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It Takes Two to Empathize: Interbrain Coupling Contributes to Distress Regulation

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While extant research on empathy has made significant progress in uncovering the mechanisms underlying the responses of an observer (empathizer) to the distress of another (target), it remains unclear how the interaction between the empathizer and the target contributes to distress regulation in the target. Here, we propose that behavioral and neural coupling during empathic interactions contribute to diminished distress. From November 2020 to November 2022, we recruited 37 pairs of previously unacquainted participants ($N = 74$) from multicultural backgrounds. They engaged in a 5 min face-to-face emotional sharing task, where one participant shared a distressing biographical experience with the other participant. We used functional near-infrared spectroscopy (fNIRS) to measure interbrain coupling in the emotion regulation system, specifically the dorsolateral prefrontal cortex (dlPFC), and the observation execution system, specifically the inferior frontal gyrus (IFG). Results indicate that during emotional sharing the target and the empathizer emotionally converge, such that the empathizer becomes sadder. Moreover, the levels of empathizers' empathy predicted both emotional convergence and target distress relief. The neuroimaging findings indicate that interbrain coupling in the dlPFC, IFG, and premotor cortex, predicted distress relief in the target, and more critically that interbrain coupling in the dlPFC played a mediating role in the relationship between distress relief and the levels of empathy of the empathizer. Considering the role of the dlPFC in emotion regulation, we conclude that interbrain coupling in this region during emotional sharing plays a key role in dyadic coregulation of distress.

Keywords: interbrain coupling, dorsal subdivisions of the prefrontal cortex, inferior frontal gyrus, emotion regulation, empathy

Humans have an inherent inclination to respond to the distress of others (Zaki & Williams, 2013). This is evident during the act of comforting a crying infant or providing support to an emotionally troubled friend. During these moments a significant dyadic interaction unfolds, allowing one individual to relieve the distress of another (Niven, 2017; Reeck et al., 2016; Zaki & Williams, 2013). One of the critical human capacities that may contribute to the ability to regulate the other's emotions is empathy (Lamm & Silani, 2014; Zaki & Williams, 2013). Empathy is a multifaceted construct (Davis, 1983) representing the ability to share the emotional state of others and take their perspective (Shamay-Tsoory, 2011) and may consequently lead to the response of alleviating another's negative emotions. While extensive research has focused on understanding the empathic response of an observer (the empathizer) to the distress of another (the target), there has been comparatively less emphasis on understanding the alleviation of distress of the target in response to an empathic response (Main et al., 2017). Moreover, numerous studies tend to neglect the interpersonal aspect of empathy by isolating it from other concurrent emotional and cognitive processes, such as emotion regulation processes (Main et al., 2017; Zaki et al., 2008). Considering empathy's fundamental and evolutionary purpose of relieving the distress experienced by a suffering target (Decety et al., 2016;

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Reeck et al., 2016; Telle & Pfister, 2016; Zaki, 2020; Zaki & Williams, 2013), there needs to be a shift in research allowing for a more integrative framework of understanding empathy and distress relief together as two tightly interrelated processes (Franklin-Gillette & Shamay-Tsoory, 2021).

To bridge this gap, we sought to investigate whether empathizers can "tune in" and align emotionally and neurally with another during emotional sharing and whether this alignment contributes to distress regulation in the target. To this end we examined the role of interbrain coupling, the coherence of two time series of interacting brains (Nummenmaa et al., 2012), in distress relief during a laboratory modeled empathic interaction. While the relationship between distress relief and empathy through interbrain coupling has not been directly examined before, certain elements within this broader concept, such as face-to-face dialogue (Jiang et al., 2012), pain relief (Goldstein et al., 2018), and shared pain (Peng et al., 2021), have been explored in dyadic neuroimaging studies, suggesting that interbrain coupling in several networks supports various types of connectedness in social interactions. Building on these studies, we propose a model according to which the distress relief of a target is linked to the empathizer's response and facilitated through interbrain coupling in two possible neural systems: (a) observation execution and (b) emotion regulation.

The observation execution system includes the inferior frontal gyrus (IFG), the inferior parietal lobule (Iacoboni et al., 2001; Lestou et al., 2008), as well as the premotor cortex (Wade & Hammond, 2015). These brain regions have been demonstrated to function in a manner where the observation of an action in someone else has the capability to automatically trigger one's own mental representations of that action (Thornton & Knoblich, 2006). Importantly, the observation execution system has been implicated in understanding emotions (Jabbi & Keysers, 2008) beliefs (Rizzolatti & Sinigaglia, 2016) and vicarious pain (Lamm et al., 2011). These characteristics of the observation execution system suggest a significant role in enabling the empathizer to align their emotional state with the target. This emotional alignment between interacting individuals is commonly known as emotional contagion (Dvash & Shamay-Tsoory, 2014), a fundamental aspect of empathy (Shamay-Tsoory, 2011).

