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► **To cite this version:**

Shanshan Ma, Erin Maresh, Andrea Coppola, Katherine Richard, Leonie Koban, et al.. When Empathy Gets Tough: Neural Responses to Overcoming the Self in a Novel Paradigm Predict Everyday Prosocial Behavior. 2024. hal-04728964

HAL Id: hal-04728964

<https://hal.science/hal-04728964v1>

Preprint submitted on 9 Oct 2024

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When Empathy Gets Tough: Neural Responses to Overcoming the Self in a Novel Paradigm Predict Everyday Prosocial Behavior

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Keywords: Empathy, self-regulation, daily support, close relationships, fMRI

Body Word Count: 7451

References Cited: 68

Tables: 1

Figures: 4

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Acknowledgments

This project was supported by funding from the National Institute of Mental Health (#1R01MH125414-01) awarded to Jessica R. Andrews-Hanna (MPI), David Sbarra (MPI) and Erin Maresh (Co-I). We thank Kayleigh Cook, Joanna Hwang, Zane Burrows, Colin Tidwell, Heather Jensen, Cate Longo, Katelyn Maughan, Reva Joshi, and Stephanie Keenan for assistance with data collection. John Allen and Matthias Mehl also assisted with helpful discussion, and contributed to aspects of study design that were not the primary focus of this manuscript.

Author contributions: DS and JAH co-led this study and take responsibility for the integrity and accuracy of the reporting.

Concept and design: DS, JAH, EM, AC

Acquisition and interpretation of data: All authors

Drafting the manuscript: SSM

Revision of the manuscript: All authors

Statistical analyses: SSM

Administrative, technical, or material support: All authors

Approval of final manuscript: All authors

Competing interests

The authors have no conflicts of interest to declare.

Data and code availability

The data and code are included in this submission: <https://osf.io/63vnc/>.

Abstract

Empathy is essential for social relationships and well-being, yet conventional studies often do not capture the self-regulatory demands inherent to everyday empathic responding in close relationships. We therefore developed a novel empathy paradigm (the CLOSE task) to mimic everyday demands to “overcome the self”, and used this paradigm to examine how the neural correlates of empathy relate to real-world prosocial behavior across 131 adults (from 71 romantic couples). The CLOSE task includes positive and negative social feedback directed at participants and their partners in separate and simultaneous conditions. When participants overcame self-directed feedback to empathize with their partner, they recruited regions critical for self-regulation (e.g., dorsolateral prefrontal cortex) beyond those typically associated with affective and cognitive empathy. Brain activity in several hypothesized regions related to variation in trait empathy and everyday supportive behavior. This study highlights the real-world significance of transcending self-focused feelings to engage in empathy and prosocial behavior.

Introduction

Empathy—the ability to understand and share the feelings of others—is thought to exert a profound influence on social connectedness^{1, 2} and mental health^{3, 4}, especially in the context of close relationships^{5, 6}. Although laboratory-based tasks often succeed at eliciting empathy in controlled experimental settings⁷⁻¹⁰, capturing the complexities of empathy as it unfolds in everyday life has proven challenging^{11, 12}. One part of this challenge is operationalizing the many ways in which empathy requires executive function to ‘overcome the self’—i.e., to overcome one’s egocentric perspective and affective states in order to fully connect with the feelings of others. Outside the laboratory and in daily life, mood fluctuations and self-focused distractions—including when we are tired, stressed, or pulled into the world of digital devices— can make empathizing with others quite difficult, if not impossible, in some circumstances¹³⁻¹⁶. In these situations, overcoming one’s own experience to understand and share the experience of a close other may require substantial cognitive effort. In this paper, we extend the neuroscientific study of empathy at levels of both the brain and behavior by examining these kinds of challenging situations in the context of romantic relationships—in which our emotional states conflict with those of our loved ones. To do so, we developed a research paradigm to better approximate how we overcome the self in everyday contexts to empathize with close others.

Self- and emotion-regulatory processes feature prominently in many models of empathy¹⁷⁻²¹, yet few of these models conceptualize self-regulation as a requirement for empathy. Rather emotion regulation is often treated as a means to dampen personal distress when facing others’ pain or as a moderator in the association between affective empathy and empathic outcomes (e.g., prosocial behaviors or affective distress)^{22, 23}. In contrast, studies of empathy manipulating demands for self-regulatory effort are lacking, and the neural underpinnings of overcoming the self to empathize with others remain unclear. Typical empathy tasks involve simply observing or processing stimuli being encountered by others (e.g., a needle puncturing a hand)^{7, 8}, a situation that cannot fully capture the complexity of empathy outside the laboratory. Prior empathy studies have made headway increasing the ecological validity of empathy paradigms through

observing videos of real-life sad events^{9, 10, 24}, social exclusion or unfairness^{25, 26}, or through imposing painful or nonpainful stimuli to others outside the scanning room depending on the participants' performance²⁷. However, there remains a need for paradigms that capture empathy in challenging self-regulatory and interpersonal situations.

Although most of the literature focuses on empathy for others' distress (such as pain, negative emotional conditions, and social exclusion)^{7, 10, 25}, in everyday life, the opportunity to empathize with positive emotions is three times as frequent as the chance to empathize with negative emotions¹². Positive empathy also plays a functional role in prosocial behavior, social closeness, and well-being²⁸⁻³¹. At the neural level, empathy for positive emotions (also known as "vicarious reward") typically evokes activity in brain regions distinct from those involved in negative empathy, with a particular emphasis on the role of ventromedial prefrontal cortex (VMPFC) instead of dorsal anterior cingulate cortex (dACC) or anterior insula (AI)^{32, 33}. In the present report, we therefore expand the study of empathy to investigate how people overcome their own affective state to empathize with both the positive and negative feelings of their romantic partner.

Empathy is often elicited in the context of close relationships¹² and is considered vital to healthy relationships and mental well-being^{5, 6, 34}. For example, the ability to accurately infer others' mental states is positively associated with romantic relationship satisfaction^{5, 6}, and affective responding within the context of romantic relationships is believed to be a critical mechanism linking relationship quality to distal health outcomes³⁴. Insight into the neural mechanisms of empathy for one's romantic partner could provide important clues to sources of individual variability in relationship quality and mental health. Yet, in the social neuroscience literature, most of the research to date focuses on empathy for strangers^{7, 10, 25, 35}, which may diverge to some degree from the neural mechanisms in the context of relationships^{26, 36}. Moreover, research on romantic relationships primarily focuses on empathy for pain, and data is typically collected from only one partner³⁷⁻³⁹. Although significant overlap exists, there are

discernible differences in the empathic responses evoked by pain compared to other social negative states (e.g., anger or distress)⁴⁰. Overall, significant gaps remain in our understanding of empathy in social context, especially within close (including romantic) relationships.

To address these limitations in our understanding of empathy and to better approximate the challenges of empathic responding in everyday life, the current study introduces a dyadic functional magnetic resonance imaging (fMRI) paradigm—the Connected Lives: Overcoming the Self through Empathy (CLOSE) task. We designed the CLOSE task to capture challenging contexts in which empathic responses require self-regulatory effort. The task measures neural correlates to empathy for one’s partner in the simultaneous presence (versus absence) of positive and negative feedback toward oneself (Fig. 1A). Specifically, the CLOSE task includes conditions in which positive, negative, or no feedback is directed towards oneself and/or one’s partner, yielding both separate and simultaneous feedback conditions. To create a more naturalistic context, we avoided explicitly instructing individuals to empathize with their partner, given that different instructions when processing the experience of others may result in different empathy responses and blood oxygenation level dependent (BOLD) activity^{41, 42}. Importantly, both partners completed the task in the MRI scanner, and each partner was led to believe that the feedback was also viewable by their partner, thus eliciting spontaneous empathy.

In this manuscript, we first validate the CLOSE task by examining self-reported affect and BOLD activity associated with traditional empathy contrasts used in previous research when demands for “overcoming the self” are minimal. These include observing one’s partner receiving positive or negative feedback alone (P_{POS} or P_{NEG} condition) versus a condition with no self-directed or partner-directed feedback (XX condition) (i.e., P_{POS-XX} and P_{NEG-XX}). BOLD activity in regions associated with cognitive empathy (e.g., dorsomedial prefrontal cortex (DMPFC), temporoparietal junction (TPJ), and posterior cingulate cortex (PCC))⁴³⁻⁴⁵ and affective empathy (e.g., AI, dACC and VMPFC (especially when empathizing with positive feedback))^{7, 9} would suggest the CLOSE task is a valid measure of spontaneous empathy in romantic relationships.

We then expand our analysis to the simultaneous incongruent feedback conditions that may require participants to overcome affective responses to their own feedback to empathize with their partner. These include a) simultaneous positive self-directed feedback and negative partner-directed feedback vs. positive self-directed feedback alone ($S_{POS}P_{NEG}-S_{POS}$), and b) simultaneous negative self-directed feedback and positive partner-directed feedback vs. negative self-directed feedback alone ($S_{NEG}P_{POS}-S_{NEG}$). In addition to regions typically associated with affective and cognitive empathy, we hypothesized that this contrast would yield BOLD activity in regions previously linked to cognitive control and emotion regulation, such as the dorsolateral prefrontal cortex (DLPFC)⁴⁶.

Finally, considering that a key aim of our study is to understand neural sources of between-person variability in trait empathy and empathic behavior, we also examine relationships between BOLD activity elicited during the challenging empathy conditions in which participants need to overcome their own feedback to empathize with the partner (e.g., $S_{NEG}P_{POS}-S_{NEG}$) and trait and everyday behavioral measures of empathy. We predicted positive relationships between cognitive (e.g., perspective taking), affective (e.g., affective responses), and emotion regulation subscale scores of the Empathy Assessment Index (EAI), and activity in key brain regions linked to cognitive empathy, affective empathy, and cognitive control, respectively. More importantly, as a real-world measure of empathic behavior, we also measured support provided to one's partner in everyday life, assessed with a week-long daily diary completed by one's partner⁴⁷. We hypothesized that this partner-rated daily support provision would be positively related to activity in key brain regions linked to empathy and cognitive control.

Results

The CLOSE task is a valid metric of spontaneous empathy

As a measure of behavioral empathy during the CLOSE task, participants reported their momentary affect following half of the stimuli within each condition (see Methods). First, we examined self-reported affect associated with conventional empathy contrasts used in previous research (P_{POS-XX} and P_{NEG-XX}). Specifically, linear mixed-

effects models showed that participants reported more positive affect in the partner-positive feedback condition than the no feedback condition ($P_{\text{POS-XX}}$, $B = 0.58$, $SE = 0.05$, 95% CI: [0.48, 0.69], $t_{(192.81)} = 10.90$, $p < 0.001$, $d = 1.19$), and more negative affect in the partner-negative condition than the no feedback condition ($P_{\text{NEG-XX}}$, $B = -0.57$, $SE = 0.06$, 95% CI: [-0.69, -0.46], $t_{(188.85)} = -9.97$, $p < 0.001$, $d = -1.12$) (Fig. 1B).

Next, we investigated how individuals responded emotionally to feedback directed at their partner, while simultaneously receiving conflicting feedback about themselves. Compared to self-related feedback conditions, participants incorporated their partner's feedback into their affect during the simultaneous incongruent feedback trials, such that they felt more positive when self-negative feedback was accompanied by partner-positive feedback versus experienced alone ($S_{\text{NEG}P_{\text{POS}}}-S_{\text{NEG}}$: $B = 0.40$, $SE = 0.06$, 95% CI: [0.28, 0.53], $t_{(188.31)} = 6.31$, $p < 0.001$, $d = 0.64$) and more negative when self-positive feedback was accompanied by partner-negative feedback versus experienced alone ($S_{\text{POS}P_{\text{NEG}}}-S_{\text{POS}}$: $B = -0.59$, $SE = 0.07$, 95% CI: [-0.72, -0.46], $t_{(188.02)} = -9.00$, $p < 0.001$, $d = -1.03$) (Fig. 1B). These results suggest that participants experienced spontaneous empathy when their partner received positive or negative feedback.

Negative self-directed feedback interferes with eliciting positive empathy

We further examined whether it is more challenging to overcome incongruent self-directed feedback to empathize with one's partner, as compared to conventional contrasts of exposure to partner-directed feedback alone. In line with this idea, participants' affect was improved less by positive feedback directed at the partner when they themselves received negative feedback, compared to when there was no negative self-directed feedback ($[S_{\text{NEG}P_{\text{POS}}}-S_{\text{NEG}}]-[P_{\text{POS-XX}}]$, $B = -0.18$, $SE = 0.06$, 95% CI: [-0.30, -0.06], $t_{(188.26)} = -2.92$, $p = 0.004$, $d = -0.33$). Interestingly, participants reported similar decreases in affect when the partner received negative feedback, irrespective of whether they received positive or no feedback ($[S_{\text{POS}P_{\text{NEG}}}-S_{\text{POS}}]-[P_{\text{NEG-XX}}]$, $B = -0.02$, $SE = 0.06$, 95% CI: [-0.14, 0.10], $t_{(187.37)} = -0.28$, $p = 0.782$, $d = -0.03$) (Fig. 1B). These results suggest that experiencing negative self-directed social feedback creates an

affectively challenging context that makes it more difficult (and likely requires emotion regulation) to empathize with one's partner.

After the CLOSE task, participants also rated how they felt overall and how they thought their partner felt in response to each feedback condition, using retrospective questionnaires. These post-task ratings of self-affect reproduced the patterns mentioned above during the CLOSE task. However, the ratings of how participants thought their partner felt did not significantly differ between $S_{NEG}P_{POS}-S_{NEG}$ and $P_{POS}-XX$, or between $S_{POS}P_{NEG}-S_{POS}$ and $P_{NEG}-XX$ (Wilcoxon Signed Rank test; Supplementary Fig. S1). This result emphasizes a gap in the cognitive understanding of one's partner's affect, especially when participants experience negative affect themselves.

Overall, these behavioral results demonstrated that across participants, the CLOSE task modulated self-reported affect in hypothesized ways, thus succeeding as a means of eliciting spontaneous empathy. Furthermore, participants' affective ratings suggest they may find it particularly challenging to feel good for their partner when doing so requires suppressing their emotional response to simultaneous negative self-directed feedback.

During conventional empathy contexts, the CLOSE task elicits activity in regions canonically associated with affective and cognitive empathy

Our first set of fMRI analyses aimed to validate the CLOSE task by examining whether observing social feedback about one's partner, in the absence of simultaneous self-feedback, evokes BOLD activity in regions canonically associated with affective and cognitive empathy found in previous studies. Consistent with our hypotheses, both $P_{POS}-XX$ and $P_{NEG}-XX$ contrasts yielded BOLD activity in regions previously linked to affective empathy (such as dACC, AI, and premotor cortex (PMC)) and cognitive empathy (such as TPJ, DMPFC, PCC, and temporal pole) ($z > 3.1$ and cluster level $p_{GRF} < .05$; Fig. 2A-B, and Supplementary Table S2). When directly contrasting positive partner-directed and negative partner-directed feedback conditions, the P_{POS} condition displayed higher activity in the visual cortex (including lingual gyrus) compared to the P_{NEG} condition (Supplementary Table S2). Overall, these results suggest that when

demands for overcoming the self are low, brain regions related to social cognition and empathy are robustly recruited⁴⁷.

Brain regions associated with self-regulation are recruited when experiencing empathy places increasing demands on overcoming the self

In the next series of analyses, we examined the patterns of brain activity recruited during the more challenging empathy contrasts involving simultaneous incongruent feedback directed towards oneself and one's partner, thereby increasing demands on overcoming the self (i.e., $S_{NEG}P_{POS}-S_{NEG}$ and $S_{POS}P_{NEG}-S_{POS}$). We then compared these patterns with those observed in conventional contrasts ($P_{POS}-XX$ and $P_{NEG}-XX$).

First, we conducted whole brain analyses to uncover patterns of brain activation associated with overcoming the self to empathize with one's partner ($S_{NEG}P_{POS}-S_{NEG}$ and $S_{POS}P_{NEG}-S_{POS}$ contrasts). In addition to the activation of regions linked to cognitive empathy (e.g., TPJ, MPFC, and precuneus) and affective empathy (e.g., AI and dACC), the novel contrasts also yielded activation in regions linked to self-regulation and cognitive control, such as the middle frontal gyrus (MFG)/DLPFC ($z > 3.1$ and cluster level $p_{GRF} < .05$; Table 1 and Fig. 2C-D). Additionally, paralleling the behavioral finding that demands on self-regulation are particularly strong in the $S_{NEG}P_{POS}$ condition, the $S_{NEG}P_{POS}-S_{NEG}$ contrast yielded statistically greater DLPFC/MFG activity than the $S_{POS}P_{NEG}-S_{POS}$ contrast ($z > 3.1$ and cluster level $p_{GRF} < .05$; Fig 3A and Table 1). The $S_{NEG}P_{POS}-S_{NEG}$ contrast also yielded higher BOLD activity than the $S_{POS}P_{NEG}-S_{POS}$ contrast in brain areas associated with reward processing (e.g., ventral and dorsal striatum), affective empathy (e.g., VMPFC), and cognitive empathy (e.g., middle cingulate cortex) ($z > 3.1$ and cluster level $p_{GRF} < .05$; Fig 3A and Table 1). These findings suggest that even when receiving simultaneous partner-directed feedback that conflicts with the self-directed feedback, participants demonstrate empathy toward their partner. However, overcoming one's response to negative feedback to empathize with a partner may require higher levels of cognitive control and cognitive empathy.

To control for participants' belief in our cover story, we conducted another analysis including the extent of participants' belief in our cover story as a covariate of no interest. The main results remained unchanged after regressing the ratings of belief in our cover story (Supplementary Table S3). Similarly, these results remained unchanged after regressing age and relationship duration (Supplementary Table S4).

We further examined whether overcoming the self to empathize with one's partner was associated with BOLD activity in additional regions not seen in the conventional contrasts. The results exhibited different patterns associated with empathy for positive and negative experiences. Specifically, the $S_{NEG}P_{POS}-S_{NEG}$ contrast, compared to $P_{POS}-XX$ contrast, yielded statistically greater BOLD activity in frontal-parietal areas⁴⁸: right MFG/DLPFC and the bilateral supramarginal gyrus/anterior inferior parietal lobule ($z > 3.1$ and cluster level $p_{GRF} < .05$; Fig. 3B and Supplementary Table S5). Conversely, activity in regions associated with cognitive empathy (e.g., left TPJ, bilateral PCC and bilateral DMPFC) and affective empathy (e.g., bilateral AI, bilateral PMC/precentral gyrus, and bilateral pre-supplementary motor area) was reduced for the $S_{NEG}P_{POS}-S_{NEG}$ contrast compared to the $P_{POS}-XX$ contrast ($z > 3.1$ and cluster level $p_{GRF} < .05$; Fig. 3B and Supplementary Table S5). Taken together, these findings suggest that incongruent negative self-directed feedback increases cognitive demands on overcoming the self but reduces affective sharing and cognitive empathy toward the partner.

Finally, when comparing the $S_{POS}P_{NEG}-S_{POS}$ and $P_{NEG}-XX$ contrasts, the $S_{POS}P_{NEG}-S_{POS}$ contrast mainly demonstrated higher activity in right frontal pole, but significantly lower activity in regions linked to cognitive empathy (such as bilateral DMPFC, bilateral PCC, and bilateral precuneus) and affective empathy (such as bilateral AI, bilateral inferior frontal gyrus, bilateral PMC/precentral gyrus, and bilateral pre-supplementary motor area) ($z > 3.1$ and cluster level $p_{GRF} < .05$; Fig. 3C and Supplementary Table S5). Together with the behavioral findings, these observations suggest that the conflicting presence of positive self-directed feedback may be not challenging to overcome but may instead enhance empathy efficiency, requiring less brain activity to achieve similar phenomenological levels of empathy.

BOLD responses to empathy when overcoming the self are related to self-reported trait empathy and partner-rated daily supportive behavior

Our final set of analyses examined whether individual differences in BOLD activity when overcoming the self to empathize with one's partner was related to individual differences in trait empathy scores and real-world empathic behavior as assessed via partner-rated support during week-long daily diary surveys. Given that our hypotheses pertain to brain regions associated with affective empathy, cognitive empathy, and cognitive control, our initial step involved a region of interest analysis on the $S_{\text{NEG}}P_{\text{POS}}-S_{\text{NEG}}$ contrast given its greatest demands on emotion/self-regulation. Noting that the distinctions between the novel and the conventional empathy contrasts predominantly manifested in the right hemisphere, spherical ROIs linked to affective empathy, cognitive empathy, and cognitive control (e.g., AI, dACC, DMPFC, TPJ, and DLPFC) in the right hemisphere were created based on the peak MNI coordinates identified from “empathy” and “cognitive control” meta-analyses using Neurosynth (<https://neurosynth.org>) (Supplementary Table S6).

Largely supporting our hypotheses, participants with greater BOLD activity in right MFG scored higher on the Emotion Regulation subscale score of the EAI, indicating a greater self-perceived emotional stability ($\beta = 0.21$, $SE = 0.08$, 95% CI: [0.04, 0.37], $t_{(124.12)} = 2.44$, $p = 0.016$, $d = 0.21$; Fig. 4A). However, contrary to our hypothesis, between-subject variability in this region was not significantly related to support provision ($\beta = 0.01$, $SE = 0.09$, 95% CI: [-0.16, 0.18], $t_{(123.75)} = 0.09$, $p = 0.927$, $d = 0.01$). Moreover, participants with greater BOLD activity in right TPJ and right DMPFC—two regions linked to cognitive empathy—scored higher on the Perspective-Taking subscale of EAI (DMPFC: $\beta = 0.19$, $SE = 0.09$, 95% CI: [0.02, 0.36], $t_{(128.99)} = 2.18$, $p = 0.031$, $d = 0.19$; TPJ: $\beta = 0.21$, $SE = 0.09$, 95% CI: [0.04, 0.38], $t_{(128.62)} = 2.44$, $p = 0.016$, $d = 0.21$; Fig. 4B-C) and demonstrated higher daily support provision, as reported by their partner (DMPFC: $\beta = 0.24$, $SE = 0.08$, 95% CI: [0.08, 0.41], $t_{(128.78)} = 2.88$, $p = 0.005$, $d = 0.25$; TPJ: $\beta = 0.18$, $SE = 0.08$, 95% CI: [0.01, 0.35], $t_{(128.27)} = 2.08$, $p = 0.040$, $d = 0.18$; Fig. 4B-C). We followed our ROI analyses with exploratory whole-

brain analyses which revealed an overall similar set of findings as the ROI analyses, with main findings in regions associated with cognitive empathy and cognitive control ($z > 3.1$ and cluster size ≥ 10 , Supplementary Table S7 and Supplementary Fig. S2). Exploratory whole brain analyses for the $S_{POS}P_{NEG}-S_{POS}$ contrast are displayed in Supplementary Table S7 and Supplementary Fig. S3.

