org/10.1016/j.neuroimage.2022.119194>.
- Morey RD, Rouder JN. 2011. Bayes factor approaches for testing interval null hypotheses. *Psychol Methods.* 16:406–419. <https://doi.org/10.1037/a0024377>.
- Morris AS, Silk JS, Steinberg L, Myers SS, Robinson LR. 2007. The role of the family context in the development of emotion regulation. *Soc Dev.* 16:361–388. <https://doi.org/10.1111/j.1467-9507.2007.00389.x>.
- Ngombe N et al. 2024. Dual-fMRI reveals that extrinsic and intrinsic inter-personal emotion regulation is underpinned by a common functional brain network [preprint]. <https://doi.org/10.31234/osf.io/4fm9x>.
- Niven K. 2017. The four key characteristics of interpersonal emotion regulation. *Curr Opin Psychol.* 17:89–93. <https://doi.org/10.1016/j.copsyc.2017.06.015>.
- Ochsner KN et al. 2004. For better or for worse: neural systems supporting the cognitive down-and up-regulation of negative emotion. *Neuroimage.* 23:483–499. <https://doi.org/10.1016/j.neuroimage.2004.06.030>.
- Ochsner KN, Silvers JA, Buhle JT. 2012. Functional imaging studies of emotion regulation: a synthetic review and evolving model of the cognitive control of emotion. *Ann N Y Acad Sci.* 1251:E1–E24. <https://doi.org/10.1111/j.1749-6632.2012.06751.x>.
- Olson IR, Plotzker A, Ezzyat Y. 2007. The enigmatic temporal pole: a review of findings on social and emotional processing. *Brain.* 130:1718–1731. <https://doi.org/10.1093/brain/awm052>.
- Olson IR, McCoy D, Klobusicky E, Ross LA. 2013. Social cognition and the anterior temporal lobes: a review and theoretical framework. *Soc Cogn Affect Neurosci.* 8:123–133. <https://doi.org/10.1093/scan/nss119>.
- Paulus MP. 2015. Cognitive control in depression and anxiety: out of control? *Curr Opin Behav Sci.* 1:113–120. <https://doi.org/10.1016/j.cobeha.2014.12.003>.
- Perner J, Aichhorn M, Kronbichler M, Staffen W, Ladurner G. 2006. Thinking of mental and other representations: the roles of left and right temporo-parietal junction. *Soc Neurosci.* 1:245–258. <https://doi.org/10.1080/17470910600989896>.

- Phelps EA. 2004. Human emotion and memory: interactions of the amygdala and hippocampal complex. *Curr Opin Neurobiol*. 14: 198–202. <https://doi.org/10.1016/j.conb.2004.03.015>.
- Phelps EA. 2006. Emotion and cognition: insights from studies of the human amygdala. *Annu Rev Psychol*. 57:27–53. <https://doi.org/10.1146/annurev.psych.56.091103.070234>.
- Picó-Pérez M, Radua J, Steward T, Menchón JM, Soriano-Mas C. 2017. Emotion regulation in mood and anxiety disorders: a meta-analysis of fMRI cognitive reappraisal studies. *Prog Neuro-Psychopharmacol Biol Psychiatry*. 79:96–104. <https://doi.org/10.1016/j.pnpbp.2017.06.001>.
- Picó-Pérez M et al. 2019. Common and distinct neural correlates of fear extinction and cognitive reappraisal: a meta-analysis of fMRI studies. *Neurosci Biobehav Rev*. 104:102–115. <https://doi.org/10.1016/j.neubiorev.2019.06.029>.
- Powers JP, LaBar KS. 2019. Regulating emotion through distancing: a taxonomy, neurocognitive model, and supporting meta-analysis. *Neurosci Biobehav Rev*. 96:155–173. <https://doi.org/10.1016/j.neubiorev.2018.04.023>.
- Powers KE, Chavez RS, Heatherton TF. 2016. Individual differences in response of dorsomedial prefrontal cortex predict daily social behavior. *Soc Cogn Affect Neurosci*. 11:121–126. <https://doi.org/10.1093/scan/nsv096>.
- Powers JP, Kako N, McIntosh DN, McRae K. 2022. Competitive interactions between cognitive reappraisal and mentalizing. *Int J Psychophysiol*. 174:17–28. <https://doi.org/10.1016/j.ijpsycho.2022.01.012>.
- Quesque F, Brass M. 2019. The role of the temporoparietal junction in self-other distinction. *Brain Topogr*. 32:943–955. <https://doi.org/10.1007/s10548-019-00737-5>.
- Radloff LS. 1977. The CES-D scale: a self-report depression scale for research in the general population. *Appl Psychol Meas*. 1:385–401. <https://doi.org/10.1177/014662167700100306>.
- Rauers A, Riediger M. 2023. Ease of mind or ties that bind? Costs and benefits of disclosing daily hassles in partnerships. *Soc Psychol Personal Sci*. 14:551–561. <https://doi.org/10.1177/19485506221112252>.
- Redcay E, Schilbach L. 2019. Using second-person neuroscience to elucidate the mechanisms of social interaction. *Nat Rev Neurosci*. 20:495–505. <https://doi.org/10.1038/s41583-019-0179-4>.