Notably, studies using functional near-infrared spectroscopy (fNIRS), demonstrated that interbrain coupling within the IFG, is associated with behaviors that require alignment, such as communication during face-to-face dialogue between partners (Jiang et al., 2012), movement synchronization (Gamliel et al., 2021; Marton-Alper et al., 2023), and synchrony during song learning (Pan et al., 2018). Considering the pivotal role of interbrain coupling within the IFG during alignment, we expect that emotional alignment will be associated with IFG coupling during empathic interactions.

In addition to the emotional alignment, during emotional sharing, individuals engage in the regulation of each other's emotions. This phenomenon is commonly referred to as the social regulation of emotion, involving the deliberate effort of one person (the empathizer) to influence the emotional response of another individual (the target) (Reeck et al., 2016). It was recently suggested that emotion regulation and empathy are related processes involving highly similar executive and internally oriented processes (Morawetz et al., 2022). From a theoretical perspective, both empathy and emotion regulation share the common aim of regulating one's emotional states. This regulation can involve either amplifying or diminishing emotional states by reevaluating the interpretation of one's own emotions or those of others (Thompson et al., 2019). Within the context of emotional sharing, both the target and empathizer may coregulate their emotions through interbrain coupling of their emotion regulation networks. Neuroimaging studies of emotion regulation, particularly those centered on cognitive strategies, have demonstrated that effective regulation is facilitated by prefrontal networks that exert modulation over predominantly subcortical emotion-generating systems (Buhle et al., 2014). Specifically, dorsal subdivisions of the prefrontal cortex (dlPFC; Barbey et al., 2013; Wager & Smith, 2003) are known to play a crucial role in various aspects of emotion regulation (Dörfel et al., 2014; Kohn et al., 2014; Morawetz et al., 2017; Ochsner et al., 2002, Zhao et al., 2021). For example, previous neuroimaging research has shown that the dlPFC is actively engaged in the direct attenuation of distressing emotions and social pain (Nishiyama et al., 2015, Zhao et al., 2021) and is also implicated in the successful implementation of emotion regulation strategies, particularly through cognitive reappraisal during explicit emotion regulation (Goldin et al., 2008). Therefore, successful interbrain coupling of the IFG and dlPFC are expected to contribute to distress regulation during empathic interaction.

The Present Research

While previous research on empathy has made substantial progress in uncovering the underlying mechanisms that govern empathic responses to a distressed target, the specific impact of empathizer–target interactions on distress regulation in the target remains unknown. To examine the coupling of behavioral and neural processes between distressed targets and empathizers, we designed a laboratory modeled empathic interaction where a target shares a sad personal story with a counterpart—the empathizer. In this study, we hypothesize that on the behavioral level, (a) the target and the empathizer will display emotional convergence, resulting in their levels of distress becoming similar during the interaction and that (b) the empathizer's levels of empathy toward the target during the task will predict both the extent of emotional convergence and target distress relief. An exploratory analysis will be conducted to identify the specific type of empathy involved, including personal distress, emotional concern, and perspective taking. On the neural level (c), we hypothesize that interbrain coupling in the dlPFC and IFG will predict target distress relief and (d) that the dlPFC will mediate the interaction between the empathizer's empathy and the distress of the target.

Method

Participants

The sample size was determined through an a priori power analysis performed using G * Power software, Version 3.1 (Faul et al., 2009), and data were not analyzed until data collection was completed. The power analysis was performed for the main hypothesis on the relationship between empathy and distress relief (Hypothesis 2), which was tested with multiple regression analysis. The power analysis used the following parameters: an effect size f^2 of 0.25 (indicating a medium effect size, as reported in studies with social interactions, Ferguson, 2016), an α level of .05, and a desired power of .80. With one predictor in the regression model, the analysis indicated that a total sample size of 34 ($N = 34$ dyads, 68 participants) was required to achieve the desired power level. Thus, the obtained sample size of $N = 37$ was more than adequate to test the study hypothesis.

To account for missing and damaged data we collected data from 45 dyads, from November 2020 to November 2022. Exclusion criteria included psychopathology, medication use, or health concerns. Two dyads were excluded from the experiment due to health concerns, and six more dyads were further excluded from the analysis due to fNIRS data acquisition difficulties and poor signal quality, leaving a final sample of 37 dyads (28 pairs of females, mean age: 24.0 8 ± 3.83, age range: 18–38). Participants, which included a multicultural sample (28 Hebrew-speaking dyads and nine Arabic-speaking dyads), were assigned to unacquainted same-sex, same-handedness, and same-native tongue pairs to reduce the effects of interpersonal variation. All participants provided written informed consent and were compensated for their participation. The study was granted ethical approval by the University of Haifa Ethics Committee (ethics approval number #4,567,476) and was performed in accordance with the Declaration of Helsinki. Data from this study are available upon direct request by contacting the corresponding authors.