In order to further assess the enhanced ecological validity of the novel empathy contrasts placing higher demands on overcoming the self, we conducted a comparative analysis of the relationships between BOLD activity in the $S_{NEG}P_{POS}-S_{NEG}$ contrast in the meta-analysis derived ROIs and partner-rated daily support provision, as compared to the relationships between BOLD activity in the P_{POS-XX}/P_{NEG-XX} contrast and partner-rated daily support provision. The findings revealed that there were no significant relationships between BOLD activity for the P_{POS-XX}/P_{NEG-XX} contrast and daily support provision, and that in contrast to the P_{POS-XX}/P_{NEG-XX} contrast, BOLD activity in the $S_{NEG}P_{POS}-S_{NEG}$ contrast showed significantly stronger associations (Supplementary Table S8). This further supports the idea that real-life empathic behavior is driven not just by empathic (brain) responses per se, but by the ability of the individual to take the perspective of and empathize with the partner when their current affective and mental state is different from the affective state of the partner.

Discussion

The neuroscientific study of empathy is bedeviled by two significant limitations. First, empathic responding is typically studied in controlled laboratory studies that do not capture the frequent need to overcome our own experiences to effectively respond to others. Second, much of the research on empathy examines individual responses to a stranger's pain, which is to some extent different from empathy with a close partner in the social context (e.g., romantic partner's social rejection). The current study aimed to address these limitations. We examined the ways in which individuals in a romantic relationship empathize with their partner, especially in contexts in which overcoming one's personal experience is challenging, similar to common situations in everyday life. To achieve this goal, we developed a dyadic fMRI task in which participants observe

positive and negative social feedback delivered to the self, their partner, or the self and partner simultaneously. In a large and diverse sample of romantic couples, we examined brain responses to social feedback directed at one's partner, while simultaneously receiving incongruent feedback about oneself, requiring participants to overcome their own affective experience to empathize with their partner. These challenging empathy situations, compared with traditional empathy conditions, elicited less activation in brain regions linked to affective and cognitive empathy, but higher activation in regions associated with cognitive control and emotion regulation, especially the $S_{NEG}P_{POS}-S_{NEG}$ contrast. Importantly, we also observed substantial inter-individual variability in recruitment of these brain regions, which was related to trait empathy and real-world, partner-rated daily supportive behaviors. By investigating the neural correlates associated with empathy in challenging contexts mimicking the complexity of everyday life, this study provides insights into real-world variability in empathy within close relationships.

During conventional empathy situations (e.g., P_{NEG-XX} or P_{POS-XX}), we observed robust changes in self-reported affect accompanied by BOLD activity in brain regions associated with both affective empathy, including the ACC and AI, and cognitive empathy, such as the TPJ, TP, DMPFC, PCC, and precuneus. These findings align with the neural substrates reported in prior empathy-related investigations^{9, 48-50}. This consistency suggests that our experimental task effectively captures empathic processes within the context of social feedback and replicates similar neural activations observed in alternative contexts, such as those involving pain and social exclusion^{9, 10, 48}. Additionally, prior work reveals that empathy for positive emotions often engage brain regions distinct from those involved in negative empathy, with a particular emphasis on VMPFC instead of dACC or AI activation^{32, 33, 51}. However, in our study, when individuals processed partner-directed feedback alone, positive and negative feedback was associated with similar levels of VMPFC, dACC and AI activity. One possible explanation for this discrepancy may be that feeling both positive and negative empathy for a close other may involve constructing emotional meaning from another's reward or suffering, combined with feelings of empathic concern toward a loved one^{52, 53}.

During the process of overcoming one's personal feelings to empathize with one's partner, BOLD activity patterns also encompassed both affective and cognitive empathy components. However, recruitment of these regions was generally not as robust as the canonical empathy contrasts. Witnessing a partner's feedback in the presence of self-feedback ($S_{NEG}P_{POS}-S_{NEG}$ and $S_{POS}P_{NEG}-S_{POS}$ contrasts) elicited lower activity in several of the above-mentioned brain regions (such as AI, PMC, TPJ, MPFC, PCC, and precuneus) than when simultaneous self-feedback was absent (e.g., P_{NEG-XX} or P_{POS-XX} contrasts). These findings parallel the behavioral affect ratings, whereby the presence of self-negative feedback partially disrupted participants' vicarious reward when witnessing their partner receive positive feedback. These findings also align with those from prior research on pain perception, whereby personal experiences of pain tend to enhance self-focused attention⁵⁴, which can inhibit affective sharing components of empathy as individuals pay less attention to feelings of others⁸. Relatedly, both acute stress and the presence of social anxiety can shift participants' perspectives toward empathic experiences dominated by an egocentric (self-focused) perspective^{15, 16}.

In our study, overcoming the self to empathize with one's partner elicited higher activity in cognitive control regions (e.g., MFG), particularly when participants received negative self-directed feedback. The ROI analysis further revealed that during both $S_{NEG}P_{POS}-S_{NEG}$ and $S_{POS}P_{NEG}-S_{POS}$ contrasts, activity in cognitive control regions (right MFG) was significantly positively correlated with activity in perspective-taking (e.g., right DMPFC and right TPJ) and affective empathy areas (e.g., right AI and right dACC) (Supplementary Table S9). Existing research has consistently demonstrated links between self-reported emotion regulation and perspective-taking or empathy⁵⁵⁻⁵⁷. The current study, from a neurological perspective, further illustrates the importance of regulating one's own emotions in affective and cognitive empathy.

Our sample was relatively large for a brain imaging study, thus enabling us to investigate the role of individual differences. The current study found that individual differences in BOLD activity underlying empathy in challenging contexts (especially during the $S_{NEG}P_{POS}-S_{NEG}$ contrast) related to variation in trait empathy. Consistent with previous studies^{44, 45, 58}, increased activity in regions implicated in cognitive empathy (right DMPFC and right TPJ) positively correlated with scores on the Perspective-Taking

subscale of the EAI. However, we did not observe hypothesized relationships between BOLD activity in regions involved in affective empathy and scores on subscales of the EAI related to affective empathy. This observation may be attributed to the inherent challenge of overcoming one's own negative emotional responses to engage in affective empathy with a partner¹³, potentially leading to lower-intensity and less varied activity within affective empathy regions. Furthermore, we observed a noteworthy positive relationship between activity in regions linked to self-regulation/cognitive control (right MFG) for the $S_{NEG}P_{POS} - S_{NEG}$ contrast and scores on the Emotion Regulation subscale of EAI. This positive relationship suggests that cognitive control areas may be employed as a means to overcome self-negative feelings to empathize with positive feedback toward one's partner, rather than to maintain an intrusive self-focus with detrimental consequences.

Importantly, participants who displayed stronger BOLD activity in regions linked to cognitive empathy (such as DMPFC, TPJ and superior temporal sulcus) during the $S_{NEG}P_{POS} - S_{NEG}$ contrast provided more support towards their partners in everyday life. Engaging in prosocial behavior is often a consequence of affective or cognitive empathy and prosocial concern is considered a key feature of empathy in many psychological models^{10, 35, 48, 58}. Our study suggests that partners who spontaneously engage in perspective-taking in the presence of conflicting self-feedback are more likely to provide support in daily life. Our study partially supports prior studies pointing to the role of the MPFC, AI, the septal area, and ventral striatum in predicting prosocial behavior towards targets of empathy^{10, 25, 35}. The present study expands this previous research by highlighting the importance of regions supporting cognitive empathy and by adopting an external measure of prosocial behavior outside the laboratory, namely, partner-rated support provision assessed with a daily diary. Moreover, results revealed that BOLD activity emerging from the $S_{NEG}P_{POS} - S_{NEG}$ contrast showed markedly stronger associations with daily support provision than associations with the $P_{POS} - XX$ contrast. This outcome suggests that the neural correlates underlying empathy in this challenging and more ecologically valid context may help us better understand variability in empathy in daily life.

The current study also further revealed varying effects of distinct self-emotions on empathy. This was evident in the differences observed between $S_{NEG}P_{POS}-S_{NEG}$ and $S_{POS}P_{NEG}-S_{POS}$, and the differences between novel empathic contrasts (i.e., $S_{NEG}P_{POS}-S_{NEG}$ or $S_{POS}P_{NEG}-S_{POS}$) and conventional contrasts (i.e., $P_{POS}-XX$ or $P_{NEG}-XX$). Specifically, when participants experienced incongruent negative self-directed feedback, they reported lower positive affect in response to positive partner-directed feedback. This was accompanied by higher activity in regions associated with cognitive control (e.g., MFG) and lower activity in regions linked to affective and cognitive empathy. In contrast, when participants experienced positive self-directed feedback that mismatched the feedback directed to their partners, they reported similar negative affect to negative partner-directed feedback but showed more significantly lower activity in affective and cognitive empathy regions. These findings align with existing evidence suggesting that regulating negative emotion is more challenging than regulating positive emotion, requiring greater recruitment of DLPFC⁴⁶. Moreover, inducing a negative mood has been linked to both increased personal distress and reduced emotional resonance when observing others' pain^{13, 59}. Consequently, simultaneous negative self-directed feedback would hinder empathy for one's partner's positive experience, despite participants attempt to recruit more cognitive control regions to overcome it, manifesting as lower affective response and insufficient engagement of affective and cognitive empathy regions. Conversely, positive mood has been shown to increase empathy and prosocial behavior^{60, 61}, suggesting that positive self-directed feedback may not only require less cognitive control to overcome but also enhance the efficiency of empathy. As a result, individuals may respond similarly to negative partner-directed feedback as they would in the absence of self-feedback, with reduced brain activity in cognitive and affective empathy regions.

This study exhibits several notable strengths. Firstly, we developed a dyadic fMRI paradigm to investigate the neural correlates associated with spontaneous empathy for one's romantic partner when participants are challenged to overcome their own affectively salient situations. Second, our investigation expands the study of empathy by studying empathy for both positive and negative experiences. Third, our research uses neuroimaging data from a diverse and sizable sample of romantic

partners, encompassing couples with diverse sexual orientations, relationship durations and stages, age ranges, and racial/ethnic backgrounds. Finally, we simultaneously assessed self-reported empathy traits through questionnaires and captured supportive behaviors through partner reports in daily diaries. Collectively, this rich combination of methods allows us to uncover novel connections between laboratory findings and real-world dynamics within romantic relationships.

However, the results of this study should be considered in light of several limitations. First, although our results remained similar after regressing age and relationship duration (Supplementary Table S4), the current results may be affected by the heterogeneity of romantic couples, with varying sexual orientation, relationship duration and stage, age, and racial/ethnic background. Second, although covariate analyses indicated that our findings were not statistically influenced by participants' belief in our cover story (Supplementary Table S3), future investigators may consider strategies to further augment participants' belief. Finally, further studies could extend the generalizability of our task by examining its applicability to various other types of social relationships, such as parent-child dyads, friends, and strangers.

In summary, this paper introduced a dyadic, ecologically valid behavioral and neuroimaging paradigm—referred to as the CLOSE task—and demonstrated that the paradigm has real-world and predictive validity for studying empathic responses within the context of close romantic relationships. Using the CLOSE task, we found that empathizing with one's partner in challenging contexts, especially in presence of negative self-directed feedback, involves more than just affect sharing and mentalizing; it also necessitates the allocation of cognitive control resources to overcome distracting self-focused emotional information. In such challenging contexts where individuals need to override their own emotional responses to empathize with their partner, BOLD activity patterns are effective predictors of empathic behaviors, including partner-reported experiences of social support outside the laboratory.

Materials and Methods

Participants

Seventy-three couples ($N = 146$ participants) in monogamous romantic relationships were recruited from the Tucson community using flyers and advertisements on social media. Couples were required to have been together for at least 18 months and to have lived together for at least 6 months. This study is part of a larger ongoing study involving the collection of neural, physiological, and behavioral data among romantic couples. The study was approved by the Institutional Review Board of the University of Arizona and all participants provided written informed consent prior to participation. Fifteen participants were excluded from the subsequent analysis without task or structural neuroimaging scanning ($n=11$), or with compromised neuroimaging data due to severe loss in coverage ($n=4$). Thus, the final neuroimaging sample contained 131 subjects from 71 couples. Among these participants, 76 individuals were married. The mean age of the final sample was 31.8 years ($SD = 8.4$, range = 19.1-56.1), the mean relationship duration was 8.3 years ($SD = 6.3$, range = 1.7-30.0), and the mean cohabiting duration was 6.5 years ($SD = 6.2$, range = 0.5-29.5). Detailed demographic characteristics are displayed in Supplementary Table S1.

Connected Lives: Overcoming the Self through Empathy (CLOSE) task

To assess behavioral and neural indicators of empathy in complex self-regulatory contexts common in everyday life, we developed and piloted the CLOSE task—a novel social feedback task designed to assess spontaneous empathy as demands to overcome the self vary across conditions. Participants were informed that the task involves viewing likability ratings made by other participants in the study about themselves and their partner. Critically, participants were told that their partner will also view identical stimuli, setting up a context to facilitate a sense of their partner's presence and promote spontaneous empathy. As described below in the Experimental Procedures, a cover story was introduced in Session 1, and the CLOSE task was completed by both partners in the scanner in Session 2.

In each trial of the CLOSE task, a different photograph of a “rater” was displayed for 3.9s, along with the rater's presumed likability ratings of the participant in the scanner (“YOU”) and/or the participant's partner (“PNR”). The rater's likeability ratings

varied in valence, consisting of positive (P, rating=YES), negative (N, rating=NO), and absent (indicated by “XX”) ratings. For absent ratings, which served as a control condition for the CLOSE task, participants were told that the rater did not view their photo or failed to make a response to their photo fast enough (Fig. 1A). On each trial, P or N ratings were displayed solely for the self (in which case, the partner-directed feedback was absent), solely for the partner (in which case, the self-related feedback was absent), or simultaneously for self and partner, yielding conditions in which feedback was congruent or incongruent. Altogether, the CLOSE task included the following task conditions: a) Self-related feedback but no partner-directed feedback (S_{NEG} and S_{POS}), b) Partner-directed feedback but no self-related feedback (P_{NEG} and P_{POS}), c) Simultaneous congruent feedback ($S_{NEG}P_{NEG}$, $S_{POS}P_{POS}$), d) Simultaneous incongruent feedback ($S_{NEG}P_{POS}$, $S_{POS}P_{NEG}$), and e) No feedback for either self or partner (XX). Although we told participants they would receive likability ratings made by other participants, all of the “raters” were photos taken from the Chicago face database⁶². All photographs were black and white headshots of individuals making a neutral expression, and conditions were matched on perceived attractiveness, age, and race/ethnicity of the photos (using normed ratings of the Chicago face database).

Following half of the trials within each condition, participants were asked to rate their affective state by referring to the question “Right now, how do you feel, with -3 being very negative and 3 being very positive?”. There was a 1.3-second interval following the presentation of likability ratings stimuli, and then participants were given 3.9s to supply their response with a button press placed in their dominant hand.

Participants completed 6 runs of the CLOSE task, and each run consisted of 36 trials with 4 trials per condition. The trial order was counterbalanced with a 1.3-7.8 s jittered fixation inter-trial interval (ITI), which was determined using the fMRI trial timing optimization program (optseq2)⁶³. In total, the duration of each run was approximately 7 minutes and 20 seconds.

Empathy-related measurements

Empathy Assessment Index (EAI)

The Empathy Assessment Index (EAI) includes 22 6-point items⁶⁴. It is built on five components of interpersonal empathy: (a) Affective Response, (b) Affective Mentalizing, (c) Self-Other Awareness, (d) Perspective-Taking, (e) Emotion Regulation. The Cronbach's alpha for the five subscales is reported as follows: 0.67, 0.84, 0.65, 0.73, and 0.76, respectively. The current study used the Affective Response subscale as a measure of the capacity of physiologically simulating the experiences of others to examine in relation with brain regions involved in affective empathy (e.g., "When I see someone receive a gift that makes them happy, I feel happy myself"). The Perspective-Taking subscale was used as a measure of ability to imagine another's situation to examine in relation to regions involved in cognitive empathy (e.g., "I can imagine what the character is feeling in a good movie"). Finally, the Emotion Regulation subscale was used as a measure of internal ability to change or control one's own emotional experience to examine in relation to regions involved in cognitive control and self-regulation (e.g., "Emotional stability describes me well")⁶⁵.

Partner-rated daily support provision in a daily diary survey

Participants completed an end-of-day online survey for the consecutive days spanning from Session 1 to Session 2, including questions assessing aspects of empathy and relationship characteristics. For the present study, we averaged responses across daily surveys from the question asked to each participant's partner about their partner's support provision that day: "How much support did you receive from your partner? (From 0 (None) to 4 (A great deal))". This measure of daily support provision served as a more objective and ecological index of empathic behavior. In cases where ratings for certain items were missing, the mean scores were computed using only the available, non-missing data. On average, the time interval for this survey was 8.1 days ($SD = 1.5$), and participants submitted a mean of 7.3 diary entries during this period ($SD = 1.5$).

Experimental procedure

The experimental procedure consisted of two sessions. In Session 1, participants completed demographic questionnaires, three social interaction tasks not analyzed in

this manuscript, and a cover story designed to increase believability of the social feedback ratings in the CLOSE task. The cover story involved completing a Face Rating Task in which participants rated the likability of 30 photos thought to be other participants who completed Session 1 (photos will be different from those in Session 2). Participants pressed the right arrow if the person appeared likable to them (displaying the word “YES” on the screen) and the left arrow if the person did not appear likable (displaying the word “NO”). If participants did not press an arrow key within 2s, the text “XX” was displayed and the task advanced to the next trial. Additionally, an experimenter also took the participant’s own photo in Session 1 to convince them that their photos would be distributed to other participants to rate the likability.

In Session 2, both partners completed the fMRI scanning with counterbalanced order. During scanning, each participant completed a resting-state scan, a structural T1 scan, the CLOSE task, and a field map. While one participant was being scanned, their partner completed trait questionnaires in a different room. After the scan, participants completed separate retrospective questionnaires in which they rated their emotions and speculated about their partner’s emotions during each condition in the CLOSE task (from -3 (very negative) to 3 (very positive)). Two participants didn’t complete this questionnaire ($N = 129$).

Because of the deception in this study, participants completed a funnel debriefing procedure following the CLOSE task in Session 2. They were asked to rate the following questions on a scale from 1 to 5: (1) “During the task, to what degree did you feel like the feedback you and your partner received about your likability was based on the photos taken of you and your partner in the first study session?” and (2) “During the task, to what degree did you feel like the feedback you and your partner received about your likability was made by other study participants?”. Two participants did not report on these two questions ($N = 129$). The mean values of these two belief ratings were 3.6 ($SD = 1.2$) and 3.6 ($SD = 1.3$), respectively.

fMRI Acquisition

Functional MR imaging was conducted with a 3-Tesla scanner Siemens MRI system. Forty-two 3.0mm axial slices were acquired using an echo-planar imaging (EPI) sequence with TR = 1300 ms, TE = 30 ms, flip angle = 68°, matrix size = 64 × 64, resolution = 3 × 3 mm², FOV = 252 × 252 mm², multiband acceleration factor = 2. One hundred seventy-six high-resolution slices were obtained using a T1-weighted sagittal 3-D magnetization prepared rapid gradient-echo sequence: TR = 2300 ms, TE = 2.95 ms, TI = 900 ms, FA = 9°, FOV = 270 × 270 mm², thickness = 1.00 mm, in-plane resolution = 1 × 1 mm². Forty-two field map slices were acquired using a gradient-echo sequence: TR = 467 ms, TE1 = 4.92 ms, TE2 = 7.38 ms, TI = 900 ms, FA = 60°, FOV = 224 × 224 mm², voxel size = 3 × 3 × 3 mm³.

Data Analysis

Behavioral Analysis

At first, the affective ratings during scanning were transformed to a scale from 1 to 7. Next, to validate that participants indeed empathized with their partners during the CLOSE task, we examined participants' affect ratings associated with the contrasts when viewing partner-directed feedback alone used in previous studies (e.g., P_{NEG-XX} and P_{POS-XX}), as well as the affective responses to social feedback directed at one's partner when receiving simultaneously incongruent social feedback about the self (e.g., S_{NEG}P_{POS}-S_{NEG} and S_{POS}P_{NEG}-S_{POS}). We also conducted additional analyses to investigate the challenge of overcoming self-centric emotions. Specifically, we compared affective ratings between the S_{NEG}P_{POS}-S_{NEG} and P_{NEG-XX} contrasts, as well as between S_{POS}P_{NEG}-S_{POS} and P_{POS-XX} contrasts. To account for the nested structure of partners within couples, linear mixed-effects models with a random intercept were employed to analyze the affective ratings during scanning (e.g., model <- lmer (y ~ x + (1 | couple_id), data = data)). The effect size (measured as *d*) was calculated using the equation provided by Westfall et al. (2014)⁶⁶:
$$\frac{\text{difference between means}}{\sqrt{\text{var}(\text{intercept}) + \text{var}(\text{residual})}}$$

Neuroimaging data analysis

Preprocessing

The functional data was preprocessed using the robust open-source preprocessing pipeline, fMRIPrep⁶⁷. Preprocessing steps included Field-Map Distortion Correction (DC), motion correction by re-alignment to the first frame (MCFLIRT), nonlinear co-registration to T1-weighted structural images (bbrregister), slice timing correction (AFNI 3dTShift), normalization to the Montreal Neurological Institute (MNI) template through nonlinear registration with antsRegistration (ANTs 2.2.0), spatial smoothing with an isotropic Gaussian kernel of 6mm FWHM (full-width half maximum), and automatic removal of motion artifacts using independent component analysis (ICA-AROMA)⁶⁸.