- Reeck C, Ames DR, Ochsner KN. 2016. The social regulation of emotion: an integrative, cross-disciplinary model. *Trends Cogn Sci*. 20:47–63. <https://doi.org/10.1016/j.tics.2015.09.003>.
- Reis HT, Lemay EP Jr, Finkenauer C. 2017. Toward understanding understanding: the importance of feeling understood in relationships. *Soc Personal Psychol Compass*. 11:e12308. <https://doi.org/10.1111/spc3.12308>.
- Ridderinkhof KR, Ullsperger M, Crone EA, Nieuwenhuis S. 2004. The role of the medial frontal cortex in cognitive control. *Science*. 306: 443–447. <https://doi.org/10.1126/science.1100301>.
- Rimé B. 2007. Interpersonal emotion regulation. *Handbook of emotion regulation*, 1(466–468):79.
- Rolls ET, Cheng W, Feng J. 2020. The orbitofrontal cortex: reward, emotion and depression. *Brain Commun*. 2:fcaa196. <https://doi.org/10.1093/braincomms/fcaa196>.
- Ross LA, Olson IR. 2010. Social cognition and the anterior temporal lobes. *Neuroimage*. 49:3452–3462. <https://doi.org/10.1016/j.neuroimage.2009.11.012>.
- Rottschy C et al. 2012. Modelling neural correlates of working memory: a coordinate-based meta-analysis. *Neuroimage*. 60:830–846. <https://doi.org/10.1016/j.neuroimage.2011.11.050>.
- Rouder JN, Speckman PL, Sun D, Morey RD, Iverson G. 2009. Bayesian t tests for accepting and rejecting the null hypothesis. *Psychon Bull Rev*. 16:225–237. <https://doi.org/10.3758/PBR.16.2.225>.
- Sahi RS et al. 2021a. The comfort in touch: immediate and lasting effects of handholding on emotional pain. *PLoS One*. 16:e0246753. <https://doi.org/10.1371/journal.pone.0246753>.
- Sahi RS, Ninova E, Silvers JA. 2021b. With a little help from my friends: selective social potentiation of emotion regulation. *J Exp Psychol Gen*. 150:1237. <https://doi.org/10.1037/xge0000853>.
- Sahi RS, He Z, Silvers JA, Eisenberger NI. 2023. One size does not fit all: decomposing the implementation and differential benefits of social emotion regulation strategies. *Emotion*. 23:1522–1535. <https://doi.org/10.1037/emo0001194>.
- Samson D, Apperly IA, Chiavarino C, Humphreys GW. 2004. Left temporoparietal junction is necessary for representing someone else's belief. *Nat Neurosci*. 7:499–500. <https://doi.org/10.1038/nn1223>.
- Satpute AB, Badre D, Ochsner KN. 2014. Distinct regions of prefrontal cortex are associated with the controlled retrieval and selection of social information. *Cereb Cortex*. 24(5):1269–1277. <https://doi.org/10.1093/cercor/bhs408>.
- Schaefer A et al. 2018. Local-global parcellation of the human cerebral cortex from intrinsic functional connectivity MRI. *Cereb Cortex*. 28:3095–3114. <https://doi.org/10.1093/cercor/bhx179>.
- Schneck N et al. 2023. The temporal dynamics of emotion regulation in subjects with major depression and healthy control subjects. *Biol Psychiatry*. 93:260–267. <https://doi.org/10.1016/j.biopsych.2022.09.002>.
- Schurz M et al. 2021. Toward a hierarchical model of social cognition: a neuroimaging meta-analysis and integrative review of empathy and theory of mind. *Psychol Bull*. 147:293. <https://doi.org/10.1037/bul0000303>.
- Semendeferi K, Armstrong E, Schleicher A, Zilles K, Van Hoesen GW. 2001. Prefrontal cortex in humans and apes: a comparative study of area 10. *Am J Phy Anthropol*. 114:224–241. [https://doi.org/10.1002/1096-8644\(200103\)114:3<224::AID-AJPA1022>3.0.CO;2-I](https://doi.org/10.1002/1096-8644(200103)114:3<224::AID-AJPA1022>3.0.CO;2-I).
- Shu J, Bolger N, Ochsner KN. 2021. Social emotion regulation strategies are differentially helpful for anxiety and sadness. *Emotion*. 21: 1144–1159. <https://doi.org/10.1037/emo0000921>.
- Silvers JA, Weber J, Wager TD, Ochsner KN. 2015. Bad and worse: neural systems underlying reappraisal of high- and low-intensity negative emotions. *Soc Cogn Affect Neurosci*. 10:172–179. <https://doi.org/10.1093/scan/nsu043>.
- Silvers JA et al. 2016. Suicide attempters with borderline personality disorder show differential orbitofrontal and parietal recruitment when reflecting on aversive memories. *J Psychiatr Res*. 81:71–78. <https://doi.org/10.1016/j.jpsychires.2016.06.020>.