Procedure

Prior to the Day of the Experiment

Participants were recruited using ads posted via the internet and around the university campus. Before the experiment, participants underwent screening for exclusion criteria and were asked in an online research platform, Qualtrics (2005; https://www.qualtrics.com), to write about a biographical event from their recent past that they still perceive as sad, distressing, and eliciting negative emotions.

To confirm that the distressing event produced negative affect, participants completed the Positive Affect Negative Affect Schedule (PANAS; Watson et al., 1988) before and after writing the distressing event. Only participants who demonstrated an increase in the PANAS negative affect subscale after describing the distressing event were recruited to the study. Participants were also requested to provide a description of a biographical neutral event outlining the sequence of events in their typical daily routine. This neutral event functioned as a control for the distressing event that was shared on the day of the experiment.

Examples of Distressing Events

The distressing events participants shared covered a large range of topics such as the difficult relationship with parents, romantic breakups, conflicts with roommates, coping with the passing of a loved one, failing in school, unresolved conflicts with siblings and friends, and coping with medical conditions. An example of a real-life distressing event shared by a target:

> After 4 months together, my girlfriend left. I was deeply in love. … Our connection was intellectual and unimaginable. The same day we broke-up, she began dating a friend from my company. … I plunged into severe depression, struggling to recover and function.

Dyad Formation and Role Assignment

To ensure unbiased interaction dynamics, participants were randomly assigned to either the "target" role, sharing personal events on the day of the experiment, or the "empathizer" role, listening to the target's personal events on the day of the experiment. The randomization process considered sex and native language (either Arabic or Hebrew). Each dyad was permitted to perform the sharing tasks in their native language to enable fluent and natural discussions. Current literature suggests that both sex (Mu et al., 2016) and linguistic background (Feng et al., 2023) may influence the dynamics of interbrain coupling, hence their consideration in dyad formation. Age was not considered a variable for matching due to the lack of empirical evidence linking it to variations in interbrain coupling.

On the Day of the Experiment

Upon arrival, participants were fitted with the Brite-24 fNIRS system (Artinis Medical Systems, Elst, Netherlands) for continuous brain activity recording. Due to the COVID-19 regulations, a transparent glass divider was placed between the targets and empathizers, allowing them to interact freely without needing to wear a face mask during the emotional and neutral sharing tasks (Figure 1).

Participants sat across from one another at approximately 150 cm.

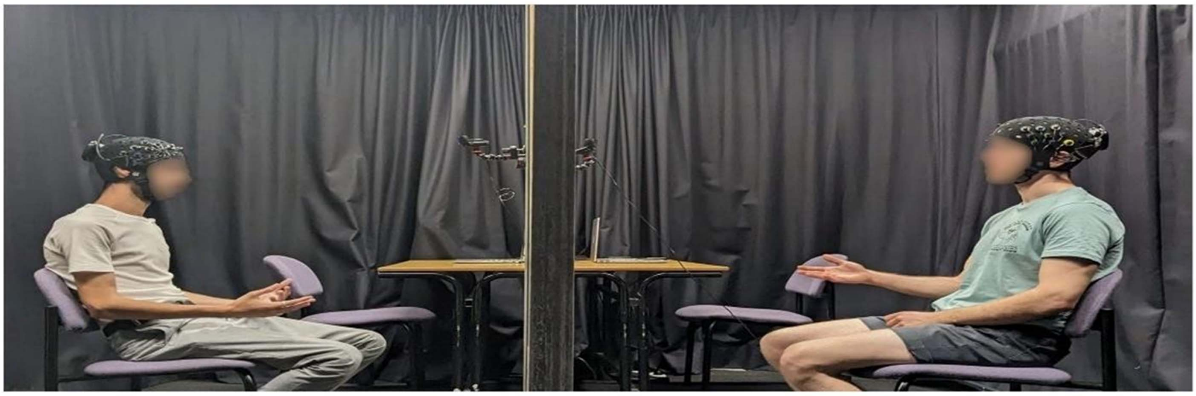
Considering that paired targets and empathizers were unfamiliar with each other, they were instructed to engage in a 5-min acquaintance conversation before the sharing tasks, aiming to foster a more natural interaction and connection. Emotional state was assessed (PANAS and sadness levels) prior to the sharing tasks.

Emotional Sharing Task: (1) Recalling the Distressing Event. Following the 5-min acquaintance conversation, participants assigned to the role of the target were presented on a computer screen with the text of their personal distressing event which they previously shared in the online section of the study. To ensure full engagement with the event, targets were instructed to read the event silently and then write down their reflections. For procedure standardization purposes, participants assigned to the role of the empathizer, engaged with their personal neutral events they had previously shared in the online section of the study during this time. Sadness levels and negative affect of targets and empathizers were measured after engaging with the events.