General Linear Model analyses and brain activity for empathy-related contrasts

The cleaned data from fMRIPrep was passed to FSL's fMRI Expert Analysis Tool (FEAT) (FMRIB, v6, Oxford, UK, www.fmrib.ox.ac.uk) for task-related General Linear Model analyses. The BOLD signal was modeled by convolving the onset of 3.9-s blocks in 9 task conditions with a double-gamma hemodynamic response function. A separate single regressor was also modeled to account for the affect ratings. Then, a second-level fixed-effects analysis was used to compute the average of the parameter estimates across the runs within each subject, and a third-level analysis with mixed effects (FLAME1) was used to test generalization to the population from which our sample was drawn.

We performed a series of whole brain analyses to examine the BOLD correlates of empathy. Firstly, we performed whole-brain analyses for contrasts approximating those used in previous research ($P_{\text{POS-XX}}$ and $P_{\text{NEG-XX}}$) to examine whether viewing positive and negative feedback directed toward one's partner is associated with activations in canonical empathy regions found in previous studies. We also examined differences between empathy for positive (e.g., $P_{\text{POS-XX}}$) and negative experiences (e.g., $P_{\text{NEG-XX}}$). Next, we conducted the whole-brain analyses to investigate the BOLD responses to social feedback directed at partner in presence of simultaneous incongruent social feedback about the self (e.g., $S_{\text{POS}}P_{\text{NEG}}-S_{\text{POS}}$ and $S_{\text{NEG}}P_{\text{POS}}-S_{\text{NEG}}$ contrasts). Additionally, we examined the distinctions between empathy for positive (e.g. $S_{\text{NEG}}P_{\text{POS}}-S_{\text{NEG}}$) and negative experiences (e.g. $S_{\text{POS}}P_{\text{NEG}}-S_{\text{POS}}$) in these contexts.

Lastly, we further investigated the disparities between empathy when transcending self-feeling ($S_{POS}P_{NEG}-S_{POS}$ or $S_{NEG}P_{POS}-S_{NEG}$) and conventional empathy (e.g., P_{NEG-XX} or P_{POS-XX}) contrasts. For these analyses, a voxel-wise threshold of $z > 3.1$ ($p < 0.001$) combined with a cluster level threshold of $p_{GRF} < .05$ was used. As a post-hoc control analysis, considering variability across participants in belief in our cover story or age and relationship duration, we reran the whole-brain analyses using participants' reported belief or age and relationship duration as covariates.

Relationships between neural empathy, trait empathy and daily empathic behavior

To investigate the predictive and ecological validity of the CLOSE task, we examined relationships between BOLD activity in the simultaneous feedback condition involving the greatest demands on overcoming the self ($S_{NEG}P_{POS}-S_{NEG}$) and relevant subscale scores from the EAI, as well as partner-rated daily support provision. First, given that the differences between novel empathy contrasts and conventional contrasts tended to be right-lateralized, spherical ROIs (radius = 6mm) were created in representative regions in the right hemisphere associated with affective empathy (right AI, right ACC), cognitive empathy (right TPJ (angular gyrus), right DMPFC), and cognitive control (right MFG) based on the peak MNI coordinates identified using the terms “empathy” and “cognitive control” from Neurosynth (<https://neurosynth.org>). We extracted the values from individualized z-statistic maps from these ROIs and then standardized BOLD activity and behavioral data across subjects. Linear mixed-effect models (participants nested within couples) with a random intercept were used to get the standardized coefficients predicting EAI subscale scores and partner-rated daily support.

Notably, our analysis exclusively focused on the relationships between the value in certain a ROI and the theoretically related empathy component. For example, we only analyzed the relationship between activity in affective empathy regions and Affective Response subscale scores, the association between activity in cognitive empathy regions and Perspective-Taking subscale scores, and the correlation between activity in cognitive control regions and Emotion Regulation subscale scores.

Whole-brain multiple regression analyses were also performed to explore whether there are regions whose activity, while not significant, might still be associated with empathy-related behaviors. For these exploratory analyses, to capture the involvement of smaller subcortical regions, we used a slightly looser cluster size threshold ($z > 3.1$ ($p < 0.001$) and cluster size ≥ 10).

References

1. Davis, M.H. 23 Empathy, Compassion, and Social Relationships. *The Oxford handbook of compassion science* **299** (2017).
2. Singer, T. & Tusche, A. Understanding others: Brain mechanisms of theory of mind and empathy. in *Neuroeconomics* 513-532 (Elsevier, 2014).
3. Hu, T., Zheng, X. & Huang, M. Absence and presence of human interaction: The relationship between loneliness and empathy. *Front. Psychol.* **11**, 768 (2020).
4. Beadle, J.N., Keady, B., Brown, V., Tranel, D. & Paradiso, S. Trait empathy as a predictor of individual differences in perceived loneliness. *Psychological reports* **110**, 3-15 (2012).
5. Sened, H., *et al.* Empathic accuracy and relationship satisfaction: A meta-analytic review. *Journal of Family Psychology* **31**, 742 (2017).
6. Kimmes, J.G., Edwards, A.B., Wetchler, J.L. & Bercik, J. Self and other ratings of dyadic empathy as predictors of relationship satisfaction. *The American Journal of Family Therapy* **42**, 426-437 (2014).
7. Lamm, C., Meltzoff, A.N. & Decety, J. How do we empathize with someone who is not like us? A functional magnetic resonance imaging study. *Journal of cognitive neuroscience* **22**, 362-376 (2010).
8. Li, X., *et al.* Ongoing first-hand pain facilitates somatosensory resonance but inhibits affective sharing in empathy for pain. *NeuroImage* **263**, 119599 (2022).
9. Fan, Y., Duncan, N.W., De Greck, M. & Northoff, G. Is there a core neural network in empathy? An fMRI based quantitative meta-analysis. *Neuroscience & Biobehavioral Reviews* **35**, 903-911 (2011).
10. Rameson, L.T., Morelli, S.A. & Lieberman, M.D. The neural correlates of empathy: experience, automaticity, and prosocial behavior. *Journal of cognitive neuroscience* **24**, 235-245 (2012).
11. Cameron, C.D., *et al.* Empathy is hard work: People choose to avoid empathy because of its cognitive costs. *Journal of Experimental Psychology: General* **148**, 962 (2019).
12. Depow, G.J., Francis, Z. & Inzlicht, M. The experience of empathy in everyday life. *Psychological Science* **32**, 1198-1213 (2021).

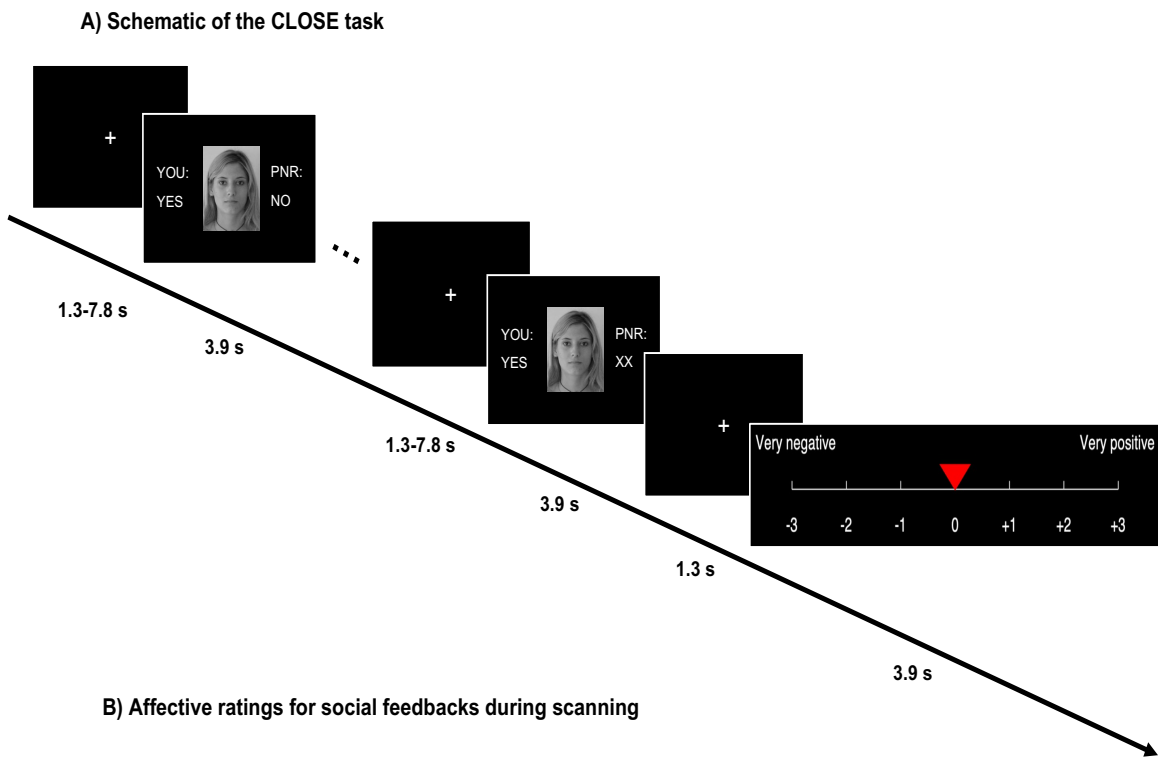
13. Li, X., Meng, X., Li, H., Yang, J. & Yuan, J. The impact of mood on empathy for pain: Evidence from an EEG study. *Psychophysiology* **54**, 1311-1322 (2017).
14. Morrison, A.S., *et al.* Empathy for positive and negative emotions in social anxiety disorder. *Behaviour research and therapy* **87**, 232-242 (2016).
15. Schulreich, S., Tusche, A., Kanske, P. & Schwabe, L. Altruism under stress: Cortisol negatively predicts charitable giving and neural value representations depending on mentalizing capacity. *Journal of Neuroscience* **42**, 3445-3460 (2022).
16. Nitschke, J.P. & Bartz, J.A. The association between acute stress & empathy: A systematic literature review. *Neuroscience & Biobehavioral Reviews* **144**, 105003 (2023).
17. Schipper, M. & Petermann, F. Relating empathy and emotion regulation: Do deficits in empathy trigger emotion dysregulation? *Social neuroscience* **8**, 101-107 (2013).
18. Zaki, J. Empathy: a motivated account. *Psychological bulletin* **140**, 1608 (2014).
19. Thompson, N.M., Uusberg, A., Gross, J.J. & Chakrabarti, B. Empathy and emotion regulation: An integrative account. *Progress in brain research* **247**, 273-304 (2019).
20. Decety, J. The neurodevelopment of empathy in humans. *Developmental neuroscience* **32**, 257-267 (2010).
21. Decety, J. & Moriguchi, Y. The empathic brain and its dysfunction in psychiatric populations: Implications for intervention across different clinical conditions. *BioPsychoSocial medicine* **1**, 1-21 (2007).
22. Powell, P.A. Individual differences in emotion regulation moderate the associations between empathy and affective distress. *Motivation and emotion* **42**, 602-613 (2018).
23. Lockwood, P.L., Seara-Cardoso, A. & Viding, E. Emotion regulation moderates the association between empathy and prosocial behavior. *PLoS One* **9**, e96555 (2014).
24. Ashar, Y.K., Andrews-Hanna, J.R., Dimidjian, S. & Wager, T.D. Empathic care and distress: predictive brain markers and dissociable brain systems. *Neuron* **94**, 1263-1273. e1264 (2017).
25. Masten, C.L., Morelli, S.A. & Eisenberger, N.I. An fMRI investigation of empathy for 'social pain' and subsequent prosocial behavior. *Neuroimage* **55**, 381-388 (2011).
26. Meyer, M.L., *et al.* Differential neural activation to friends and strangers links interdependence to empathy. *Culture and Brain* **3**, 21-38 (2015).

27. Koban, L., Corradi-Dell'Acqua, C. & Vuilleumier, P. Integration of Error Agency and Representation of Others' Pain in the Anterior Insula. *Journal of Cognitive Neuroscience* **25**, 258-272 (2013).
28. Zaki, J. & Mitchell, J.P. Intuitive prosociality. *Curr. Dir. Psychol.* **22**, 466-470 (2013).
29. Harbaugh, W.T., Mayr, U. & Burghart, D.R. Neural responses to taxation and voluntary giving reveal motives for charitable donations. *Science* **316**, 1622-1625 (2007).
30. Gable, S.L. Approach and avoidance social motives and goals. *Journal of personality* **74**, 175-222 (2006).
31. Morelli, S.A., Lieberman, M.D. & Zaki, J. The emerging study of positive empathy. *Social and Personality Psychology Compass* **9**, 57-68 (2015).
32. Mobbs, D., *et al.* A key role for similarity in vicarious reward. *Science* **324**, 900-900 (2009).
33. Morelli, S.A., Sacchet, M.D. & Zaki, J. Common and distinct neural correlates of personal and vicarious reward: A quantitative meta-analysis. *NeuroImage* **112**, 244-253 (2015).
34. Sbarra, D.A. & Coan, J.A. Relationships and health: The critical role of affective science. *Emotion Review* **10**, 40-54 (2018).
35. Morelli, S.A., Rameson, L.T. & Lieberman, M.D. The neural components of empathy: predicting daily prosocial behavior. *Social cognitive and affective neuroscience* **9**, 39-47 (2014).
36. Hein, G., Silani, G., Preuschoff, K., Batson, C.D. & Singer, T. Neural responses to ingroup and outgroup members' suffering predict individual differences in costly helping. *Neuron* **68**, 149-160 (2010).
37. Cheng, Y., Chen, C., Lin, C.-P., Chou, K.-H. & Decety, J. Love hurts: an fMRI study. *Neuroimage* **51**, 923-929 (2010).
38. López-Solà, M., Koban, L., Krishnan, A. & Wager, T.D. When pain really matters: A vicarious-pain brain marker tracks empathy for pain in the romantic partner. *Neuropsychologia* **145**, 106427 (2020).
39. Mazzola, V., *et al.* Affective response to a loved one's pain: insula activity as a function of individual differences. *PLoS One* **5**, e15268 (2010).

40. Timmers, I., *et al.* Is empathy for pain unique in its neural correlates? A meta-analysis of neuroimaging studies of empathy. *Frontiers in behavioral neuroscience* **12**, 289 (2018).
41. McAuliffe, W.H., Carter, E.C., Berhane, J., Snihur, A.C. & McCullough, M.E. Is empathy the default response to suffering? A meta-analytic evaluation of perspective taking's effect on empathic concern. *Personality and Social Psychology Review* **24**, 141-162 (2020).
42. Meffert, H., Gazzola, V., Den Boer, J.A., Bartels, A.A. & Keysers, C. Reduced spontaneous but relatively normal deliberate vicarious representations in psychopathy. *Brain* **136**, 2550-2562 (2013).
43. Denny, B.T., Kober, H., Wager, T.D. & Ochsner, K.N. A meta-analysis of functional neuroimaging studies of self-and other judgments reveals a spatial gradient for mentalizing in medial prefrontal cortex. *Journal of cognitive Neuroscience* **24**, 1742-1752 (2012).
44. Frith, C.D. & Frith, U. The neural basis of mentalizing. *Neuron* **50**, 531-534 (2006).
45. Van Overwalle, F. & Baetens, K. Understanding others' actions and goals by mirror and mentalizing systems: a meta-analysis. *Neuroimage* **48**, 564-584 (2009).
46. Kim, S.H. & Hamann, S. Neural correlates of positive and negative emotion regulation. *Journal of cognitive neuroscience* **19**, 776-798 (2007).
47. Bolger, N., Davis, A. & Rafaeli, E. Diary methods: Capturing life as it is lived. *Annual review of psychology* **54**, 579-616 (2003).
48. Zaki, J. & Ochsner, K.N. The neuroscience of empathy: progress, pitfalls and promise. *Nature neuroscience* **15**, 675-680 (2012).
49. Chen, C., Chen, Y.-H. & Cheng, Y. Meta-analysis of functional neuroimaging and dispositional variables for clinical empathy. *Neuroscience & Biobehavioral Reviews*, 104874 (2022).
50. Engen, H.G. & Singer, T. Empathy circuits. *Curr. Opin. Neurobiol.* **23**, 275-282 (2013).
51. Jabbi, M., Swart, M. & Keysers, C. Empathy for positive and negative emotions in the gustatory cortex. *Neuroimage* **34**, 1744-1753 (2007).
52. Beadle, J.N., Paradiso, S. & Tranel, D. Ventromedial prefrontal cortex is critical for helping others who are suffering. *Frontiers in Neurology* **9**, 288 (2018).

53. Hastings, P.D., Miller, J.G., Kahle, S. & Zahn-Waxler, C. The neurobiological bases of empathic concern for others. in *Handbook of moral development* 411-434 (Psychology Press, 2013).
54. Rimmele, U. & Lobmaier, J.S. Stress increases the feeling of being looked at. *Psychoneuroendocrinology* **37**, 292-298 (2012).
55. Okun, M.A., Shepard, S.A. & Eisenberg, N. The relations of emotionality and regulation to dispositional empathy-related responding among volunteers-in-training. *Personality and Individual Differences* **28**, 367-382 (2000).
56. Contardi, A., Imperatori, C., Penzo, I., Del Gatto, C. & Farina, B. The association among difficulties in emotion regulation, hostility, and empathy in a sample of young Italian adults. *Front. Psychol.* **7**, 1068 (2016).
57. Thompson, N.M., Van Reekum, C.M. & Chakrabarti, B. Cognitive and affective empathy relate differentially to emotion regulation. *Affective Science* **3**, 118-134 (2022).
58. Decety, J. & Jackson, P.L. The functional architecture of human empathy. *Behavioral and cognitive neuroscience reviews* **3**, 71-100 (2004).
59. Cao, Y., Dingle, G., Chan, G.C. & Cunnington, R. Low mood leads to increased empathic distress at seeing others' pain. *Front. Psychol.* **8**, 2024 (2017).
60. Isen, A.M. & Levin, P.F. Effect of feeling good on helping: cookies and kindness. *Journal of personality and social psychology* **21**, 384 (1972).
61. Carlson, M., Charlin, V. & Miller, N. Positive mood and helping behavior: a test of six hypotheses. *Journal of personality and social psychology* **55**, 211 (1988).
62. Ma, D.S., Correll, J. & Wittenbrink, B. The Chicago face database: A free stimulus set of faces and norming data. *Behavior research methods* **47**, 1122-1135 (2015).
63. Greve, D. Optseq2. *Computer software*]. <http://surfer.nmr.mgh.harvard.edu/optseq> (2002).
64. Lietz, C.A., *et al.* The Empathy Assessment Index (EAI): A confirmatory factor analysis of a multidimensional model of empathy. *Journal of the Society for Social Work and Research* **2**, 104-124 (2011).
65. Segal, E.A., Gerdes, K.E., Lietz, C.A., Wagaman, M.A. & Geiger, J.M. *Assessing empathy* (Columbia University Press, 2017).

66. Westfall, J., Kenny, D.A. & Judd, C.M. Statistical power and optimal design in experiments in which samples of participants respond to samples of stimuli. *Journal of Experimental Psychology: General* **143**, 2020 (2014).
67. Esteban, O., *et al.* fMRIPrep: a robust preprocessing pipeline for functional MRI. *Nature methods* **16**, 111-116 (2019).
68. Pruim, R.H., *et al.* ICA-AROMA: A robust ICA-based strategy for removing motion artifacts from fMRI data. *Neuroimage* **112**, 267-277 (2015).



B) Affective ratings for social feedbacks during scanning

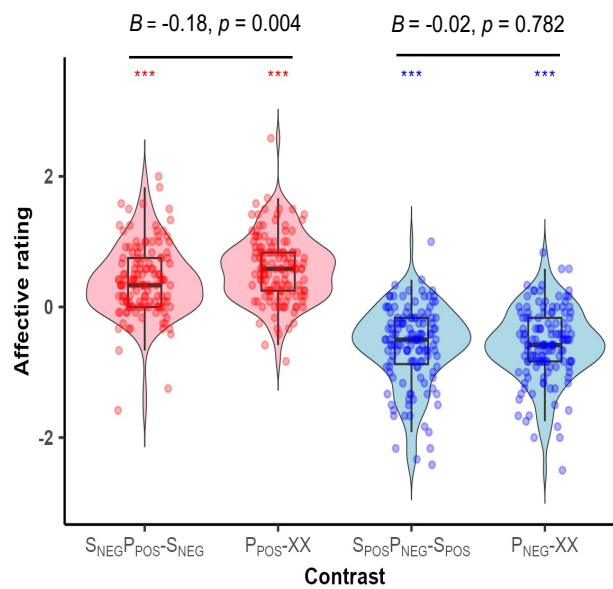


Fig. 1. Schematic of the CLOSE task and affective ratings during the task.

(A) Schematic of the CLOSE task.

The CLOSE task presents positive (YES), negative (NO) or no feedback (XX) directed towards oneself and/or one's partner. Following half of the trials within each condition,

participants were asked to rate their affective state from -3 (very negative) to 3 (very positive).

(B) Affective ratings for social feedbacks during scanning of the CLOSE task ($N = 131$).

$S_{NEG}P_{POS}-S_{NEG}$: Participants reported higher affective ratings when they received negative self-directed feedback and positive partner-directed feedback ($M = 3.93$, $SD = 0.65$), compared to when they received negative self-directed feedback alone ($M = 3.52$, $SD = 0.60$).

$P_{POS}-XX$: Participants reported higher affective ratings when they received positive partner-directed feedback alone ($M = 4.57$, $SD = 0.58$), compared to when they received no feedback about their partner or themselves ($M = 3.99$, $SD = 0.37$).

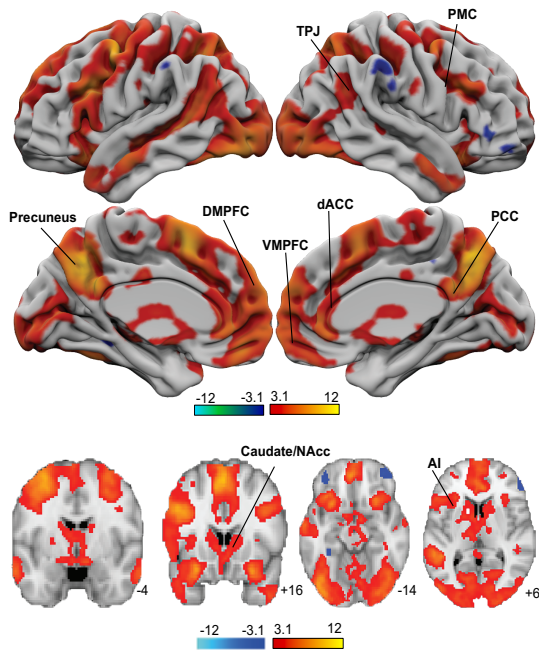
$S_{POS}P_{NEG}-S_{POS}$: Participants reported lower affective ratings when they received positive self-directed feedback and negative partner-directed feedback ($M = 4.01$, $SD = 0.68$), compared to when they received positive self-directed feedback alone ($M = 4.60$, $SD = 0.45$).