- Simmonds DJ, Pekar JJ, Mostofsky SH. 2008. Meta-analysis of go/no-go tasks demonstrating that fMRI activation associated with response inhibition is task-dependent. *Neuropsychologia*. 46: 224–232. <https://doi.org/10.1016/j.neuropsychologia.2007.07.015>.
- Spielberger CD. 1983. State-trait anxiety inventory for adults. *Mind Garden*. <https://doi.org/10.1037/t06496-000>.
- Sridhar M, Azeez A, Lissemore JI. 2024. TMS-fMRI supports roles for VLPFC and downstream regions in cognitive reappraisal. *J Neurosci*. 44:e2213232024. <https://doi.org/10.1523/JNEUROSCI.2213-23.2024>.
- Stark CEL, Squire LR. 2001. When zero is not zero: the problem of ambiguous baseline conditions in fMRI. *Proc Natl Acad Sci*. 98: 12760–12766. <https://doi.org/10.1073/pnas.221462998>.
- Stelzer J, Chen Y, Turner R. 2013. Statistical inference and multiple testing correction in classification-based multi-voxel pattern analysis (MVPA): random permutations and cluster size control. *Neuroimage*. 65:69–82. <https://doi.org/10.1016/j.neuroimage.2012.09.063>.

- Swerdlow BA, Johnson SL. 2022. The interpersonal regulation interaction scale (IRIS): a multistudy investigation of receivers' retrospective evaluations of interpersonal emotion regulation interactions. *Emotion*. 22:1119–1136. <https://doi.org/10.1037/emo0000927>.
- Tamir DI, Thornton MA. 2018. Modeling the predictive social mind. *Trends Cogn Sci*. 22:201–212. <https://doi.org/10.1016/j.tics.2017.12.005>.
- Tamir DI, Thornton MA, Contreras JM, Mitchell JP. 2016. Neural evidence that three dimensions organize mental state representation: rationality, social impact, and valence. *Proc Natl Acad Sci*. 113:194–199. <https://doi.org/10.1073/pnas.1511905112>.
- Thompson NM, Uusberg A, Gross JJ, Chakrabarti B. 2019. Empathy and emotion regulation: an integrative account. *Prog Brain Res*. 247:273–304. <https://doi.org/10.1016/bs.pbr.2019.03.024>.
- Thompson-Schill SL, Bedny M, Goldberg RF. 2005. The frontal lobes and the regulation of mental activity. *Curr Opin Neurobiol*. 15: 219–224. <https://doi.org/10.1016/j.conb.2005.03.006>.
- Torres-Morales C, Cansino S. 2024. Brain representations of space and time in episodic memory: a systematic review and meta-analysis. *Cogn Affect Behav Neurosci*. 24:1–18. <https://doi.org/10.3758/s13415-023-01140-1>.
- Uchino BN. 2006. Social support and health: a review of physiological processes potentially underlying links to disease outcomes. *J Behav Med*. 29:377–387. <https://doi.org/10.1007/s10865-006-9056-5>.
- Uddin LQ, Nomi JS, Hébert-Seropian B, Ghaziri J, Boucher O. 2017. Structure and function of the human insula. *J Clin Neurophysiol*. 34:300–306. <https://doi.org/10.1097/WNP.0000000000000377>.
- Varoquaux G et al. 2015. Scikit-learn: machine learning without learning the machinery. *GetMobile*. 19:29–33. <https://doi.org/10.1145/2786984.2786995>.
- Vu HL, Ng KTW, Richter A, An C. 2022. Analysis of input set characteristics and variances on k-fold cross validation for a recurrent neural network model on waste disposal rate estimation. *J Environ Manag*. 311:114869. <https://doi.org/10.1016/j.jenvman.2022.114869>.
- Wager TD, Smith EE. 2003. Neuroimaging studies of working memory. *Cogn Affect Behav Neurosci*. 3:255–274. <https://doi.org/10.3758/CABN.3.4.255>.
- Weaverdyck ME, Lieberman MD, Parkinson C. 2020. Tools of the trade multivoxel pattern analysis in fMRI: a practical introduction for social and affective neuroscientists. *Soc Cogn Affect Neurosci*. 15: 487–509. <https://doi.org/10.1093/scan/nsaa057>.
- Wright RN, Adcock RA, LaBar KS. 2024. Learning emotion regulation: an integrative framework. *Psychol Rev*. 132:173–203. <https://doi.org/10.1037/rev0000506>.
- Xie X et al. 2016. How do you make me feel better? Social cognitive emotion regulation and the default mode network. *NeuroImage*. 134:270–280. <https://doi.org/10.1016/j.neuroimage.2016.04.015>.
- Zaki J, Ochsner KN. 2012. The neuroscience of empathy: progress, pitfalls and promise. *Nat Neurosci*. 15:675–680. <https://doi.org/10.1038/nn.3085>.
- Zaki J, Williams WC. 2013. Interpersonal emotion regulation. *Emotion*. 13:803. <https://doi.org/10.1037/a0033839>.
- Zayas V, Surenkok G, Pandey G. 2017. Implicit ambivalence of significant others: Significant others trigger positive and negative evaluations. *Soc Personal Psychol Compass*. 11(11):e12360. <https://doi.org/10.1111/spc3.12360>.