Emotional Sharing Task: (2) Sharing the Distressing Event. After targets engaged with their distressing event, the experimenter asked them to share a detailed description of their distressing event with the empathizer, including both their thoughts and emotions. The empathizer was encouraged to be attentive and engaged during this sharing process. During the 5-min sharing, there was continuous fNIRS recording. Following the emotional sharing task, both targets and empathizers reported their sadness levels and negative affect with the negative affect scale, PANAS. In addition, empathizers were specifically asked about their empathy levels (i.e., state personal distress, state emotional concern, and state perspective taking) during the emotional sharing task.

Neutral Sharing Task. A neutral sharing task was included in the study to serve as a control to the emotional sharing task. The neutral sharing task procedure mirrored that of the emotional sharing task, with the only difference being that the target recalled, engaged,

Figure 1
Illustration of Participants During the Sharing Tasks



Note. Targets and empathizers were positioned facing each other during the sharing tasks, undergoing continuous real-time fNIRS scanning. Participants in this figure provided full consent for the use of their images for publication purposes. fNIRS = functional near-infrared spectroscopy. See the online article for the color version of this figure.

and shared his/her neutral content event, detailing his/her typical day's routine. The order of the tasks was counterbalanced between dyads. The tasks were separated by a 5-min distraction task to minimize potential carryover effects (Figure 2).

Measures

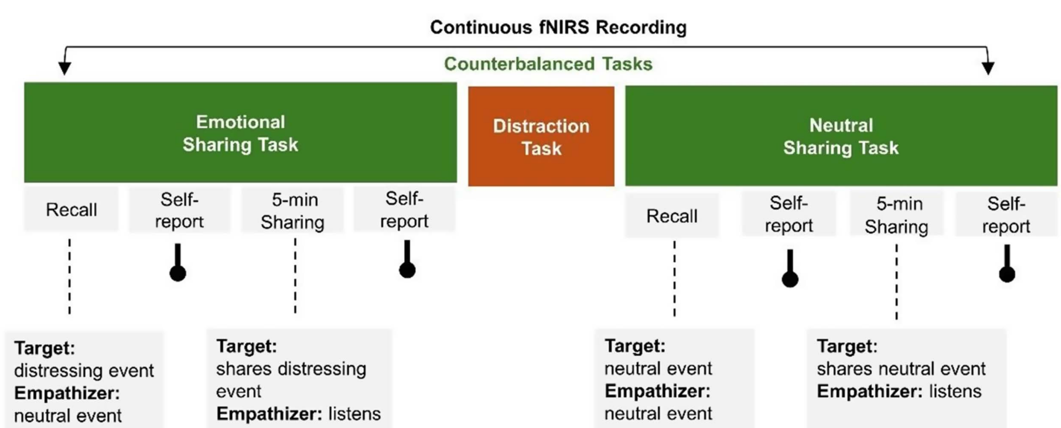
Distraction Task

An object characteristics task was introduced between the emotional and neutral sharing tasks to prevent potential carryover effects. During this task, targets and empathizers were given 5-min to jot down physical characteristics of common objects (Fink et al., 2010; Lu et al., 2021).

Assessment of Emotional State

Targets and empathizers reported their sadness levels and overall negative affect in their respective native tongues (Hebrew or Arabic) both pre- and postsharing tasks. Our focus on measuring sadness levels, using a continuous 5-point Likert scale ranging from 1 (*not at all*) to 5 (*to a very high degree*) was intentional, aligning with our

Figure 2
Illustration of the Emotional and Neutral Sharing Tasks



Note. The experiment included emotional and neutral sharing tasks, in counterbalanced order. During the emotional sharing task, targets recalled and shared their personal distressing events, while in the neutral task, they recalled and shared their daily routine neutral event. Empathizers actively listened throughout both tasks. Self-report measures included the negative affect subscale of PANAS and sadness levels. Specifically postemotional sharing, empathizers reported their state empathy levels (personal distress, emotional concern, perspective taking). Brain activity was continuously recorded with fNIRS. Participant role is presented in bold. fNIRS = functional near-infrared spectroscopy; PANAS = Positive Affect Negative Affect Schedule. See the online article for the color version of this figure.

primary goal of eliciting sadness during the emotional sharing task. Furthermore, to affirm that the emotional sharing task effectively induced a broader negative emotional state, we utilized the Negative Affect Scale from the PANAS. The PANAS is a well-validated self-report questionnaire comprising of 20 emotions divided into two dispositional dimensions: Negative Affect (NA) and Positive Affect (PA). The NA scale includes the following 10 items: distressed, upset, guilty, ashamed, hostile, irritable, nervous, jittery, scared, and afraid. Each emotion is graded on a 5-point Likert scale, expressing the extent of which this feeling is being experienced, ranging from 1 (*not at all*) to 5 (*to a very high degree*). The PANAS exhibits robust internal consistency reliability with Cronbach's α ranging from .84 to .87 for Negative Affect, as it also shows strong construct and convergent validity (Crawford & Henry, 2004). In our study, the items of the NA subscale also showed high internal consistency (α = .82; based on the first PANAS measurement prior to any engagement with sharing tasks).