$P_{NEG}-XX$: Participants reported lower affective ratings when they received negative partner-directed feedback alone ($M = 3.41$, $SD = 0.62$), compared to when they received no feedback about their partner or themselves ($M = 3.99$, $SD = 0.37$).

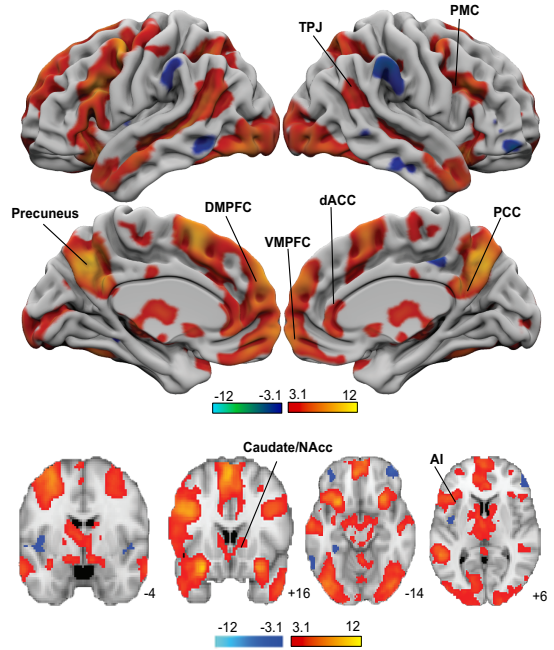
The broader shape of the violin plot illustrates the data distribution, with wider sections indicating higher density. The nested box plot displays the median line, quartiles (box edges), and potential outliers.

Note: ***: $p < 0.001$.

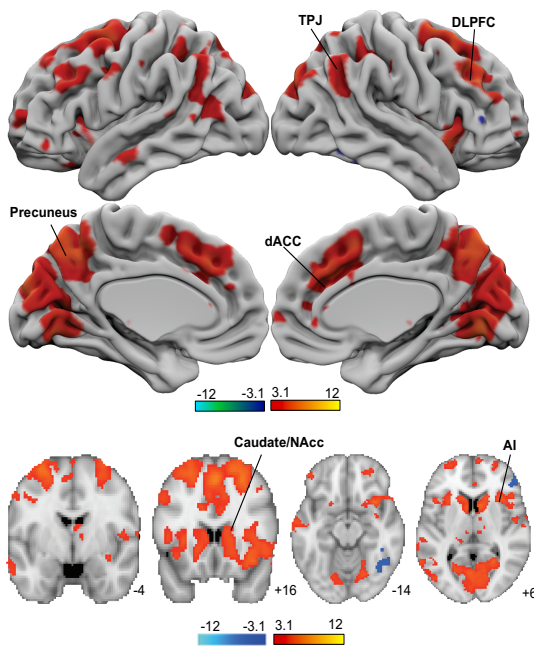
A) Partner-directed feedback alone (P_{POS-XX})



B) Partner-directed feedback alone (P_{NEG-XX})



C) Simultaneous incongruent feedback ($S_{NEG}P_{POS}-S_{NEG}$)



D) Simultaneous incongruent feedback ($S_{POS}P_{NEG}-S_{POS}$)

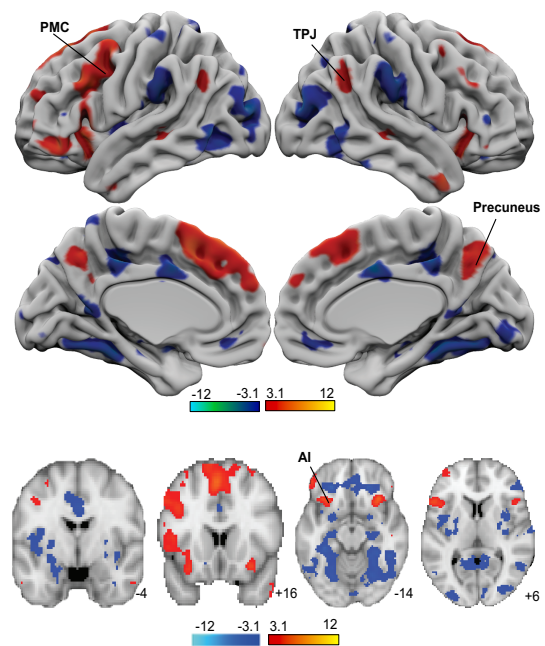


Fig. 2. BOLD activity associated with traditional empathy contrasts and more difficult empathy contrasts involving simultaneous incongruent self-directed feedback.

(A) BOLD responses to positive partner-directed feedback alone (P_{POS-XX} contrast).

(B) BOLD responses to negative partner-directed feedback alone (P_{NEG-XX} contrast).

(C) BOLD responses to positive partner-directed feedback, in the presence of negative self-directed feedback ($S_{NEG}P_{POS}-S_{NEG}$ contrast).

(D) BOLD responses to negative partner-directed feedback, in the presence of positive self-directed feedback ($S_{POS}P_{NEG}-S_{POS}$ contrast).

Per recommendation from Surf Ice (<https://www.nitrc.org/projects/surfice/>), inflated brain images are shown at a voxel-wise threshold of $z > 3.1$ without cluster correction, whereas slice views additionally employ a cluster level threshold of $p_{GRF} < .05$. All images are displayed in neurological orientation. AI: anterior insula; dACC: dorsal anterior cingulate cortex; TPJ: temporoparietal junction; PCC: posterior cingulate cortex; DMPFC: dorsomedial prefrontal cortex; VMPFC: ventromedial prefrontal cortex; NAcc: nucleus accumbens; PMC: premotor cortex; DLPFC: dorsolateral prefrontal gyrus.

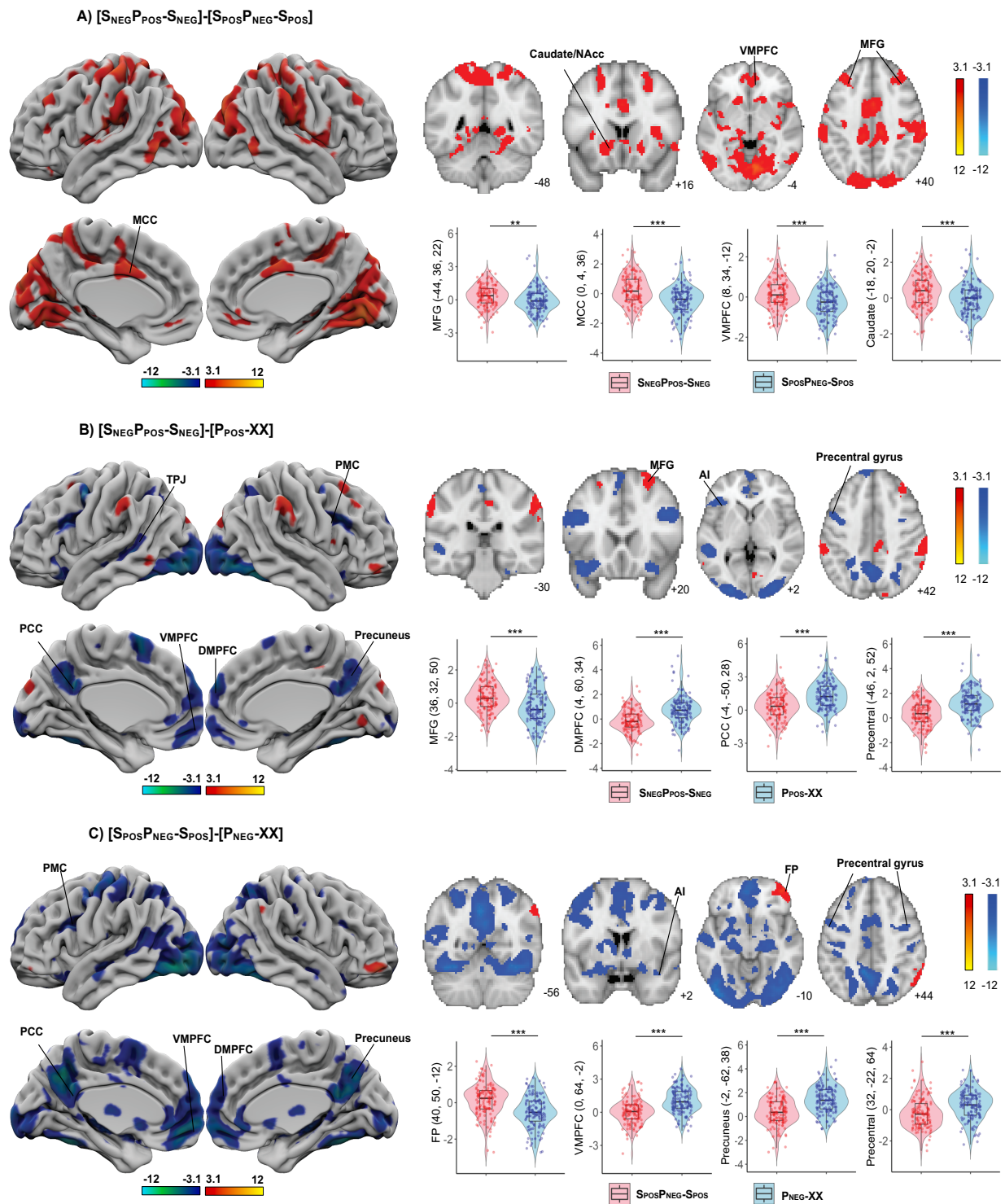


Fig. 3. Comparisons between positive vs. negative empathy, and between challenging empathy contrasts involving simultaneous incongruent self-directed feedback and traditional empathy contrasts.

(A) Higher BOLD responses to positive partner-directed social feedback in the presence of negative self-directed feedback ($S_{NEG}P_{POS}-S_{NEG}$) compared to negative partner-directed feedback in the presence of positive self-directed feedback ($S_{POS}P_{NEG}-S_{POS}$).

(B) Differences between BOLD responses to positive partner-directed social feedback in the presence of negative self-directed feedback ($S_{NEG}P_{POS}-S_{NEG}$) and BOLD responses to positive partner-directed feedback alone (P_{POS-XX}).

(C) Differences between BOLD responses to negative partner-directed social feedback in the presence of positive self-directed feedback ($S_{POS}P_{NEG}-S_{POS}$) and BOLD responses to negative partner-directed feedback alone (P_{NEG-XX}).

Per recommendation from Surf Ice (<https://www.nitrc.org/projects/surface/>), inflated brain images are shown at a voxel-wise threshold of $z > 3.1$ without cluster correction, whereas slice views additionally employ a cluster level threshold of $p_{GRF} < .05$. All images are displayed in neurological orientation. The bar plots display extracted signals from spherical ROIs, utilizing identified coordinates of representative brain regions, to aid in visualization.

MCC: middle cingulate cortex; PCC: posterior cingulate cortex; MFG: middle frontal gyrus; TPJ: temporoparietal junction; AI: anterior insula; DMPFC: dorsomedial prefrontal cortex; VMPFC: ventromedial prefrontal cortex; NAcc: nucleus accumbens; PMC: premotor cortex; FP: frontal pole.

** $: p < 0.01$; *** $: p < 0.001$. The p values are computed using linear mixed-effects models with a random intercept.

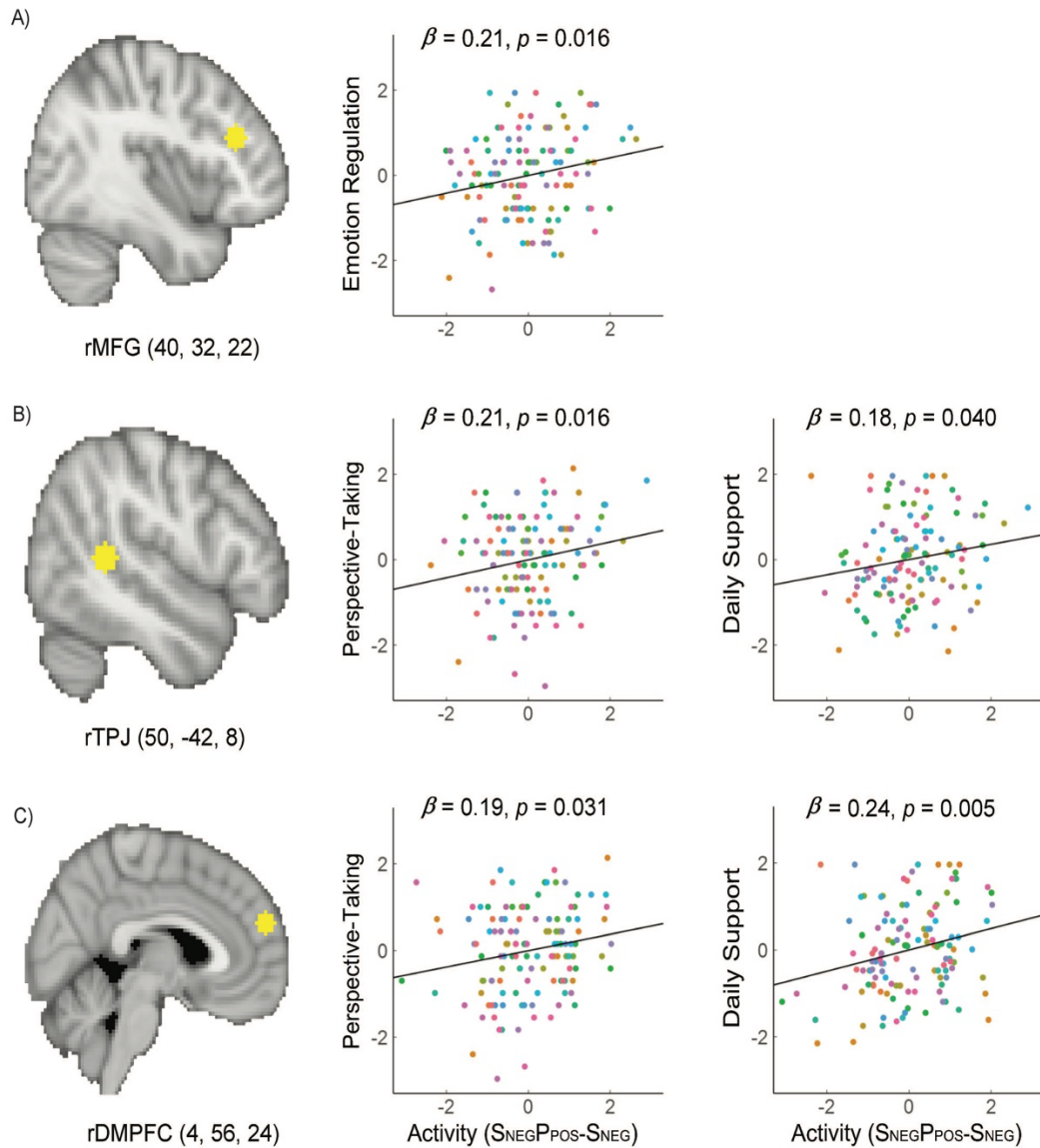


Fig. 4. Relationships between BOLD activity during challenging empathy contexts, trait empathy and daily support provision.

(A) Increased activity during $S_{NEG}P_{POS}-S_{NEG}$ contrast in the right middle frontal gyrus relates to higher Emotion Regulation subscale score of Empathy Assessment Index.

(B) Increased activity during $S_{NEG}P_{POS}-S_{NEG}$ contrast in the right temporoparietal junction relates to higher Perspective-Taking subscale scores of the Empathy Assessment Index and partner-rated daily support provision.

(C) Increased activity during $S_{NEG}P_{POS}-S_{NEG}$ contrast in the right dorsomedial prefrontal cortex relates to higher Perspective-Taking subscale scores of the Empathy Assessment Index and partner-rated daily support provision.

rMFG: right middle frontal gyrus; rTPJ: right temporoparietal junction; rDMPFC: right dorsomedial prefrontal cortex. The values of the horizontal and vertical coordinates have been standardized. Each different colored dot in the scatter plot represents a different couple.

Table 1. Neural activity in $S_{NEG}P_{POS}-S_{NEG}$ and $S_{POS}P_{NEG}-S_{POS}$ contrasts

Contrast	Voxels	Z value	X	Y	Z	p (cluster-GRF)	Brain region
$S_{NEG}P_{POS}>S_{NEG}$	25460	7.44	-4	-58	50	0.000	Precuneus Cortex
		7.37	-4	-60	54		Precuneus Cortex
		7.15	-2	-70	56		Precuneus Cortex
		7.00	-2	-62	58		Precuneus Cortex
		6.58	2	14	54		Superior Frontal Gyrus
		6.56	10	-72	-6		Lingual Gyrus
	2754	5.71	36	14	-12	0.000	Insular Cortex
		5.27	10	10	6		Right Caudate
		5.26	38	18	-6		Insular Cortex
		5.14	48	20	0		Frontal Operculum Cortex
		5.12	42	20	-4		Frontal Orbital Cortex
		5.11	-18	20	-2		Left Caudate
	2418	5.43	42	-44	42	0.000	Posterior Supramarginal Gyrus
		5.18	60	-60	28		Superior Lateral Occipital Cortex
		4.96	56	-60	30		Superior Lateral Occipital Cortex
		4.87	52	-58	28		Angular Gyrus
		4.83	56	-64	34		Superior Lateral Occipital Cortex
		4.80	38	-40	34		Posterior Supramarginal Gyrus
	325	4.35	-26	54	14	0.000	Frontal Pole
		4.34	-30	64	12		Frontal Pole
		4.23	-28	58	8		Frontal Pole
		4.08	-22	64	2		Frontal Pole
	312	4.75	-60	-8	-16	0.000	Anterior Middle Temporal Gyrus
		4.46	-64	-12	-20		Posterior Middle Temporal Gyrus
		4.20	-68	-14	-16		Posterior Middle Temporal Gyrus
		4.04	-62	-2	-22		Anterior Middle Temporal Gyrus
		3.93	-66	-10	-8		Anterior Middle Temporal Gyrus
		3.73	-64	-12	-26		Posterior Middle Temporal Gyrus
	233	4.65	-10	-24	-4	0.000	Left Thalamus
		4.28	4	-22	0		Right Thalamus
		4.00	12	-18	14		Right Thalamus
		3.96	8	-22	10		Right Thalamus
	167	4.66	4	40	0	0.004	Anterior Cingulate Gyrus
		3.99	-2	30	12		Anterior Cingulate Gyrus
		3.83	4	34	10		Anterior Cingulate Gyrus
	145	4.31	-14	-20	14	0.008	Left Thalamus
		4.17	-14	-32	8		Left Thalamus
		4.10	-22	-28	0		Left Thalamus
		3.39	-22	-22	-2		Left Cerebral White Matter
	132	4.21	64	-14	10	0.013	Central Opercular Cortex

		3.97	52	-8	6		Central Opercular Cortex
		3.96	52	-4	8		Central Opercular Cortex
		3.69	64	-4	8		Central Opercular Cortex
		3.25	56	-12	4		Heschl's Gyrus
	122	4.23	-50	44	-12	0.019	Frontal Pole
		3.95	-40	42	-8		Frontal Pole
		3.73	-46	44	-6		Frontal Pole
		3.58	-36	46	-2		Frontal Pole
	110	4.41	6	62	2	0.030	Frontal Pole
		4.05	4	68	2		Frontal Pole
	101	4.55	-66	-40	10	0.042	Posterior Superior Temporal Gyrus
		3.80	-60	-28	6		Planum Temporale
		3.65	-68	-40	4		Posterior Superior Temporal Gyrus
		3.21	-60	-48	8		Middle Temporal Gyrus
$S_{NEG}P_{POS} < S_{NEG}$	256	4.65	40	-42	-18	0.000	Temporal Occipital Fusiform Cortex
		4.45	46	-48	-22		Temporal Occipital Fusiform Cortex
		4.28	46	-44	-22		Temporal Occipital Fusiform Cortex
		4.22	46	-56	-16		Temporal Occipital Fusiform Cortex
		4.21	50	-56	-16		Inferior Temporal Gyrus
		4.13	40	-58	-16		Temporal Occipital Fusiform Cortex
	181	5.44	52	44	8	0.002	Frontal Pole
		3.98	54	36	18		Frontal Pole
		3.83	52	36	-2		Frontal Pole
		3.81	46	36	8		Frontal Pole
$S_{POS}P_{NEG} > S_{POS}$	3375	6.09	-52	20	2	0.000	Inferior Frontal Gyrus
		5.96	-30	20	-12		Frontal Orbital Cortex
		5.92	-40	20	30		Middle Frontal Gyrus
		5.87	-46	46	-8		Frontal Pole
		5.85	-50	20	36		Middle Frontal Gyrus
		5.75	-36	22	-14		Frontal Orbital Cortex
	2915	6.81	-2	14	52	0.000	Paracingulate Gyrus
		6.40	-8	36	56		Superior Frontal Gyrus
		5.45	-4	28	40		Paracingulate Gyrus
		5.36	-6	48	50		Frontal Pole
		5.34	-2	56	28		Superior Frontal Gyrus
		5.32	2	44	52		Superior Frontal Gyrus
	969	5.29	-6	-62	46	0.000	Precuneus Cortex
		5.08	2	-66	48		Precuneus Cortex
		4.35	4	-60	36		Precuneus Cortex
		3.85	-10	-50	28		Posterior Cingulate Gyrus
		3.84	-10	-54	34		Precuneus Cortex
	780	5.22	56	-58	38	0.000	Angular Gyrus
		4.81	44	-58	44		Angular Gyrus

		4.66	38	-48	42		Superior Parietal Lobule
		4.59	46	-58	32		Angular Gyrus
		3.82	52	-64	46		Superior Lateral Occipital Cortex
		3.60	34	-44	36		Posterior Supramarginal Gyrus
634		6.87	34	24	-12	0.000	Frontal Orbital Cortex
		4.86	32	28	0		Frontal Orbital Cortex
		4.65	46	20	8		Inferior Frontal Gyrus
		4.45	44	20	0		Frontal Operculum Cortex
		4.01	50	38	-10		Frontal Pole
		3.69	56	28	-6		Inferior Frontal Gyrus
493		4.68	-40	-50	48	0.000	Superior Parietal Lobule
		4.63	-34	-60	44		Superior Lateral Occipital Cortex
		3.83	-34	-46	40		Superior Parietal Lobule
		3.46	-48	-40	44		Anterior Supramarginal Gyrus
		3.45	-44	-40	42		Anterior Supramarginal Gyrus
292		5.54	54	10	-30	0.000	Temporal Pole
		5.06	52	8	-36		Temporal Pole
		4.55	58	0	-30		Anterior Middle Temporal Gyrus
271		4.51	-54	-58	30	0.000	Angular Gyrus
		4.37	-46	-58	34		Angular Gyrus
		3.80	-56	-60	42		Superior Lateral Occipital Cortex
242		4.86	-56	-32	0	0.000	Posterior Superior Temporal Gyrus
		4.58	-52	-30	-4		Posterior Middle Temporal Gyrus
		3.53	-48	-38	-4		Posterior Middle Temporal Gyrus
220		6.04	56	-32	-4	0.001	Posterior Middle Temporal Gyrus
		3.64	50	-22	-12		Posterior Middle Temporal Gyrus
209		4.80	48	30	38	0.001	Middle Frontal Gyrus
		3.95	52	22	40		Middle Frontal Gyrus
		3.91	52	20	44		Middle Frontal Gyrus
		3.62	52	34	28		Middle Frontal Gyrus
125		4.32	-48	2	-36	0.020	Temporal Pole
		4.18	-44	2	-38		Temporal Pole
		3.77	-50	6	-30		Temporal Pole
$S_{POS}P_{NEG} < S_{POS}$	4477	6.56	30	-58	-8	0.000	Temporal Occipital Fusiform Cortex
		6.35	30	-38	-18		Posterior Temporal Fusiform Cortex
		5.97	26	-66	-12		Occipital Fusiform Gyrus
		5.92	50	-44	-18		Inferior Temporal Gyrus
		5.87	30	-44	-10		Temporal Occipital Fusiform Cortex
		5.86	38	-84	16		Superior Lateral Occipital Cortex
2927		6.41	-48	-60	0	0.000	Middle Temporal Gyrus
		6.21	-32	-34	-16		Posterior Parahippocampal Gyrus
		5.79	-56	-66	-4		Inferior Lateral Occipital Cortex
		5.43	-26	-46	-20		Temporal Occipital Fusiform Cortex

	5.42	-30	-46	-8		Temporal Occipital Fusiform Cortex
	5.40	-26	-64	-10		Occipital Fusiform Gyrus
1989	6.21	-8	-34	44	0.000	Posterior Cingulate Gyrus
	5.50	16	-36	42		Precuneus Cortex
	5.39	6	-36	42		Posterior Cingulate Gyrus
	5.30	8	-38	52		Precuneus Cortex
	5.22	-10	-54	68		Superior Parietal Lobule
	5.04	10	-32	44		Posterior Cingulate Gyrus
1597	5.87	-66	-30	30	0.000	Anterior Supramarginal Gyrus
	5.53	-60	-30	22		Parietal Operculum Cortex
	5.07	-34	6	10		Insular Cortex
	4.92	-58	-16	16		Central Opercular Cortex
	4.88	-38	-14	0		Insular Cortex
	4.88	-36	2	10		Insular Cortex
1186	5.62	64	-22	30	0.000	Anterior Supramarginal Gyrus
	5.46	62	-22	22		Anterior Supramarginal Gyrus
	5.35	62	-30	40		Anterior Supramarginal Gyrus
	5.26	64	-28	46		Anterior Supramarginal Gyrus
	4.68	64	-18	46		Postcentral Gyrus
	4.59	66	-14	8		Planum Temporale
1175	6.25	-34	-88	16	0.000	Superior Lateral Occipital Cortex
	5.15	-26	-88	16		Superior Lateral Occipital Cortex
	4.78	-32	-90	2		Inferior Lateral Occipital Cortex
	4.52	-42	-78	24		Superior Lateral Occipital Cortex
	4.39	-20	-74	44		Superior Lateral Occipital Cortex
	4.37	-38	-82	26		Superior Lateral Occipital Cortex
958	6.51	-26	36	-14	0.000	Frontal Orbital Cortex
	5.87	22	36	-14		Frontal Pole
	5.57	-32	38	-6		Frontal Pole
	5.06	2	44	-12		Frontal Medial Cortex
	4.66	32	36	-16		Frontal Pole
	4.63	-6	38	-14		Frontal Medial Cortex
883	5.95	-8	-58	12	0.000	Precuneus Cortex
	4.76	12	-50	10		Precuneus Cortex
	4.70	8	-58	16		Precuneus Cortex
	4.45	6	-56	4		Lingual Gyrus
	4.28	18	-44	2		Posterior Cingulate Gyrus
	4.13	-4	-46	6		Posterior Cingulate Gyrus
622	6.79	2	4	38	0.000	Anterior Cingulate Gyrus
	4.25	0	14	32		Anterior Cingulate Gyrus
	3.74	-16	10	32		Left Cerebral White Matter
317	4.70	22	0	-12	0.000	Right Cerebral Cortex
	4.44	36	-16	4		Insular Cortex

		4.26	40	-8	-4		Insular Cortex	
		3.94	26	-10	4		Right Putamen	
		3.90	30	-16	-2		Right Putamen	
		3.72	42	2	-20		Planum Polare	
218		4.70	-46	-28	64	0.001	Postcentral Gyrus	
		4.07	-38	-24	68		Postcentral Gyrus	
		3.66	-30	-28	74		Postcentral Gyrus	
		3.58	-32	-26	58		Precentral Gyrus	
		3.55	-40	-40	66		Postcentral Gyrus	
203		4.77	32	-42	74	0.001	Superior Parietal Lobule	
		4.41	50	-30	62		Postcentral Gyrus	
		4.10	30	-46	66		Superior Parietal Lobule	
		3.98	28	-38	60		Postcentral Gyrus	
		3.63	24	-42	74		Superior Parietal Lobule	
		3.59	40	-32	66		Postcentral Gyrus	
200		4.35	28	-20	-12	0.002	Right Hippocampus	
		4.24	42	-12	-28		Posterior Temporal Fusiform Cortex	
		4.18	34	-14	-20		Anterior Parahippocampal Gyrus	
		4.06	22	-20	-14		Posterior Parahippocampal Gyrus	
		3.75	36	-8	-38		Anterior Temporal Fusiform Cortex	
		3.37	18	-22	-20		Anterior Parahippocampal Gyrus	
193		5.06	38	2	4	0.002	Insular Cortex	
		4.13	34	10	10		Insular Cortex	
167		5.15	52	40	12	0.005	Frontal Pole	
		4.96	48	40	10		Frontal Pole	
146		4.68	18	-54	64	0.010	Superior Parietal Lobule	
		4.10	16	-50	66		Superior Parietal Lobule	
		4.04	18	-46	64		Superior Parietal Lobule	
124		4.94	22	-74	46	0.021	Superior Lateral Occipital Cortex	
		3.92	26	-72	38		Superior Lateral Occipital Cortex	
	[S _{NEG} P _{POS} -S _{NEG}] >[S _{POS} P _{NEG} -S _{POS}]	31332	7.07	14	-74	-8	0.000	Lingual Gyrus
			7.04	8	-72	-6		Lingual Gyrus
			6.61	22	-68	-12		Occipital Fusiform Gyrus
			6.39	0	4	36		Anterior Cingulate Gyrus
			6.34	64	-14	10		Central Opercular Cortex
			5.89	-48	-60	0		Middle Temporal Gyrus
905		4.79	8	34	-12	0.000	Frontal Medial Cortex	
		4.56	4	40	-2		Anterior Cingulate Gyrus	
		4.50	-16	38	-18		Frontal Pole	
		4.49	-24	32	-16		Frontal Orbital Cortex	
		4.48	-20	32	-20		Frontal Orbital Cortex	
		4.41	4	42	-10		Paracingulate Gyrus	
310		5.15	-22	12	-12	0.000	Frontal Orbital Cortex	

	5.01	-18	20	-2		Left Caudate
231	4.32	22	10	-12	0.000	Frontal Orbital Cortex
	3.95	22	20	-6		Right Putamen
	3.94	18	20	-4		Right Caudate
	3.84	2	16	0		Subcallosal Cortex
	3.80	8	22	0		Right Caudate
	3.79	8	18	-8		Subcallosal Cortex
216	4.86	28	-24	-14	0.001	Posterior Parahippocampal Gyrus
	4.68	32	-16	-22		Anterior Parahippocampal Gyrus
	4.06	34	-22	-14		Posterior Parahippocampal Gyrus
	4.00	42	-12	-30		Posterior Temporal Fusiform Cortex
	3.91	34	-26	-16		Posterior Parahippocampal Gyrus
	3.48	20	-20	-14		Posterior Parahippocampal Gyrus
125	4.13	-42	36	12	0.018	Frontal Pole
	3.96	-38	32	14		Inferior Frontal Gyrus
	3.72	-44	36	22		Middle Frontal Gyrus
122	4.19	-58	0	44	0.020	Precentral Gyrus
	4.13	-60	8	26		Precentral Gyrus
	4.05	-58	0	38		Precentral Gyrus
	3.68	-58	8	18		Precentral Gyrus
	3.46	-60	6	34		Precentral Gyrus

Supplementary Materials for
**When Empathy Gets Tough: Neural Responses to Overcoming the Self in a
Novel Paradigm Predict Everyday Prosocial Behavior**

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This PDF file includes:

Figs. S1 to S3
Tables S1 to S9

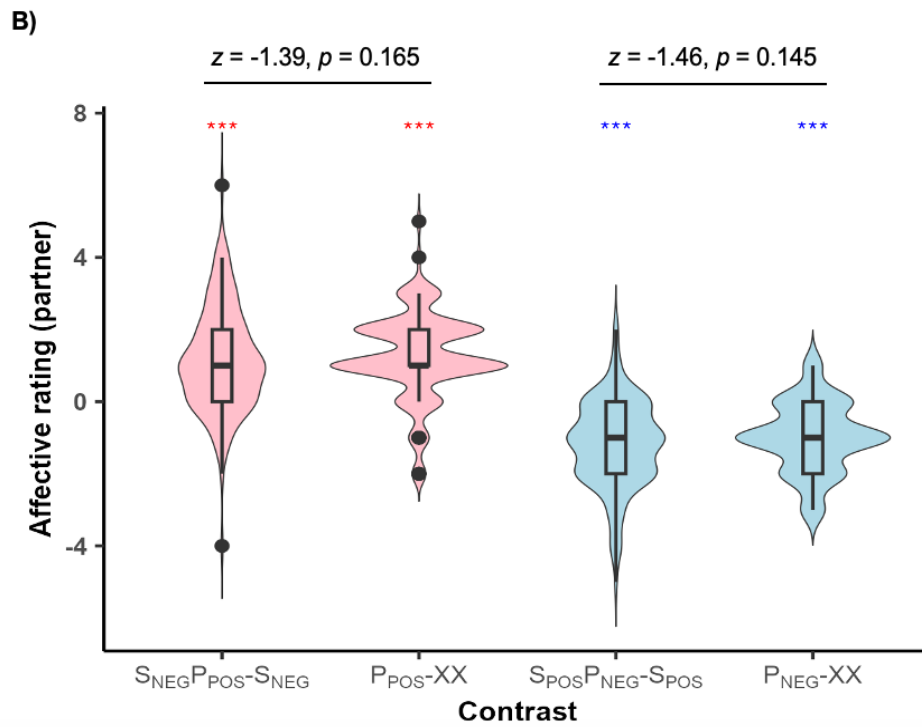
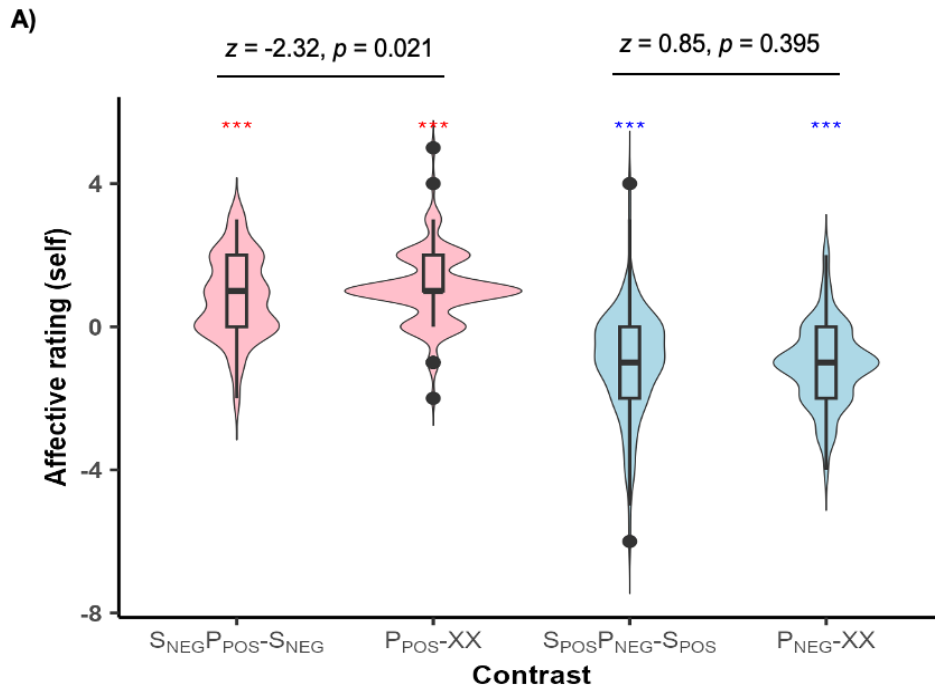


Fig. S1. Affective ratings completed retrospectively in questionnaires after scanning.

Participants ($N=129$) rated their emotions and speculated about their partner's emotions during each condition in the CLOSE task (from -3 (very negative) to 3 (very positive)).

(A) Affective ratings of self. (B) Affective ratings of partner.

Differences assessed using Wilcoxon signed-rank test due to the non-normal distribution.

$S_{NEG}P_{POS}-S_{NEG}$: affective ratings in the condition where participants received negative self-directed feedback and positive partner-directed feedback minus those in the condition where participants only received negative self-directed feedback.

$P_{POS}-XX$: affective ratings in the condition where participants only received positive partner-directed feedback minus those in the condition where participants received no feedback about themselves or their partners.

$S_{POS}P_{NEG}-S_{POS}$: affective ratings in the condition where participants received positive self-directed feedback and negative partner-directed feedback minus those in the condition where participants only received positive self-directed feedback.

$P_{NEG}-XX$: affective ratings in the condition where participants only received negative partner-directed feedback minus those in the condition where participants received no feedback about themselves or their partners.

Note: ***: $p < .001$.

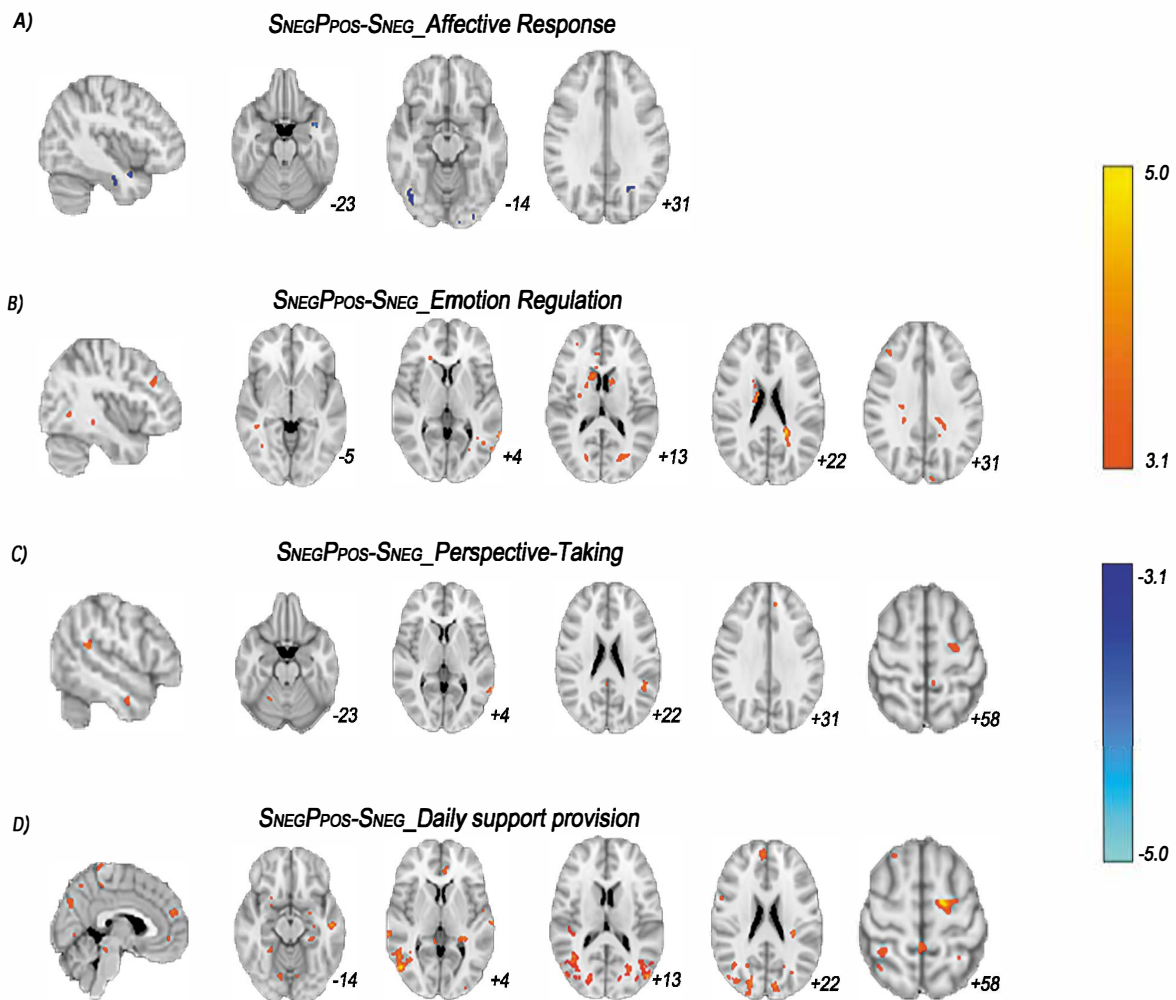


Fig. S2. Results of whole-brain regression analysis in $S_{NEG}P_{POS}-S_{NEG}$ contrast.

The regions are shown at the voxel-wise threshold of $z > 3.1$ and cluster size ≥ 10 .

(A) BOLD activity in $S_{NEG}P_{POS}-S_{NEG}$ contrast associated with Affective Response subscale score of Empathy Assessment Index.

(B) BOLD activity in $S_{NEG}P_{POS}-S_{NEG}$ contrast associated with Emotion Regulation subscale score of Empathy Assessment Index.

(C) BOLD activity in $S_{NEG}P_{POS}-S_{NEG}$ contrast associated with Perspective-Taking subscale score of Empathy Assessment Index.

(D) BOLD activity in $S_{NEG}P_{POS}-S_{NEG}$ contrast associated with partner-rated daily support provision.

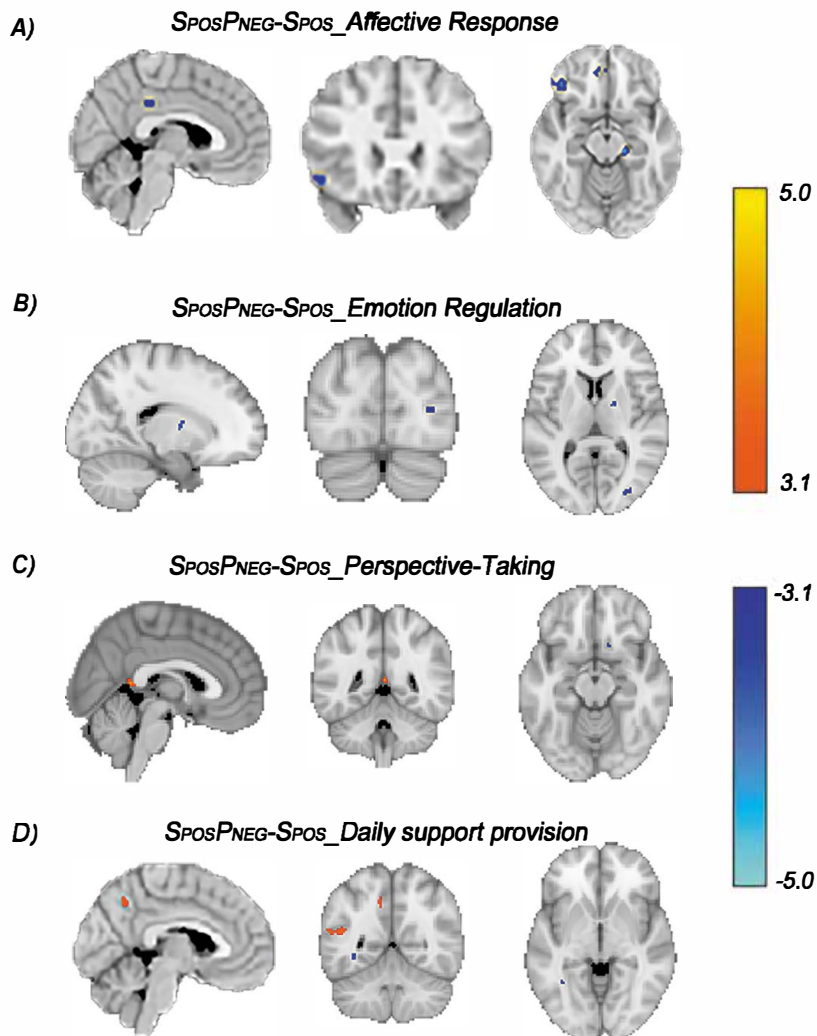


Fig. S3. Results of whole-brain regression analysis in $S_{POS}P_{NEG}-S_{POS}$ contrast.

The regions are shown at the voxel-wise threshold of $z > 3.1$ and cluster size ≥ 10 .

(A) BOLD activity in $S_{POS}P_{NEG}-S_{POS}$ contrast associated with Affective Response subscale score of Empathy Assessment Index.

(B) BOLD activity in $S_{POS}P_{NEG}-S_{POS}$ contrast associated with Emotion Regulation subscale score of Empathy Assessment Index.