Assessment of State Empathy

To explore the role of empathy during the emotional sharing task, we asked empathizers to report their empathy levels after hearing the target's sad story. Given that empathy is a multifaceted construct, it was important to examine empathy during the emotional sharing task in a similar manner as presented in the Interpersonal Reactivity Index (IRI; Davis, 1983). While the IRI qualifies trait empathy into four different subscales (personal distress, emotional concern, personal distress, and fantasy) it was essential for the purpose of our experiment to qualify state empathy, recognizing potential differences between trait and state (Batson et al., 1987).

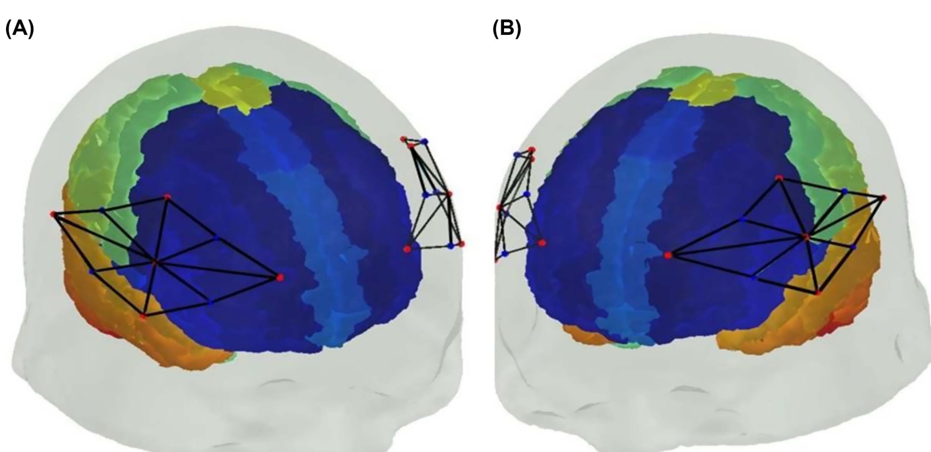
The adaptation procedure of empathy items from trait to state included taking 25 items from all four subscales of the original IRI and adapting them specifically to an online empathy task showing colored pictures of hands and feet in painful scenarios (task images adapted from Naor et al., 2020).

After the presentation of the painful pictures, 32 healthy participants were asked to rate on a scale of 1–5 their state empathy levels during the task. The internal consistency of the items within each subscale were examined with Cronbach's α. Results showed high internal consistency between the items in each subscale: State Fantasy subscale (α = .81), State Emotional Concern subscale (α = .81), State Personal Distress subscale (α = .84), and Moderately High internal consistency between the items in the state perspective taking scale (α = .75). Due to the high internal consistency observed in the state IRI items across all subscales, we opted to choose one item from the subscales for the emotional sharing task. The fantasy subscale was excluded from our task as it lacked direct applicability to real-time conversational contexts. These are the state IRI items presented to the empathizers after the emotional sharing task: (a) "While listening to my partner, I felt apprehensive and ill-at-ease" (adapted from the personal distress scale); (b) "While listening to my partner share his/her story, I had tender and concerned feelings for him/her" (adapted from the empathic concern scale); (c) "While listening to my partner, I felt that I understood my partner's thoughts and feelings" (adapted from the perspective taking scale).

Neural Measure

Neural Signal Acquisition. Brain activity was measured with the Brite-24 fNIRS system using Artinis Medical Systems' OxySoft software, Version 3.4.12.5. The optode montage covered bilateral prefrontal cortical areas with a total of 24 channels, including five transmitters and four detectors on each hemisphere (Figure 3). The optode placement followed the international 10–20 system anchor

Figure 3
Placement Against Anatomical Brain Areas



Note. All available channels, right-side view (A); all available channels, left-side view (B); channels (marked as black lines) are formed between transmitters (light/red dots), and adjacent receivers (dark/blue dots). Channels cover six anatomical regions of interest: left inferior frontal gyrus (IFG), right IFG, left dorsolateral prefrontal cortex (dlPFC), right dlPFC, left premotor area and right premotor area. See the online article for the color version of this figure.

points, inion, nasion, top center (Cz), and left and right tragus, and confirmation of alignment with the 1,020 system was conducted using a Polhemus Patriot 3D Digitizer (Polhemus, Colchester, Vermont, United States). The fNIRS placement was adjusted for different head sizes by fitting each participant with a suitable cap determined by their head diameter and adherence to the 10–20 system criteria (Khazi et al., 2012). Montreal Neurological Institute coordinates for each optode and channel are provided (see Tables A1–A2). Transmitters emitted light at two wavelengths in the near-infrared spectrum, 760 nm and 850 nm, while each adjacent detector measured their reflectance. To maximize the transmission of light through the scalp, a lighted probe was used to remove hair underneath each optode. Data were sampled at a rate of 50 samples per second and the OxySoft software adjusted raw signals, accounting for the participant's bone density, calculated based on their age.