(C) BOLD activity in $S_{POS}P_{NEG}-S_{POS}$ contrast associated with Perspective-Taking subscale score of Empathy Assessment Index.

(D) BOLD activity in $S_{POS}P_{NEG}-S_{POS}$ contrast associated with partner-rated daily support provision.

Table S1. Demographic characteristics of participants (N = 131)

	<i>M (SD)</i>
Age	31.8 (8.4)
Relationship duration	8.3 (6.3)
Cohabiting duration	6.5 (6.2)
Married (n)	76
Previously divorced (n)	8
Number with children (n)	46
Ethnicity	
Not Hispanic or Latino	93
Hispanic or Latino	37
Not answered	1
Race[†]	
White	106
American Indian or Alaska Native	2
Native Hawaiian or Other Pacific Islander	1
Asian	9
Black or African American	7
Other	9
Prefer not to disclose	5
Gender	
Woman	71
Man	51
Non-binary	6
Trans woman	0
Trans man	1
Other	1
Prefer not to disclose	1
Sexual orientation	
Bisexual	21
Gay/Lesbian	8
Heterosexual	89
Other	10
Prefer not to disclose	3
Education	
High school degree or equivalent	28
Bachelor's degree	54
Doctorate	10
Master's degree	27
Other	10
Prefer not to disclose	2

[†]: Seven participants identified as more than one race.

Table S2. BOLD activity for P_{POS}-XX and P_{NEG}-XX contrasts

Contrast	Voxels	Z value	X	Y	Z	p (cluster-GRF)	Brain region	
P _{POS} >XX	62690	11.1	2	-64	48	< 0.001	Precuneus Cortex	
		10.2	-4	10	56		Superior Frontal Gyrus	
		9.66	-6	-52	28		Posterior Cingulate Gyrus	
		9.33	-34	-2	62		Middle Frontal Gyrus	
		9.31	-32	-2	54		Middle Frontal Gyrus	
		9.22	-46	2	52		Precentral Gyrus	
	1852	8.4	28	18	-18	< 0.001	Frontal Orbital Cortex	
		6.3	64	-4	-22		Anterior Middle Temporal Gyrus	
		5.81	46	16	-38		Temporal Pole	
		5.81	32	28	2		Frontal Orbital Cortex	
		5.57	50	14	-34		Temporal Pole	
	255	5.29	56	4	-30	< 0.001	Anterior Middle Temporal Gyrus	
		5.01	30	50	10		Frontal Pole	
	241	3.82	38	46	16	< 0.001	Frontal Pole	
		6.14	-2	-18	34		Posterior Cingulate Gyrus	
	132	4.25	-4	-30	24	0.013	Posterior Cingulate Gyrus	
		5	-50	-24	18		Parietal Operculum Cortex	
	P _{POS} <XX	395	3.22	-62	-14	18	< 0.001	Postcentral Gyrus
			5.34	52	44	0		Frontal Pole
4.91			38	52	-14	Frontal Pole		
267		4.79	44	56	-12	< 0.001	Frontal Pole	
		5.03	64	-30	46		Anterior Supramarginal Gyrus	
		4.28	68	-36	38		Posterior Supramarginal Gyrus	
126		4.21	64	-28	28	0.017	Anterior Supramarginal Gyrus	
		5.79	-32	-40	-12		Posterior Temporal Fusiform Cortex	
113		4.62	-38	44	-14	0.027	Frontal Pole	
		3.87	-36	52	-14		Frontal Pole	
98		4.39	-64	-32	46	0.050	Anterior Supramarginal Gyrus	
		3.77	-62	-28	32		Anterior Supramarginal Gyrus	
		3.77	-66	-26	40		Anterior Supramarginal Gyrus	
P _{NEG} >XX	20827	3.31	-58	-32	38	< 0.001	Anterior Supramarginal Gyrus	
		11.2	0	-64	42		Precuneus Cortex	
		10.4	-6	-58	42		Precuneus Cortex	
		10.1	-28	16	-18		Frontal Orbital Cortex	
		9.58	-38	2	58		Middle Frontal Gyrus	
		9.43	-34	2	58		Middle Frontal Gyrus	
	19135	8.98	-40	20	30	< 0.001	Middle Frontal Gyrus	
		8.73	30	18	-16		Frontal Orbital Cortex	
		8.06	-46	-78	-12		Inferior Lateral Occipital Cortex	
		7.94	-38	-56	-20		Temporal Occipital Fusiform Cortex	
		7.82	-40	-78	-16		Inferior Lateral Occipital Cortex	
		7.67	-4	-28	-2		Midbrain	
		7.45	-38	-88	-12		Inferior Lateral Occipital Cortex	
		9574	9.57	-2	14		58	< 0.001
9.54	-4		14	54	Superior Frontal Gyrus			
8.96	-6		58	30	Frontal Pole			

		8.64	-2	66	-4		Frontal Pole
		8.47	-4	58	26		Frontal Pole
		8.19	4	58	22		Frontal Pole
	570	4.91	4	-18	68	< 0.001	Precentral Gyrus
		4.59	2	-16	60		Precentral Gyrus
		4.31	-10	-34	64		Precentral Gyrus
		4.28	-4	-24	56		Precentral Gyrus
		4.03	-2	-18	54		Precentral Gyrus
		3.86	-2	-44	70		Postcentral Gyrus
	138	5.63	-2	-18	36	0.009	Posterior Cingulate Gyrus
	119	4.67	50	-28	44	0.019	Anterior Supramarginal Gyrus
	118	4.65	32	54	10	0.020	Frontal Pole
P _{NEG} <XX	709	6.27	62	-36	50	< 0.001	Posterior Supramarginal Gyrus
		5.59	62	-44	46		Posterior Supramarginal Gyrus
		5.37	62	-40	42		Posterior Supramarginal Gyrus
		4.56	62	-26	34		Anterior Supramarginal Gyrus
		4.54	62	-26	28		Anterior Supramarginal Gyrus
		4.2	68	-26	28		Anterior Supramarginal Gyrus
	442	6.17	40	52	-14	< 0.001	Frontal Pole
		5.17	48	46	-6		Frontal Pole
		4.54	50	46	2		Frontal Pole
	273	4.45	-60	-36	46	< 0.001	Anterior Supramarginal Gyrus
		4.45	-62	-28	34		Anterior Supramarginal Gyrus
		4.3	-66	-28	40		Anterior Supramarginal Gyrus
		4.28	-62	-32	48		Anterior Supramarginal Gyrus
		3.99	-58	-30	28		Anterior Supramarginal Gyrus
		3.8	-60	-34	52		Anterior Supramarginal Gyrus
	262	5	8	-36	44	< 0.001	Posterior Cingulate Gyrus
		4.77	8	-30	42		Posterior Cingulate Gyrus
	242	5.63	-60	-58	-10	< 0.001	Middle Temporal Gyrus
	190	4.69	-40	-2	6	0.001	Insular Cortex
		4.01	-42	-10	-4		Insular Cortex
		3.96	-44	-6	-4		Insular Cortex
		3.76	-48	-10	2		Heschl's Gyrus (includes H1 and H2)
		3.56	-54	-2	0		Planum Polare
		3.53	-58	-2	0		Planum Polare
	147	5.12	-32	-38	-12	0.007	Posterior Parahippocampal Gyrus
		3.89	-28	-30	-20		Posterior Parahippocampal Gyrus
	132	4.85	-36	46	-14	0.012	Frontal Pole
		4.11	-36	38	-10		Frontal Pole
		3.67	-32	40	-8		Frontal Pole
	102	4.56	54	-18	-26	0.038	Posterior Inferior Temporal Gyrus
		4.42	54	-18	-22		Posterior Middle Temporal Gyrus

		4.02	58	-28	-22		Posterior Inferior Temporal Gyrus
		3.88	58	-24	-22		Posterior Inferior Temporal Gyrus
	102	4.46	44	4	-2	0.038	Insular Cortex
		4.06	48	-8	-2		Planum Polare
		3.68	42	-6	-4		Insular Cortex
		3.41	60	0	0		Planum Polare
P _{NEG} <P _{POS}	326	4.69	10	-76	-2	< 0.001	Lingual Gyrus
		4.56	12	-80	0		Intracalcarine Cortex
		4.27	12	-78	-8		Lingual Gyrus
		4.16	16	-84	6		Intracalcarine Cortex
		3.38	22	-66	-6		Lingual Gyrus

Table S3. BOLD activity for $S_{POS}P_{NEG}-S_{POS}$ and $S_{NEG}P_{POS}-S_{NEG}$ contrasts after regressing the belief in cover story (N = 129)

Contrast	Voxels	Z value	X	Y	Z	p (cluster-GRF)	Brain region
$S_{NEG}P_{POS}>S_{NEG}$	27089	7.35	-4	-58	50	< 0.001	Precuneus Cortex
		7.33	-4	-60	54		Precuneus Cortex
		7.13	-2	-70	56		Precuneus Cortex
		6.95	-2	-62	58		Precuneus Cortex
		6.54	10	-72	-6		Lingual Gyrus
		6.49	6	-70	58		Precuneus Cortex
	2662	5.57	36	14	-12	< 0.001	Insular Cortex
		5.31	38	18	-6		Insular Cortex
		5.21	-18	20	-2		Left Caudate
		5.19	10	12	6		Right Caudate
		5.10	42	20	-4		Frontal Orbital Cortex
		5.07	48	20	0		Frontal Operculum Cortex
	375	4.59	-10	-24	-4	< 0.001	Left Thalamus
		4.35	-14	-20	14		Left Thalamus
		4.25	14	-26	0		Right Thalamus
		4.22	-14	-32	8		Left Thalamus
		4.21	4	-22	0		Right Thalamus
		4.14	8	-22	10		Right Thalamus
	365	4.32	-28	58	8	< 0.001	Frontal Pole
		4.31	-30	64	12		Frontal Pole
		4.29	-26	54	14		Frontal Pole
		4.16	-22	64	2		Frontal Pole
	308	4.71	-60	-8	-16	< 0.001	Anterior Middle Temporal Gyrus
		4.46	-64	-12	-20		Posterior Middle Temporal Gyrus
		4.15	-62	-2	-22		Anterior Middle Temporal Gyrus
		3.95	-66	-10	-8		Anterior Middle Temporal Gyrus
		3.70	-66	-16	-8		Posterior Middle Temporal Gyrus
		3.62	-64	-12	-26		Posterior Middle Temporal Gyrus
	164	4.56	2	40	0	0.004	Anterior Cingulate Gyrus
		3.92	-2	30	12		Anterior Cingulate Gyrus
		3.78	4	34	10		Anterior Cingulate Gyrus
	129	4.19	-50	44	-12	0.014	Frontal Pole
		4.12	-48	48	-12		Frontal Pole
3.89		-40	42	-8	Frontal Pole		
3.86		-46	46	-4	Frontal Pole		
3.77		-36	46	-2	Frontal Pole		
108	4.68	-66	-40	10	0.032	Posterior Superior Temporal Gyrus	
	3.90	-60	-28	6		Planum Temporale	

		3.68	-68	-40	4		Posterior Superior Temporal Gyrus
	104	4.23	6	62	2	0.038	Frontal Pole
		4.09	10	64	4		Frontal Pole
		3.89	4	68	2		Frontal Pole
S _{NEG} P _{POS} <S _{NEG}	273	4.79	40	-42	-18	< 0.001	Temporal Occipital Fusiform Cortex
		4.49	46	-48	-22		Temporal Occipital Fusiform Cortex
		4.25	40	-58	-16		Temporal Occipital Fusiform Cortex
		4.25	46	-56	-16		Temporal Occipital Fusiform Cortex
	201	5.89	52	44	8	0.001	Frontal Pole
		4.55	52	36	-2		Frontal Pole
		4.05	46	36	8		Frontal Pole
S _{POS} P _{NEG} >S _{POS}	3391	6.15	-52	20	2	< 0.001	Inferior Frontal Gyrus
		5.87	-48	20	10		Inferior Frontal Gyrus
		5.86	-40	20	30		Middle Frontal Gyrus
		5.80	-46	46	-8		Frontal Pole
		5.76	-50	20	36		Middle Frontal Gyrus
		5.70	-30	20	-12		Frontal Orbital Cortex
	2959	6.92	-4	14	54	< 0.001	Superior Frontal Gyrus
		6.37	-6	38	56		Superior Frontal Gyrus
		5.53	-8	14	66		Superior Frontal Gyrus
		5.32	-4	26	40		Paracingulate Gyrus
		5.26	-8	22	42		Paracingulate Gyrus
		5.20	-2	56	28		Superior Frontal Gyrus
	910	5.18	-6	-60	48	< 0.001	Precuneus Cortex
		5.07	4	-66	50		Precuneus Cortex
		4.31	4	-60	36		Precuneus Cortex
		3.81	-10	-54	34		Precuneus Cortex
	753	5.11	56	-58	38	< 0.001	Angular Gyrus
		4.82	38	-48	42		Superior Parietal Lobule
		4.78	44	-58	44		Angular Gyrus
		4.49	46	-58	32		Angular Gyrus
		3.69	52	-64	46		Superior Lateral Occipital Cortex
		3.47	34	-42	36		Posterior Supramarginal Gyrus
	635	6.69	34	24	-12	< 0.001	Frontal Orbital Cortex
		4.83	32	28	0		Frontal Orbital Cortex
		4.71	44	20	0		Frontal Operculum Cortex
		4.56	46	20	8		Inferior Frontal Gyrus
		3.96	50	38	-10		Frontal Pole
		3.58	56	28	-6		Inferior Frontal Gyrus
	478	4.68	-42	-54	48	< 0.001	Angular Gyrus

		4.64	-40	-50	48		Superior Parietal Lobule
		4.52	-34	-60	44		Superior Lateral Occipital Cortex
		3.82	-34	-46	40		Superior Parietal Lobule
		3.54	-40	-62	58		Superior Lateral Occipital Cortex
	305	5.57	54	10	-30	< 0.001	Temporal Pole
		4.96	52	8	-36		Temporal Pole
		4.67	58	0	-30		Anterior Middle Temporal Gyrus
	240	4.32	-54	-58	30	< 0.001	Angular Gyrus
		4.22	-46	-58	34		Angular Gyrus
		3.77	-56	-60	42		Superior Lateral Occipital Cortex
		3.72	-50	-58	54		Angular Gyrus
		3.72	-52	-60	50		Superior Lateral Occipital Cortex
		3.18	-64	-54	26		Angular Gyrus
	239	4.74	-58	-34	0	< 0.001	Posterior Superior Temporal Gyrus
		4.67	-50	-30	-4		Posterior Middle Temporal Gyrus
		3.50	-48	-38	-4		Posterior Middle Temporal Gyrus
	229	6.00	56	-32	-4	0.001	Posterior Middle Temporal Gyrus
		3.52	50	-22	-12		Posterior Middle Temporal Gyrus
	206	4.70	48	30	38	0.001	Middle Frontal Gyrus
		3.99	52	22	40		Middle Frontal Gyrus
		3.69	52	34	28		Middle Frontal Gyrus
	135	4.40	-48	2	-36	0.014	Temporal Pole
		4.30	-44	2	-38		Temporal Pole
		3.77	-50	6	-30		Temporal Pole
S _{POS} P _{NEG} <S _{POS}	3991	6.33	30	-38	-18	< 0.001	Posterior Temporal Fusiform Cortex
		6.33	30	-58	-8		Temporal Occipital Fusiform Cortex
		6.13	50	-44	-18		Inferior Temporal Gyrus
		5.88	38	-86	16		Superior Lateral Occipital Cortex
		5.77	26	-66	-12		Occipital Fusiform Gyrus
		5.71	30	-44	-10		Temporal Occipital Fusiform Cortex
	2668	6.28	-48	-60	0	< 0.001	Middle Temporal Gyrus
		6.11	-32	-34	-16		Posterior Parahippocampal Gyrus
		5.59	-56	-66	-4		Inferior Lateral Occipital Cortex
		5.30	-26	-46	-20		Temporal Occipital Fusiform Cortex
		5.28	-46	-66	-8		Inferior Lateral Occipital Cortex
		5.23	-48	-70	-6		Inferior Lateral Occipital Cortex
	1435	5.99	-8	-34	44	< 0.001	Posterior Cingulate Gyrus
		5.93	-12	-36	40		Posterior Cingulate Gyrus

	5.28	6	-36	40		Posterior Cingulate Gyrus
	5.19	8	-38	52		Precuneus Cortex
	5.00	14	-36	42		Posterior Cingulate Gyrus
	4.80	10	-32	44		Posterior Cingulate Gyrus
1105	5.66	62	-22	22	< 0.001	Anterior Supramarginal Gyrus
	5.43	64	-22	28		Anterior Supramarginal Gyrus
	5.08	64	-28	46		Anterior Supramarginal Gyrus
	5.01	62	-30	40		Anterior Supramarginal Gyrus
	4.58	64	-18	46		Postcentral Gyrus
	4.47	66	-14	8		Planum Temporale
1067	6.04	-34	-88	16	< 0.001	Superior Lateral Occipital Cortex
	4.93	-26	-88	16		Superior Lateral Occipital Cortex
	4.82	-34	-90	4		Inferior Lateral Occipital Cortex
	4.52	-44	-78	24		Superior Lateral Occipital Cortex
	4.26	-38	-82	26		Superior Lateral Occipital Cortex
	4.22	-20	-74	44		Superior Lateral Occipital Cortex
949	6.37	-26	36	-14	< 0.001	Frontal Orbital Cortex
	5.84	22	36	-14		Frontal Pole
	5.40	-32	38	-6		Frontal Pole
	4.93	2	44	-12		Frontal Medial Cortex
	4.78	32	36	-18		Frontal Pole
	4.70	10	36	-14		Frontal Medial Cortex
856	6.04	-8	-58	12	< 0.001	Precuneus Cortex
	5.09	-2	-56	8		Precuneus Cortex
	4.89	10	-52	12		Precuneus Cortex
	4.88	8	-58	14		Precuneus Cortex
	4.45	6	-56	4		Lingual Gyrus
	4.37	-4	-46	6		Posterior Cingulate Gyrus
828	5.66	-66	-30	30	< 0.001	Anterior Supramarginal Gyrus
	5.51	-60	-30	22		Parietal Operculum Cortex
	4.97	-58	-16	16		Central Opercular Cortex
	4.37	-66	-28	40		Anterior Supramarginal Gyrus
	4.27	-66	-24	38		Anterior Supramarginal Gyrus
	3.96	-66	-16	10		Posterior Superior Temporal Gyrus
664	4.78	-42	2	6	< 0.001	Central Opercular Cortex
	4.72	-36	2	10		Insular Cortex
	4.69	-38	-14	0		Insular Cortex
	4.34	-38	-6	-4		Insular Cortex
	4.23	-40	-16	-4		Insular Cortex
	4.17	-26	-2	4		Left Putamen

555	6.74	2	4	38	< 0.001	Anterior Cingulate Gyrus
	4.17	0	14	32		Anterior Cingulate Gyrus
	3.59	10	0	48		Supplementary Motor Cortex
	3.56	-16	10	32		Left Cerebral White Matter
492	5.07	-10	-54	68	< 0.001	Superior Parietal Lobule
	4.20	-12	-52	60		Precuneus Cortex
	4.02	-26	-42	68		Superior Parietal Lobule
	3.98	-20	-42	70		Postcentral Gyrus
	3.90	-20	-46	56		Superior Parietal Lobule
	3.77	-22	-52	74		Superior Parietal Lobule
	200	4.39	36	-16		4
4.18		40	-8	-4	Insular Cortex	
3.86		28	-8	6	Right Putamen	
3.68		30	-16	-2	Right Putamen	
3.50		42	2	-20	Planum Polare	
3.34		38	-6	-12	Insular Cortex	
182		4.21	28	-20	-12	0.003
	4.13	20	-20	-14	Posterior Parahippocampal Gyrus	
	4.11	42	-12	-28	Posterior Temporal Fusiform Cortex	
	4.00	34	-14	-20	Anterior Parahippocampal Gyrus	
	3.94	32	-18	-14	Right Hippocampus	
	3.62	36	-8	-38	Anterior Temporal Fusiform Cortex	
	173	4.63	32	-42	74	
4.29		50	-28	62	Postcentral Gyrus	
4.04		28	-46	68	Superior Parietal Lobule	
3.87		28	-38	60	Postcentral Gyrus	
3.56		30	-48	58	Superior Parietal Lobule	
3.50		38	-34	66	Postcentral Gyrus	
172		5.02	38	2	4	0.004
	3.97	34	10	10	Insular Cortex	
165	4.53	-46	-28	64	0.005	Postcentral Gyrus
	3.99	-38	-24	68		Postcentral Gyrus
	3.55	-32	-26	74		Postcentral Gyrus
	3.54	-32	-26	58		Precentral Gyrus
	3.40	-38	-26	60		Postcentral Gyrus

	141	4.95	52	40	12	0.012	Frontal Pole
		4.85	48	40	10		Frontal Pole
	134	4.69	18	-54	66	0.015	Superior Parietal Lobule
		3.96	18	-46	64		Superior Parietal Lobule
	109	4.67	22	-74	46	0.037	Superior Lateral Occipital Cortex
		3.77	26	-72	38		Superior Lateral Occipital Cortex
[S _{NEG} P _{POS} - S _{NEG}] > [S _{POS} P _{NEG} - S _{POS}]	27101	7.00	14	-74	-8	< 0.001	Lingual Gyrus
		6.99	10	-72	-6		Lingual Gyrus
		6.46	22	-68	-12		Occipital Fusiform Gyrus
		6.30	64	-14	10		Central Opercular Cortex
		6.06	26	-86	30		Superior Lateral Occipital Cortex
		5.91	-60	-18	16		Central Opercular Cortex
	2016	6.26	0	4	36	< 0.001	Anterior Cingulate Gyrus
		5.26	-34	36	40		Middle Frontal Gyrus
		5.20	-16	-10	62		Superior Frontal Gyrus
		4.64	-6	-8	36		Anterior Cingulate Gyrus
		4.54	-20	16	50		Superior Frontal Gyrus
		4.22	-2	-6	58		Supplementary Motor Cortex
	863	4.88	10	36	-12	< 0.001	Frontal Medial Cortex
		4.49	4	40	-2		Anterior Cingulate Gyrus
		4.34	8	50	-4		Paracingulate Gyrus
		4.29	0	48	-8		Paracingulate Gyrus
		4.28	2	42	-8		Paracingulate Gyrus
		4.24	-24	32	-16		Frontal Orbital Cortex
	384	4.55	28	40	48	< 0.001	Frontal Pole
		4.37	36	32	44		Middle Frontal Gyrus
		4.32	36	38	42		Frontal Pole
		4.18	32	32	36		Middle Frontal Gyrus
		4.14	40	40	32		Frontal Pole
		4.09	32	36	44		Frontal Pole
	283	5.12	-18	20	-2	< 0.001	Left Caudate
		5.00	-22	12	-12		Frontal Orbital Cortex
	210	4.31	26	16	48	0.001	Middle Frontal Gyrus
		3.81	24	16	58		Superior Frontal Gyrus
		3.69	24	24	54		Superior Frontal Gyrus
		3.61	20	12	58		Superior Frontal Gyrus
		3.59	22	6	56		Superior Frontal Gyrus
	191	4.57	28	-24	-14	0.002	Posterior Parahippocampal Gyrus

		4.55	32	-16	-22		Anterior Parahippocampal Gyrus
		3.90	34	-22	-14		Posterior Parahippocampal Gyrus
		3.78	42	-12	-28		Posterior Temporal Fusiform Cortex
		3.71	34	-26	-16		Posterior Parahippocampal Gyrus
		3.51	18	-18	-16		Right Hippocampus
	180	4.10	22	10	-12	0.003	Frontal Orbital Cortex
		3.99	22	20	-6		Right Putamen
		3.74	2	16	0		Subcallosal Cortex
		3.71	8	22	0		Right Cerebral White Matter
		3.63	8	18	-8		Subcallosal Cortex
$[S_{NEG}P_{POS} - S_{NEG}] <$	104	4.54	-48	26	-2	0.041	Frontal Operculum Cortex
$[S_{POS}P_{NEG} - S_{POS}]$		4.15	-44	32	-6		Frontal Orbital Cortex

Table S4. Activity for $S_{POS}P_{NEG}-S_{POS}$ and $S_{NEG}P_{POS}-S_{NEG}$ contrasts
after regressing age and relationship duration

Contrast	Voxels	Z value	X	Y	Z	p (cluster-GRF)	Brain region
$S_{NEG}P_{POS}>S_{NEG}$	26051	7.41	-4	-58	50	< 0.001	Precuneus Cortex
		7.35	-4	-60	54		Precuneus Cortex
		7.19	-2	-62	58		Precuneus Cortex
		7.12	-2	-70	56		Precuneus Cortex
		6.62	10	-72	-6		Lingual Gyrus
		6.57	2	14	54		Superior Frontal Gyrus
	2774	5.85	36	14	-12	< 0.001	Insular Cortex
		5.38	38	18	-6		Insular Cortex
		5.20	42	20	-4		Frontal Orbital Cortex
		5.20	10	10	6		Right Caudate
		5.17	50	20	0		Inferior Frontal Gyrus
		5.10	-18	20	-2		Left Caudate
	2442	5.61	42	-44	42	< 0.001	Posterior Supramarginal Gyrus
		5.10	62	-58	28		Angular Gyrus
		5.06	56	-60	30		Superior Lateral Occipital Cortex
		5.01	50	-38	46		Posterior Supramarginal Gyrus
		4.97	52	-58	28		Angular Gyrus
		4.96	48	-44	60		Posterior Supramarginal Gyrus
	398	4.58	-28	58	8	< 0.001	Frontal Pole
		4.51	-26	54	14		Frontal Pole
		4.49	-30	64	12		Frontal Pole
		4.11	-22	64	2		Frontal Pole
	380	4.66	-10	-24	-4	< 0.001	Left Thalamus
		4.30	4	-22	0		Right Thalamus
		4.29	-14	-18	14		Left Thalamus
		4.12	-14	-32	8		Left Thalamus
		4.12	-22	-28	0		Left Cerebral White Matter
		3.99	12	-18	14		Right Thalamus
	291	4.56	-60	-8	-16	< 0.001	Anterior Middle Temporal Gyrus
		4.34	-68	-16	-16		Posterior Middle Temporal Gyrus
		3.92	-62	-2	-22		Anterior Middle Temporal Gyrus
		3.86	-66	-10	-8		Anterior Middle Temporal Gyrus
		3.56	-52	-12	-18		Posterior Middle Temporal Gyrus
		3.48	-48	-12	-16		Posterior Middle Temporal Gyrus
	157	4.60	2	40	0	0.005	Anterior Cingulate Gyrus
		3.95	-2	30	12		Anterior Cingulate Gyrus
		3.84	4	34	10		Anterior Cingulate Gyrus
	110	4.26	-48	48	-12	0.030	Frontal Pole

		3.99	-40	42	-8		Frontal Pole
		3.65	-46	46	-4		Frontal Pole
		3.50	-36	46	-2		Frontal Pole
$S_{NEG}P_{POS} < S_{NEG}$	237	4.56	40	-42	-18	< 0.001	Temporal Occipital Fusiform Cortex
		4.25	46	-48	-22		Temporal Occipital Fusiform Cortex
		4.23	46	-56	-16		Temporal Occipital Fusiform Cortex
		4.17	40	-58	-16		Temporal Occipital Fusiform Cortex
		4.11	46	-44	-22		Temporal Occipital Fusiform Cortex
	163	5.26	52	44	8	0.004	Frontal Pole
		3.87	54	36	18		Frontal Pole
		3.76	52	36	-2		Frontal Pole
		3.74	46	36	8		Frontal Pole
$S_{POS}P_{NEG} > S_{POS}$	3341	6.02	-52	20	2	< 0.001	Inferior Frontal Gyrus
		5.95	-50	20	36		Middle Frontal Gyrus
		5.86	-40	20	30		Middle Frontal Gyrus
		5.86	-30	20	-12		Frontal Orbital Cortex
		5.83	-46	46	-8		Frontal Pole
		5.65	-28	28	0		Frontal Orbital Cortex
	3047	6.86	-2	16	52	< 0.001	Superior Frontal Gyrus
		6.55	-8	36	58		Superior Frontal Gyrus
		5.64	-6	48	50		Frontal Pole
		5.55	-4	28	40		Paracingulate Gyrus
		5.39	-2	56	28		Superior Frontal Gyrus
		5.23	-8	22	42		Paracingulate Gyrus
	1001	5.23	-6	-62	46	< 0.001	Precuneus Cortex
		5.19	2	-66	48		Precuneus Cortex
		4.78	10	-62	48		Precuneus Cortex
		4.58	4	-60	36		Precuneus Cortex
		3.96	-12	-54	30		Posterior Cingulate Gyrus
		3.88	-10	-50	28		Posterior Cingulate Gyrus
	846	5.47	54	-56	38	< 0.001	Angular Gyrus
		4.91	44	-58	44		Angular Gyrus
		4.87	38	-48	42		Superior Parietal Lobule
		4.68	46	-58	32		Angular Gyrus
		3.90	52	-64	46		Superior Lateral Occipital Cortex
		3.84	32	-42	36		Superior Parietal Lobule
	594	6.90	34	24	-12	< 0.001	Frontal Orbital Cortex
		4.87	32	28	0		Frontal Orbital Cortex
		4.67	46	20	8		Inferior Frontal Gyrus
		4.59	44	20	0		Frontal Operculum Cortex
		3.69	56	28	-6		Inferior Frontal Gyrus
	539	4.82	-40	-52	48	< 0.001	Angular Gyrus
		4.64	-34	-60	44		Superior Lateral Occipital Cortex

		4.00	-34	-46	40		Superior Parietal Lobule
		3.55	-40	-62	58		Superior Lateral Occipital Cortex
		3.48	-48	-40	44		Anterior Supramarginal Gyrus
	300	5.37	54	8	-32	< 0.001	Temporal Pole
		5.11	52	8	-36		Temporal Pole
		4.50	58	0	-30		Anterior Middle Temporal Gyrus
	254	4.81	48	30	38	< 0.001	Middle Frontal Gyrus
		4.21	52	22	40		Middle Frontal Gyrus
		3.74	52	34	28		Middle Frontal Gyrus
	249	4.38	-54	-58	30	< 0.001	Angular Gyrus
		4.32	-46	-58	34		Angular Gyrus
		3.68	-56	-60	42		Superior Lateral Occipital Cortex
		3.40	-62	-58	28		Angular Gyrus
		3.19	-64	-54	26		Angular Gyrus
	249	6.18	56	-32	-4	< 0.001	Posterior Middle Temporal Gyrus
		3.93	50	-22	-10		Posterior Middle Temporal Gyrus
	233	4.69	-58	-34	0	0.001	Posterior Superior Temporal Gyrus
		4.50	-50	-30	-4		Posterior Middle Temporal Gyrus
		3.50	-48	-38	-4		Posterior Middle Temporal Gyrus
	146	4.30	-48	2	-36	0.010	Temporal Pole
		4.17	-44	2	-38		Temporal Pole
		3.78	-50	6	-30		Temporal Pole
		3.42	-62	-2	-24		Anterior Middle Temporal Gyrus
S _{POS} P _{NEG} <S _{POS}	4378	6.50	30	-58	-8	< 0.001	Temporal Occipital Fusiform Cortex
		6.38	30	-38	-18		Posterior Temporal Fusiform Cortex
		5.98	30	-44	-10		Temporal Occipital Fusiform Cortex
		5.81	38	-84	18		Superior Lateral Occipital Cortex
		5.78	50	-44	-18		Inferior Temporal Gyrus
		5.72	42	-66	-10		Inferior Lateral Occipital Cortex
	2927	6.28	-48	-60	0	< 0.001	Middle Temporal Gyrus
		6.20	-32	-34	-16		Posterior Parahippocampal Gyrus
		5.63	-54	-68	-6		Inferior Lateral Occipital Cortex
		5.59	-30	-46	-8		Temporal Occipital Fusiform Cortex
		5.39	-26	-46	-20		Temporal Occipital Fusiform Cortex
		5.39	-32	-26	-18		Posterior Parahippocampal Gyrus
	1642	5.81	-66	-30	30	< 0.001	Anterior Supramarginal Gyrus
		5.63	-60	-30	22		Parietal Operculum Cortex
		5.30	-34	6	10		Insular Cortex
		4.98	-36	2	10		Insular Cortex
		4.90	-58	-16	16		Central Opercular Cortex
		4.87	-42	2	6		Central Opercular Cortex

1441	6.13	-8	-34	44	< 0.001	Posterior Cingulate Gyrus
	5.98	-12	-36	40		Posterior Cingulate Gyrus
	5.45	16	-36	42		Precuneus Cortex
	5.28	6	-36	42		Posterior Cingulate Gyrus
	5.28	8	-38	52		Precuneus Cortex
	4.99	10	-32	44		Posterior Cingulate Gyrus
1155	5.60	64	-22	30	< 0.001	Anterior Supramarginal Gyrus
	5.36	62	-22	22		Anterior Supramarginal Gyrus
	5.17	62	-30	40		Anterior Supramarginal Gyrus
	4.94	64	-28	46		Anterior Supramarginal Gyrus
	4.60	64	-18	46		Postcentral Gyrus
	4.59	66	-14	8		Planum Temporale
1133	6.11	-34	-88	16	< 0.001	Superior Lateral Occipital Cortex
	5.12	-26	-88	16		Superior Lateral Occipital Cortex
	4.79	-32	-90	6		Occipital Pole
	4.74	-32	-90	2		Inferior Lateral Occipital Cortex
	4.53	-42	-78	24		Superior Lateral Occipital Cortex
	4.32	-38	-82	26		Superior Lateral Occipital Cortex
1000	6.40	-26	36	-14	< 0.001	Frontal Orbital Cortex
	5.87	22	36	-14		Frontal Pole
	5.49	-32	38	-6		Frontal Pole
	5.17	2	44	-12		Frontal Medial Cortex
	4.79	-6	38	-14		Frontal Medial Cortex
	4.66	30	36	-16		Frontal Pole
872	5.87	-8	-58	12	< 0.001	Precuneus Cortex
	5.41	-6	-60	18		Precuneus Cortex
	4.86	12	-50	10		Precuneus Cortex
	4.70	8	-58	16		Precuneus Cortex
	4.44	6	-56	4		Lingual Gyrus
	4.31	18	-44	2		Posterior Cingulate Gyrus
601	6.70	2	2	38	< 0.001	Anterior Cingulate Gyrus
	3.77	-16	10	32		Left Cerebral White Matter
	3.48	10	0	48		Supplementary Motor Cortex
532	5.51	-10	-56	68	< 0.001	Superior Parietal Lobule
	4.49	-12	-54	60		Precuneus Cortex
	4.29	-16	-56	62		Superior Parietal Lobule
	4.03	-20	-46	56		Superior Parietal Lobule
	3.92	-26	-42	68		Superior Parietal Lobule
494	3.76	-20	-42	70	< 0.001	Postcentral Gyrus
	5.10	38	2	4		Insular Cortex

		4.66	22	0	-12		Right Cerebral Cortex
		4.41	36	-16	4		Insular Cortex
		4.18	40	-8	-4		Insular Cortex
		4.04	34	10	10		Insular Cortex
		3.98	26	-10	6		Right Putamen
218		4.63	-46	-28	64	0.001	Postcentral Gyrus
		4.05	-38	-24	68		Postcentral Gyrus
		3.54	-32	-26	58		Precentral Gyrus
		3.53	-32	-26	74		Postcentral Gyrus
		3.42	-40	-40	66		Postcentral Gyrus
203		4.49	32	-42	74	0.001	Superior Parietal Lobule
		4.41	50	-28	62		Postcentral Gyrus
		4.01	30	-46	66		Superior Parietal Lobule
		4.00	28	-38	60		Postcentral Gyrus
		3.61	30	-48	58		Superior Parietal Lobule
		3.54	24	-42	74		Superior Parietal Lobule
200		4.34	28	-20	-12	0.002	Right Hippocampus
		4.29	34	-14	-20		Anterior Parahippocampal Gyrus
		4.20	42	-12	-28		Posterior Temporal Fusiform Cortex
		4.04	22	-20	-14		Posterior Parahippocampal Gyrus
		3.68	36	-8	-38		Anterior Temporal Fusiform Cortex
		3.34	18	-22	-20		Anterior Parahippocampal Gyrus
155		4.69	18	-54	66	0.007	Superior Parietal Lobule
		4.23	16	-50	66		Superior Parietal Lobule
		3.98	18	-46	64		Superior Parietal Lobule
148		5.03	52	40	12	0.009	Frontal Pole
119		4.87	22	-74	46	0.025	Superior Lateral Occipital Cortex
		3.84	26	-72	38		Superior Lateral Occipital Cortex
[S _{NEG} P _{POS} -S _{NEG}] [S _{POS} P _{NEG} -S _{POS}]	28757	7.22	10	-72	-6	< 0.001	Lingual Gyrus
		7.13	14	-74	-8		Lingual Gyrus
		6.52	22	-68	-12		Occipital Fusiform Gyrus
		6.31	64	-14	10		Central Opercular Cortex
		6.01	28	-86	30		Superior Lateral Occipital Cortex
		5.97	18	-64	-8		Lingual Gyrus
2224		6.33	0	4	36	< 0.001	Anterior Cingulate Gyrus
		5.15	-8	2	40		Anterior Cingulate Gyrus
		5.15	-16	-10	62		Superior Frontal Gyrus
		5.15	-34	36	40		Middle Frontal Gyrus
		5.01	0	16	32		Anterior Cingulate Gyrus

	4.78	-6	-8	36		Anterior Cingulate Gyrus
868	4.69	8	34	-12	< 0.001	Frontal Medial Cortex
	4.57	4	42	-10		Paracingulate Gyrus
	4.45	-20	32	-20		Frontal Orbital Cortex
	4.43	4	40	-2		Anterior Cingulate Gyrus
	4.36	-12	36	-12		Frontal Medial Cortex
	4.33	-24	32	-16		Frontal Orbital Cortex
471	4.71	36	38	42	< 0.001	Frontal Pole
	4.59	30	40	48		Frontal Pole
	4.55	38	34	42		Middle Frontal Gyrus
	4.52	40	40	32		Frontal Pole
	4.34	32	32	36		Middle Frontal Gyrus
	4.19	34	34	50		Middle Frontal Gyrus
311	5.09	-22	12	-12	< 0.001	Frontal Orbital Cortex
	4.98	-18	20	-2		Left Caudate
	3.31	-20	16	12		Left Cerebral White Matter
233	4.89	28	-24	-14	< 0.001	Posterior Parahippocampal Gyrus
	4.76	32	-16	-22		Anterior Parahippocampal Gyrus
	4.06	34	-22	-14		Posterior Parahippocampal Gyrus
	4.01	42	-12	-30		Posterior Temporal Fusiform Cortex
	3.91	34	-26	-16		Posterior Parahippocampal Gyrus
	3.64	46	-14	-30		Posterior Inferior Temporal Gyrus
221	4.30	22	10	-12	0.001	Frontal Orbital Cortex
	3.95	18	20	-4		Right Cerebral White Matter
	3.94	22	20	-6		Right Putamen
	3.74	8	22	0		Right Cerebral White Matter
	3.73	8	18	-6		Subcallosal Cortex
	3.72	2	16	0		Subcallosal Cortex
120	3.94	-42	36	12	0.022	Frontal Pole
	3.81	-38	32	14		Inferior Frontal Gyrus
	3.79	-44	36	22		Middle Frontal Gyrus

Table S5. Differences between activity for $S_{NEG}P_{POS}-S_{NEG}/S_{POS}P_{NEG}-S_{POS}$ contrasts and P_{POS-XX}/P_{NEG-XX} contrasts

Contrast	Voxels	Z value	X	Y	Z	p (cluster-GRF)	Brain region
[$S_{NEG}P_{POS}-S_{NEG}$] [P_{POS-XX}]	566	5.56	62	-32	44	< 0.001	Anterior Supramarginal Gyrus
		4.13	66	-26	28		Anterior Supramarginal Gyrus
		4.09	60	-50	42		Angular Gyrus
		4.00	68	-22	32		Anterior Supramarginal Gyrus
		3.53	64	-42	38		Posterior Supramarginal Gyrus
	368	4.98	12	-92	30	< 0.001	Occipital Pole
		4.39	8	-90	20		Occipital Pole
		3.79	24	-88	34		Occipital Pole
		3.71	16	-84	40		Superior Lateral Occipital Cortex
	360	5.49	36	32	50	< 0.001	Middle Frontal Gyrus
		4.18	28	24	58		Superior Frontal Gyrus
		3.70	24	18	64		Superior Frontal Gyrus
		3.61	44	28	46		Middle Frontal Gyrus
		3.32	30	30	40		Middle Frontal Gyrus
	301	5.22	36	50	-14	< 0.001	Frontal Pole
		5.17	46	48	-12		Frontal Pole
		4.08	42	60	-8		Frontal Pole
		3.40	50	48	-2		Frontal Pole
	232	5.34	-62	-32	44	0.001	Anterior Supramarginal Gyrus
		4.36	-62	-28	34		Anterior Supramarginal Gyrus
		3.85	-66	-26	40		Anterior Supramarginal Gyrus
		3.29	-58	-40	52		Posterior Supramarginal Gyrus
	220	4.61	-8	-90	26	0.001	Occipital Pole
		3.79	-12	-80	30		Cuneal Cortex
		3.53	-10	-92	36		Occipital Pole
	205	4.25	14	-72	-8	0.001	Lingual Gyrus
		4.17	8	-70	-6		Lingual Gyrus
		3.90	6	-72	0		Lingual Gyrus
		3.74	8	-76	-6		Lingual Gyrus
	173	4.78	4	-34	46	0.003	Posterior Cingulate Gyrus
		4.77	6	-30	44		Posterior Cingulate Gyrus
		3.56	10	-40	48		Precuneus Cortex
		3.40	14	-40	46		Precuneus Cortex
159	5.19	-38	40	-10	0.006	Frontal Pole	
	4.59	-40	46	-14		Frontal Pole	
	3.82	-20	42	-16		Frontal Pole	
	3.50	-30	50	-10		Frontal Pole	
158	4.67	-60	-56	-6	0.006	Middle Temporal Gyrus	

		4.13	-64	-60	0		Middle Temporal Gyrus
		4.05	-62	-62	-8		Middle Temporal Gyrus
	105	4.41	-24	16	56	0.040	Superior Frontal Gyrus
		3.87	-20	6	64		Superior Frontal Gyrus
		3.82	-20	10	62		Superior Frontal Gyrus
[S _{NEG} P _{POS} -S _{NEG}] [P _{POS} -XX]	6897	7.43	36	-82	-12	< 0.001	Inferior Lateral Occipital Cortex
		7.09	42	-56	-20		Temporal Occipital Fusiform Cortex
		7.07	-36	-88	-10		Inferior Lateral Occipital Cortex
		7.01	38	-58	-16		Temporal Occipital Fusiform Cortex
		6.96	42	-66	-14		Occipital Fusiform Gyrus
		6.95	44	-78	-10		Inferior Lateral Occipital Cortex
	2703	6.23	-46	2	52	< 0.001	Precentral Gyrus
		6.20	-28	16	-16		Frontal Orbital Cortex
		5.74	-38	22	-16		Frontal Orbital Cortex
		5.58	-42	16	28		Middle Frontal Gyrus
		5.39	-34	-2	50		Precentral Gyrus
		5.27	-50	14	30		Middle Frontal Gyrus
	2609	6.21	4	60	34	< 0.001	Frontal Pole
		6.09	-2	66	-2		Frontal Pole
		5.99	-4	48	-18		Frontal Medial Cortex
		5.80	-4	60	34		Frontal Pole
		5.71	4	60	26		Frontal Pole
		5.27	4	34	-6		Anterior Cingulate Gyrus
	2346	6.52	-4	-50	28	< 0.001	Posterior Cingulate Gyrus
		6.00	-2	-56	42		Precuneus Cortex
		5.77	8	-52	22		Posterior Cingulate Gyrus
		5.74	2	-58	46		Precuneus Cortex
		5.42	-22	-64	48		Superior Lateral Occipital Cortex
		4.97	-28	-48	44		Superior Parietal Lobule
	1024	5.87	40	18	30	< 0.001	Middle Frontal Gyrus
		5.80	46	14	32		Middle Frontal Gyrus
		5.70	52	26	24		Middle Frontal Gyrus
		5.51	48	20	30		Middle Frontal Gyrus
		5.09	42	2	58		Middle Frontal Gyrus
		4.67	36	0	60		Middle Frontal Gyrus
	856	6.09	34	-68	34	< 0.001	Superior Lateral Occipital Cortex
		4.89	20	-64	56		Superior Lateral Occipital Cortex
		4.80	28	-62	50		Superior Lateral Occipital Cortex
		4.80	24	-62	52		Superior Lateral Occipital Cortex
		4.77	26	-62	46		Superior Lateral Occipital Cortex
		4.62	32	-60	54		Superior Lateral Occipital Cortex
	807	5.78	-56	-38	4	< 0.001	Posterior Superior Temporal Gyrus