Signal Preprocessing. The light absorption levels for each of the two wavelengths (760 nm and 850 nm) in every available channel were transformed into concentration changes for oxyhemoglobin (O2Hb), deoxyhemoglobin (HHb), and their sum, using the modified Beer–Lambert equation (Cope et al., 1988). In the present study, we focused on measured changes in brain activity using the oxyhemoglobin (O2Hb) signal, as it was found to be more accurate and sensitive to changes in blood flow in fNIRS research (Hoshi, 2007). Signal preprocessing was conducted with Homer3 software (Huppert et al., 2009) using Matlab *R*2023a (The MathWorks Inc, 2022). The preprocessing steps undertaken are described as follows: (1) All fNIRS channels were manually inspected with the Homer3 software for the presence of heartbeat (~1 Hz). Channels in which no heartbeat was detected were excluded from further analyses. (2) Raw intensity values were converted to optical density (OD) using the modified Beer–Lambert law. (3) Motion artifacts were removed using two methods: (a) using standard deviation (*SD*) and amplitude change thresholding over 0.5 s windows and (b) using a spline correction method to remove motion-induced spikes in the signal. (4) A bandpass filter (hpf = 0.01 Hz.; lpf = 0.5 Hz.) was applied to the signal to remove artifacts related to cardiovascular and pulmonary activity. (5) The OD values were converted to O2Hb and HHb concentration values for further analysis.

Anatomical Regions of Interest. Anatomical regions of interest (ROIs) were selected, comprising six areas: left IFG, right IFG, left dorsolateral prefrontal cortex (dlPFC), right dlPFC, left premotor area, and right premotor area. Concentration values of preprocessed O2Hb from fNIRS channels covering each ROI were averaged per participant, excluding channels with no detected heartbeat, creating a singular data vector per ROI per participant.

Interbrain Coupling Analysis. We performed wavelet transform coherence (WTC) analysis, using the WTC toolbox for Matlab (Grinsted et al., 2004) to assess interbrain coupling (i.e., brain synchrony). WTC values of O2Hb concentration vectors were obtained, using a Morlet wavelet, the mother wavelet function. This Morlet function was constructed for wavelengths in the range of 6–66 s (~0.015 Hz–~0.1666 Hz), following the expected time-range of the blood oxygenation level dependent signals, as part of the hemodynamic response function (Müller et al., 2004). WTC was calculated between data vectors representing each ROI of the target and those representing each ROI of the empathizer. Overall, we analyzed 36 ROI combinations for each dyad, including both homologous and nonhomologous regions. The resultant WTC matrices were separated into epochs, representing the time course of each experimental task. The resultant segments were averaged across the selected wavelengths, which allowed us to produce a single numeric value representing the mean coherence value in each condition for each ROI combination.

Statistical Analysis

Behavioral Data Analyses

Data pertaining to self-reported emotional states (sadness levels and negative affect) during the emotional and neutral sharing tasks were analyzed with linear mixed effects (LME) models using the R language Version 4.2.3 (Baayen et al., 2008), and the lme4 package (Bates et al., 2007) which allows testing for interaction effects between two or more fixed factors while accounting for the dependency between related observations. Beyond this, we performed exploratory regression analyses to assess which specific type of state empathy (emotional concern, perspective taking, and personal distress) contributes to emotional convergence and target distress relief during the emotional sharing task. All comparisons were Bonferroni corrected for multiple comparisons. For some of these analyses, IBM SPSS Version 27.0 was used.

Furthermore, to quantify dyadic emotional convergence into a single score, we calculated the change in dyadic sadness levels from presharing ($t1$) to postsharing ($t2$):

$$\Delta 1 = (\text{Target's sadness levels at} t1) - (\text{Empathizer's sadness levels} at t1), \quad (1)$$

$$\Delta 2 = (\text{Target's sadness levels at} t2) - (\text{Empathizer's sadness levels at} t2), \quad (2)$$

$$|\Delta 1| - |\Delta 2| = \text{emotional convergence score}. \quad (3)$$

The emotional convergence score of each dyad indicated the extent to which empathizers and their targets jointly shift toward each other's emotional state throughout the sharing.

Neural Data Analyses

WTC data were also analyzed using LME models. For analysis purposes, we generated a set of dyad pseudopairings to test whether interbrain coupling in the real-dyads was significantly above chance level. For this, we created a group of 37 pseudodyads by randomly pairing participants who did not interact with each other in our experiment. Pseudopairs consisted of a real target matched with a random empathizer from another dyad. The calculated WTC values for pseudodyads served as an initial examination confirming that observed effects of interbrain coupling were not an artifact of the fact that individuals were performing a similar task. Multiple linear regression analysis was further utilized to assess which of the ROI interbrain coupling combinations predict target distress relief. Finally, we carried out a mediation analysis to examine whether interbrain coupling mediates the relationship between empathy and distress relief.

Transparency and Openness

The present study reports on sample size determination, recruitment, exclusionary criteria, data analyses, data exclusion due to missing data or exclusion criteria, and all measures collected in the study following the Journal Article Reporting Standards (Kazak, 2018). Research materials obtained during the present study are not available via a repository, as most of our data contains sensitive and identifiable information (e.g., personal and biographical distressed events). However, all data, analysis codes, and other study materials are available upon request for research purposes.

Experimental designs and data analysis plans were not preregistered.

Results

Behavioral Results

Manipulation Check: Self-Reported Negative Affect

We used LMEs modeling to analyze negative affect levels among study participants. The LME model considered self-reported negative affect (Negative Affect subscale, PANAS) as the dependent variable, incorporating fixed factors such as role (target, empathizer), time of measurement (presharing: event recall, postsharing), and condition (neutral sharing task, emotional sharing task). In addition, the dyads' assigned couple number was treated as a random factor.

We constructed three versions of the LME model, each one incrementally increasing in complexity. This hierarchical approach allowed us to assess the impact of each level of complexity on the explanatory power of the model. The first LME model examined only the main effects of fixed factors (one-way); the second LME model incorporated interactions of up to two levels (two-way); and the third LME model considered potential interactions among all fixed factors (three-way).

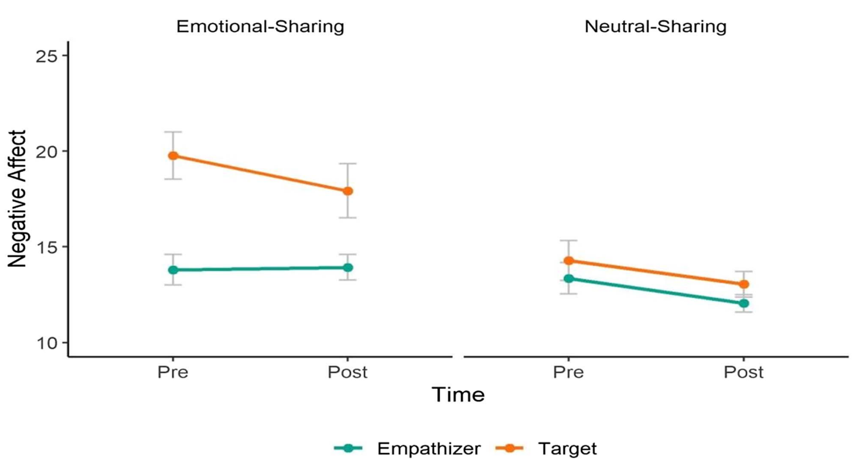
LME model comparison, evaluated through Type II Wald χ^2 tests, revealed that the second LME model (two-way) demonstrated significantly enhanced predictive power compared to the first LME model, $\chi^2(3) = 18.83$; $p < .001$; $\chi^2(3) = 12.63$; $p < .01$, whereas the third LME model did not provide significantly better predictions, as compared to the second, $\chi^2(1) = 0.79$; *n.s.* The second model was therefore used in further analyses.

The selected LME model revealed a significant main effect for role, $F(1, 253) = 25.97$, $p < .0001$, $\eta_p^2 = 0.09$, due to overall higher NA levels among targets (M = 16.26, SD = 7.3) compared to empathizers (M = 13.28, SD = 4.28). There was also a main effect for condition, $F(1, 253) = 29.63$, $p < .0001$, $\eta_p^2 = 0.1$, with overall higher NA levels in the emotional sharing task (M = 16.36, SD = 6.97) compared the neutral sharing task (M = 13.18, SD = 4.74). Since the LME model also showed a significant interaction between condition and role, $F(1, 253) = 11.87$, $p < .001$, $\eta_p^2 = 0.04$, pairwise comparisons with Bonferroni correction were carried out. The analysis revealed significantly increased NA levels among targets in the emotional sharing task (M = 18.85, SD = 8.08) in comparison to the neutral sharing task (M = 13.66, SD = 5.32), $\chi^2(1) = 39.5$; $p <$ .0001, further confirming the manipulation of our emotional sharing task in inducing negative affect. There were no significant differences between conditions among empathizers, $\chi^2(1) = 2$; *n.s.*; Figure 4).