		5.21	-46	-42	4		Posterior Superior Temporal Gyrus
		5.04	-46	-46	12		Posterior Supramarginal Gyrus
		4.56	-50	-16	-8		Posterior Superior Temporal Gyrus
		4.40	-54	-50	18		Angular Gyrus
		3.66	-56	-48	24		Posterior Supramarginal Gyrus
	574	6.86	-4	10	58	< 0.001	Superior Frontal Gyrus
		6.62	-2	8	64		Supplementary Motor Cortex
		5.16	-8	14	48		Paracingulate Gyrus
		3.13	10	6	58		Supplementary Motor Cortex
	182	5.29	26	18	-18	0.003	Frontal Orbital Cortex
		4.48	36	26	-18		Frontal Orbital Cortex
	149	4.38	4	-24	58	0.008	Precentral Gyrus
		4.18	-2	-28	60		Precentral Gyrus
		3.36	-10	-26	56		Precentral Gyrus
		3.32	8	-18	54		Precentral Gyrus
	105	5.78	8	-72	-20	0.040	Lingual Gyrus
		4.48	-6	-74	-20		Occipital Fusiform Gyrus
[S _{POS} P _{NEG} -S _{POS}]> [P _{NEG} -XX]	355	6.06	40	50	-12	< 0.001	Frontal Pole
	149	4.63	56	-56	40	0.007	Angular Gyrus
		4.29	52	-64	46		Superior Lateral Occipital Cortex
		3.83	62	-44	46		Posterior Supramarginal Gyrus
		3.48	60	-50	42		Angular Gyrus
		3.36	52	-46	46		Posterior Supramarginal Gyrus
[S _{POS} P _{NEG} -S _{POS}]< [P _{NEG} -XX]	34788	7.93	-2	-62	38	< 0.001	Precuneus Cortex
		7.85	-42	-80	-10		Inferior Lateral Occipital Cortex
		7.83	36	-60	-18		Temporal Occipital Fusiform Cortex
		7.68	-32	-54	-20		Temporal Occipital Fusiform Cortex
		7.66	-36	-48	-22		Temporal Occipital Fusiform Cortex
		7.55	-38	-90	-6		Inferior Lateral Occipital Cortex
	4087	7.22	0	64	-2	< 0.001	Frontal Pole
		7.07	-6	50	-14		Frontal Medial Cortex
		7.00	0	48	-18		Frontal Medial Cortex
		6.78	-6	58	-4		Frontal Pole
		6.56	6	50	-14		Frontal Medial Cortex
		6.45	0	56	-10		Frontal Pole
	482	5.50	42	0	60	< 0.001	Middle Frontal Gyrus
		4.97	28	0	48		Precentral Gyrus
		4.51	38	0	44		Precentral Gyrus
		4.32	44	0	52		Precentral Gyrus
		4.30	34	0	56		Middle Frontal Gyrus
		4.24	28	-4	60		Superior Frontal Gyrus
	338	5.93	32	-22	64	< 0.001	Precentral Gyrus

	4.28	40	-30	54		Postcentral Gyrus
	4.16	50	-28	58		Postcentral Gyrus
	3.93	38	-34	58		Postcentral Gyrus
	3.68	42	-14	66		Precentral Gyrus
	3.49	48	-14	60		Postcentral Gyrus
259	5.07	54	-8	-18	< 0.001	Posterior Middle Temporal Gyrus
	4.50	66	-4	-20		Anterior Middle Temporal Gyrus
	3.71	62	0	-12		Anterior Superior Temporal Gyrus
232	4.79	42	22	28	< 0.001	Middle Frontal Gyrus
	4.38	46	28	20		Inferior Frontal Gyrus
	3.71	50	20	30		Middle Frontal Gyrus
	3.54	36	26	22		Middle Frontal Gyrus
	3.53	42	14	28		Inferior Frontal Gyrus
167	4.67	50	-22	40	0.004	Postcentral Gyrus
	3.48	56	-22	38		Anterior Supramarginal Gyrus
	3.41	62	-16	46		Postcentral Gyrus
	3.39	58	-16	46		Postcentral Gyrus
	3.26	48	-28	30		Parietal Operculum Cortex
163	5.30	-38	28	2	0.004	Frontal Operculum Cortex
	4.05	-42	26	10		Inferior Frontal Gyrus
151	4.07	-28	22	44	0.006	Middle Frontal Gyrus
	3.93	-24	38	44		Frontal Pole
	3.79	-24	40	50		Frontal Pole
	3.69	-16	38	38		Superior Frontal Gyrus
	3.65	-26	34	42		Middle Frontal Gyrus
117	4.86	32	32	-14	0.022	Frontal Orbital Cortex
	4.03	26	32	-14		Frontal Orbital Cortex
	3.62	26	38	-20		Frontal Pole
97	4.84	-56	-22	18	0.049	Central Opercular Cortex
	4.71	-60	-16	16		Central Opercular Cortex
	3.37	-46	-20	16		Central Opercular Cortex

Table S6. ROIs selected in regression analysis

Index	Neurosynth search term	Brain region	Z value	x	y	z
1	Empathy	Right Temporoparietal Junction	9.04	50	-50	18
2	Empathy	Right Temporoparietal Junction	5.49	50	-42	8
3	Empathy	Right Dorsomedial Prefrontal Cortex	6.03	4	56	24
4	Empathy	Right Anterior Insula	4.99	40	18	-8
5	Empathy	Right Anterior Cingulate Cortex	4.57	6	16	26
6	Cognitive control	Right Middle Frontal Gyrus	7.62	46	18	32
7	Cognitive control	Right Middle Frontal Gyrus	5.93	40	32	22

Table S7. Summary of whole-brain multiple regression analysis with subscale scores of Empathy Assessment Index (EAI) and daily support provision

Contrast	Behavior	Relationship	Voxels	Z value	x	y	z	Brain region
S _{NEG} P _{POS} - S _{NEG}	EAI - Affective Response	Pos	10	4.00	32	-56	10	Precuneus Cortex
			10	3.99	-52	-34	28	Parietal Operculum Cortex
		Neg	60	3.62	44	-66	-12	Inferior Lateral Occipital Cortex
				3.59	40	-74	-12	Inferior Lateral Occipital Cortex
				3.32	48	-66	-8	Inferior Lateral Occipital Cortex
				3.13	44	-72	-8	Inferior Lateral Occipital Cortex
			29	3.66	-38	-14	-26	Posterior Temporal Fusiform Cortex
				3.56	-32	-16	-30	Anterior Parahippocampal Gyrus
			28	3.71	-32	-96	-10	Occipital Pole
			17	4.31	-40	2	-22	Planum Polare
			14	3.45	-28	-62	34	Superior Lateral Occipital Cortex
				3.25	-22	-62	32	Superior Lateral Occipital Cortex
			14	3.75	-20	40	-10	Frontal Pole
				3.26	-14	38	-8	Paracingulate Gyrus
	11	3.70	-12	-98	-12	Occipital Pole		
	EAI - Emotion Regulation	Pos	327	4.65	22	30	10	Right Cerebral White Matter
				4.33	12	-6	22	Right Cerebral White Matter
				3.84	12	14	12	Right Caudate
				3.82	6	24	10	Right Cerebral White Matter
				3.74	14	4	26	Right Cerebral White Matter
				3.73	22	-22	20	Right Caudate
			193	4.81	-22	-44	22	Left Cerebral White Matter
				4.51	-24	-48	24	Left Cerebral White Matter
				4.48	-22	-38	28	Left Cerebral White Matter
				3.69	-20	-48	28	Precuneus Cortex
				3.68	-24	-56	20	Precuneus Cortex
				3.54	-16	-32	32	Posterior Cingulate Gyrus
117			4.29	20	-32	28	Right Cerebral White Matter	
	3.79	26	-20	32	Right Cerebral White Matter			
	3.64	34	-16	30	Right Cerebral White Matter			
	3.61	28	-16	28	Right Cerebral White Matter			
82	4.63	-28	-72	10	Intracalcarine Cortex			
	3.77	-28	-68	0	Occipital Fusiform Gyrus			
	3.66	-20	-78	14	Intracalcarine Cortex			

	56	4.26	34	-56	0	Lingual Gyrus	
	35	3.40	26	54	10	Frontal Pole	
		3.36	30	58	8	Frontal Pole	
		3.36	30	48	12	Frontal Pole	
	33	4.62	-10	6	16	Left Caudate	
		3.14	-16	-2	16	Left Cerebral White Matter	
	33	4.15	-66	-52	4	Middle Temporal Gyrus	
	32	3.73	24	-4	18	Right Cerebral White Matter	
		3.56	22	4	14	Right Caudate	
	28	4.00	42	-34	-8	Right Cerebral White Matter	
		3.56	44	-40	-4	Posterior Middle Temporal Gyrus	
	26	4.01	-58	-68	8	Inferior Lateral Occipital Cortex	
	26	3.72	42	36	32	Frontal Pole	
	23	4.59	24	-2	38	Right Cerebral White Matter	
	23	3.72	-12	-60	40	Precuneus Cortex	
		3.72	-10	-64	44	Precuneus Cortex	
	23	3.78	-34	-54	0	Lingual Gyrus	
		3.69	-38	-58	2	Inferior Temporal Gyrus	
	18	3.84	-46	-62	6	Middle Temporal Gyrus	
		3.34	-42	-72	10	Inferior Lateral Occipital Cortex	
	17	3.93	-38	-20	-10	Planum Polare	
	13	3.80	20	-78	16	Cuneal Cortex	
	13	3.52	8	38	12	Anterior Cingulate Gyrus	
	13	3.69	-34	-46	-30	Left Cerebral Cortex	
	13	3.39	-10	-90	32	Occipital Pole	
		3.23	-12	-88	28	Occipital Pole	
	12	3.42	-32	32	8	Frontal Operculum Cortex	
	10	3.41	-54	-36	2	Posterior Superior Temporal Gyrus	
EAI - Perspective- Taking	Pos	51	3.98	16	-56	-28	Cerebellum Anterior Lobe
			3.61	24	-56	-22	Cerebellum Posterior Lobe
			3.43	24	-52	-28	Cerebellum Anterior Lobe
	45	4.06	-66	-54	4	Middle Temporal Gyrus	
		3.79	-62	-54	0	Middle Temporal Gyrus	
	37	4.23	-48	-46	20	Posterior Supramarginal Gyrus	
	25	3.52	2	-46	26	Posterior Cingulate Gyrus	
		3.28	-2	-54	28	Posterior Cingulate Gyrus	
		3.27	-2	-52	24	Posterior Cingulate Gyrus	
	21	3.89	-10	40	32	Superior Frontal Gyrus	
		3.36	-10	44	26	Paracingulate Gyrus	
	21	3.97	22	28	12	Right Cerebral White Matter	
	20	3.47	-26	-12	58	Precentral Gyrus	

		19	3.56	-40	-32	62	Postcentral Gyrus
		18	3.90	-52	-8	-28	Anterior Middle Temporal Gyrus
		18	3.80	24	-90	38	Occipital Pole
			3.37	24	-84	36	Superior Lateral Occipital Cortex
		16	3.86	-12	-62	42	Precuneus Cortex
		13	3.76	-28	24	-26	Frontal Orbital Cortex
		13	4.22	20	-12	-2	Right Pallidum
		12	3.62	44	26	-10	Frontal Orbital Cortex
		11	3.29	-8	-40	50	Precuneus Cortex
			3.21	-6	-38	58	Postcentral Gyrus
		10	3.69	-18	-76	16	Cuneal Cortex
Daily Support Provision	Pos	896	5.23	40	-66	8	Inferior Lateral Occipital Cortex
			4.66	52	-70	4	Inferior Lateral Occipital Cortex
			4.26	38	-62	18	Superior Lateral Occipital Cortex
			4.23	50	-46	-2	Middle Temporal Gyrus
			4.20	20	-82	22	Superior Lateral Occipital Cortex
			4.06	40	-54	12	Middle Temporal Gyrus
		186	4.17	-50	-78	14	Inferior Lateral Occipital Cortex
			4.13	-46	-62	10	Middle Temporal Gyrus
			3.90	-42	-64	16	Superior Lateral Occipital Cortex
			3.89	-40	-60	12	Middle Temporal Gyrus
			3.27	-56	-68	10	Inferior Lateral Occipital Cortex
			3.20	-56	-64	14	Superior Lateral Occipital Cortex
		98	4.75	-16	-8	58	Superior Frontal Gyrus
		92	4.17	38	-54	62	Superior Parietal Lobule
			4.02	36	-58	62	Superior Lateral Occipital Cortex
			3.62	32	-44	56	Superior Parietal Lobule
			3.53	38	-44	62	Superior Parietal Lobule
			3.35	32	-58	54	Superior Lateral Occipital Cortex
		79	3.72	14	-74	44	Superior Lateral Occipital Cortex
			3.69	6	-76	34	Cuneal Cortex
			3.35	8	-82	48	Superior Lateral Occipital Cortex
		71	3.90	22	-36	-2	Posterior Parahippocampal Gyrus
			3.33	12	-44	0	Posterior Cingulate Gyrus
		65	3.84	-10	-86	20	Cuneal Cortex
			3.46	-16	-80	14	Intracalcarine Cortex
		54	4.06	-6	-28	52	Precentral Gyrus
			3.24	0	-30	42	Posterior Cingulate Gyrus
		54	4.00	66	-32	2	Posterior Superior Temporal Gyrus
		51	3.98	-26	-70	14	Intracalcarine Cortex
			3.61	-24	-66	18	Supracalcarine Cortex

44	4.43	50	-28	52	Postcentral Gyrus
42	4.13	2	-40	56	Precuneus Cortex
	3.27	8	-30	52	Precentral Gyrus
	3.20	6	-34	52	Postcentral Gyrus
41	3.99	-12	-28	34	Posterior Cingulate Gyrus
	3.58	-6	-30	34	Posterior Cingulate Gyrus
40	3.97	-32	-38	4	Left Hippocampus
	3.95	-28	-38	2	Left Hippocampus
40	3.87	6	54	24	Superior Frontal Gyrus
37	4.24	10	48	-8	Paracingulate Gyrus
37	4.31	-48	2	-32	Temporal Pole
36	3.92	28	-70	30	Superior Lateral Occipital Cortex
	3.37	26	-60	18	Supracalcarine Cortex
	3.34	26	-66	22	Supracalcarine Cortex
36	3.70	42	-32	12	Planum Temporale
	3.51	46	-28	12	Planum Temporale
34	4.20	-66	-20	6	Posterior Superior Temporal Gyrus
31	3.66	54	10	26	Precentral Gyrus
30	4.17	-32	-30	22	Parietal Operculum Cortex
30	3.86	8	-42	10	Posterior Cingulate Gyrus
	3.46	8	-40	2	Posterior Cingulate Gyrus
29	3.71	-20	-74	46	Superior Lateral Occipital Cortex
	3.44	-14	-80	48	Superior Lateral Occipital Cortex
28	4.02	14	-72	-16	Lingual Gyrus
28	4.28	-56	-16	-14	Posterior Middle Temporal Gyrus
26	4.00	10	-46	30	Posterior Cingulate Gyrus
	3.35	18	-48	34	Posterior Cingulate Gyrus
25	3.49	20	-44	-18	Temporal Occipital Fusiform Cortex
	3.37	26	-44	-14	Temporal Occipital Fusiform Cortex
25	3.61	-30	-98	0	Occipital Pole
23	4.14	26	26	54	Superior Frontal Gyrus
22	3.99	6	-62	52	Precuneus Cortex
22	4.05	22	26	42	Superior Frontal Gyrus
21	3.72	-26	6	0	Left Putamen
20	3.81	-34	-10	-18	Left Hippocampus
20	3.66	-4	38	4	Anterior Cingulate Gyrus
20	3.64	8	20	0	Right Caudate
19	3.45	26	14	-10	Frontal Orbital Cortex
	3.27	24	4	-12	Frontal Orbital Cortex
18	3.78	-4	-74	-18	Occipital Fusiform Gyrus
16	3.54	-42	-54	-8	Inferior Temporal Gyrus
	3.21	-48	-56	-12	Inferior Temporal Gyrus

			16	3.66	60	-16	-18	Posterior Middle Temporal Gyrus
			16	3.46	24	-64	-6	Lingual Gyrus
			16	3.64	60	6	-8	Anterior Superior Temporal Gyrus
			15	3.61	-56	-4	0	Planum Polare
				3.43	-58	4	-4	Temporal Pole
			15	3.78	38	-36	26	Parietal Operculum Cortex
			15	3.42	-34	-78	12	Superior Lateral Occipital Cortex
			15	3.36	-28	-32	-14	Posterior Parahippocampal Gyrus
			15	3.50	4	-42	70	Postcentral Gyrus
				3.41	4	-38	76	Postcentral Gyrus
			14	3.89	22	52	10	Frontal Pole
			14	3.95	-26	-4	-16	Anterior Parahippocampal Gyrus
			14	3.92	52	-30	38	Anterior Supramarginal Gyrus
			13	3.59	-46	-20	28	Postcentral Gyrus
			13	3.48	-32	-20	-10	Left Hippocampus
			13	3.60	58	-8	-2	Anterior Superior Temporal Gyrus
			12	3.80	-14	28	18	Anterior Cingulate Gyrus
			12	3.49	-34	-50	60	Superior Parietal Lobule
			12	3.52	2	-70	-2	Lingual Gyrus
			11	3.54	2	-30	-16	Brainstem
			11	3.65	-12	-84	36	Superior Lateral Occipital Cortex
			10	3.98	70	-34	16	Posterior Superior Temporal Gyrus
			10	4.16	-14	-22	-24	Anterior Parahippocampal Gyrus
			10	3.39	36	-10	48	Precentral Gyrus
				3.34	38	-8	42	Precentral Gyrus
			10	3.45	42	-52	-22	Temporal Occipital Fusiform Cortex
SPOS _{NEG} -SPOS	EAI - Affective Response	Pos	14	3.90	30	44	44	Frontal Pole
		Neg	12	3.86	-22	30	10	Left Cerebral White Matter
			11	4.03	-6	-8	-16	Left Cerebral White Matter
	EAI - Emotion Regulation	Neg	48	3.76	44	34	-12	Frontal Orbital Cortex
			24	3.51	-40	-64	-8	Inferior Lateral Occipital Cortex
			22	3.81	28	-86	8	Superior Lateral Occipital Cortex
			17	3.84	18	-4	8	Right Pallidum
			14	3.45	-28	-62	-12	Temporal Occipital Fusiform Cortex
			13	3.78	-34	-16	-20	Anterior Parahippocampal Gyrus
			11	3.45	38	-16	-32	Posterior Temporal Fusiform Cortex
				3.35	40	-16	-24	Posterior Temporal Fusiform Cortex

			3.28	38	-16	-28	Posterior Temporal Fusiform Cortex
		11	3.44	6	48	-12	Frontal Medial Cortex
			3.27	6	52	-14	Frontal Medial Cortex
			3.15	10	44	-14	Frontal Medial Cortex
EAI - Perspective-Taking	Pos	18	4.05	2	-46	10	Posterior Cingulate Gyrus
	Neg	14	4.02	12	16	-12	Subcallosal Cortex
Daily Support Provision	Pos	96	3.86	0	-58	50	Precuneus Cortex
			3.70	-8	-56	42	Precuneus Cortex
			3.53	-2	-60	44	Precuneus Cortex
			3.47	0	-66	52	Precuneus Cortex
		59	3.77	-56	-52	16	Angular Gyrus
			3.55	-46	-54	16	Angular Gyrus
		32	3.86	46	-40	12	Posterior Supramarginal Gyrus
		10	3.63	-36	-60	18	Superior Lateral Occipital Cortex
	Neg	11	3.67	-34	-54	-8	Temporal Occipital Fusiform Cortex

Table S8. Comparisons of relationships between BOLD activity and daily support provision

ROI	S _{NEG} P _{POS} -S _{NEG}			P _{POS} -XX			P _{NEG} -XX			S _{NEG} P _{POS} -S _{NEG} vs. P _{POS} -XX		S _{NEG} P _{POS} -S _{NEG} vs. P _{NEG} -XX	
	β	SE	<i>p</i>	β	SE	<i>p</i>	β	SE	<i>p</i>	<i>t</i>	<i>p</i>	<i>t</i>	<i>p</i>
rDMPFC (4, 56, 24)	0.24	0.08	0.005	-0.06	0.09	0.466	-0.02	0.09	0.793	2.54	0.011	2.21	0.027
rTPJ (50, -42, 8)	0.18	0.09	0.040	-0.14	0.08	0.094	-0.04	0.08	0.662	2.66	0.008	1.79	0.074

β : Standardized coefficient.

rTPJ: right temporoparietal junction; rDMPFC: right dorsomedial prefrontal cortex.

Table S9. Correlations between activity in cognitive control regions and activity in affective and cognitive empathy areas

Contrast		Middle Frontal Gyrus (40, 32, 22)	Middle Frontal Gyrus (46, 18, 32)
S _{NEG} P _{POS} -S _{NEG}	Anterior Cingulate Cortex (6, 16, 26)	0.39***	0.34***
	Anterior Insula (40, 18, -8)	0.38***	0.37***
	Medial Prefrontal Cortex (4, 56, 24)	0.28***	0.50***
	Temporoparietal Junction (50, -42, 8)	0.52***	0.50***
	Temporoparietal Junction (50, -50, 18)	0.33***	0.41***
S _{POS} P _{NEG} -S _{POS}	Anterior Cingulate Cortex (6, 16, 26)	0.48***	0.41***
	Anterior Insula (40, 18, -8)	0.40***	0.44***
	Medial Prefrontal Cortex (4, 56, 24)	0.31***	0.45***
	Temporoparietal Junction (50, -42, 8)	0.55***	0.48***
	Temporoparietal Junction (50, -50, 18)	0.47***	0.62***

***: $p < 0.001$.