Manipulation Check: Self-Reported Sadness Levels

We further utilized the same LME modeling method described above for negative affect assessment to assess sadness levels. Sadness levels were used as the dependent variable, with fixed and random factors consistent with those in the LME model for negative

Figure 4
Levels of Negative Affect



Note. The means and standard errors of negative affect levels (as measured by the Negative Affect subscale of the Positive Affect Negative Affect Schedule [PANAS]) for both targets and empathizers are presented at presharing and postsharing time points across each sharing task. Negative affect levels were significantly higher in the emotional sharing task compared to the neutral sharing task among targets. See the online article for the color version of this figure.

affect. Following a similar hierarchical approach, we developed three versions of this LME model, each increasing in complexity.

To select the LME model that demonstrated enhanced predictive power, we compared the three models with Type II Wald χ^2 tests, revealing that the second model (two-way) demonstrated significantly enhanced predictive power compared to the first model, $\chi^2(3) = 18.83$; $p < .001$. As the third model did not yield significantly improved predictions over the second model, $\chi^2(1) = 1.89$; *n.s.*, the second model was selected for subsequent analysis.

The LME model revealed a significant main effect for role, $F(1, 252) = 18.32$, $p < .0001$, $\eta_p^2 = 0.07$, with overall higher sadness levels among targets ($M = 1.98$, $SD = 1.18$) compared to empathizers ($M = 1.51$, $SD = 0.92$). The analysis also revealed a main effect for condition, $F(1, 252) = 46.41$, $p < .0001$, $\eta_p^2 = 0.16$, with overall higher sadness levels in the emotional sharing condition ($M = 2.11$, $SD = 1.19$) compared to the neutral sharing condition ($M = 1.37$, $SD = 0.8$). Furthermore, there was a significant interaction between role and time, $F(1, 252) = 6.32$, $p < .05$, $\eta_p^2 = 0.02$, and between condition and role, $F(1, 252) = 9.53$, $p < .01$, $\eta_p^2 = 0.04$.

To further understand the significant interaction between condition and role, pairwise comparisons with Bonferroni correction revealed increased sadness levels among targets in the emotional sharing condition ($M = 2.52$, $SD = 1.22$) in comparison to the neutral sharing condition ($M = 1.44$, $SD = 0.86$), $\chi^2(1) = 49.17$, $p < .0001$. This outcome demonstrates the validation of the task manipulation, as engaging with distressing biographical events led to an increase in sadness levels among the targets. Interestingly, empathizers also showed increased sadness levels in the emotional sharing condition ($M = 1.72$, $SD = 1.04$) in comparison to the neutral sharing condition ($M = 1.31$, $SD = 0.74$), $\chi^2(1) = 6.91$, $p < .05$.

Considering that dyads consisted exclusively of either males or females and performed sharing tasks in a counterbalanced order, dyad sex and order of condition completion were incorporated as additional fixed factors in the LME models. This was done to assess their potential impact on sadness levels and negative affect. Main effects were found nonsignificant in the LME model predicting sadness levels, *sex:* $F(1, 34) = 0.23$; *n.s.*, *order:* $F(1, 34) = 0.22$; *n.s.*, and NA levels, *sex:* $F(1, 34) = 1.37$; *n.s.*, *order:* $F(1, 34) = 1.23$; *n.s.* Therefore, dyad sex and order of condition completion were not included in the final LME models depicted above.

Emotional Convergence

To explore our first hypothesis, whether the sadness levels of interacting targets and empathizers converged during the emotional sharing task, we utilized the third LME model described above, which considers all potential interactions among fixed factors (three-way). Sadness levels served as the dependent variable and all the fixed and random factors were the same. The model revealed a significant main effect for role, $F(1, 252) = 18.42$, $p < .0001$, $\eta_p^2 = 0.07$, and condition, $F(1, 252) = 46.62$, $p < .0001$, $\eta_p^2 = 0.16$, a significant interaction between role and time, $F(1, 252) = 6.31$, $p < .05$, $\eta_p^2 = 0.02$, and between condition and role, $F(1, 252) = 9.53$, $p < .01$, $\eta_p^2 = 0.04$.

To assess the similarity of sadness levels both before ($\Delta 1$) and after ($\Delta 2$) the emotional/neutral sharing between targets and their empathizers, we conducted further analyses using pairwise comparisons with Bonferroni correction. In the emotional sharing task, findings showed that $\Delta 1$ gaps between empathizers ($M = 1.44$, $SD = 0.85$) and their targets ($M = 2.66$, $SD = 1.19$) were found significantly different, $\chi^2(1) = 31.75$; $p < .001$, whereas $\Delta 2$ gaps between empathizers ($M = 1.99$, $SD = 1.14$) and their targets ($M = 2.37$, $SD = 1.25$) were not found significantly different, $\chi^2(1) = 3.09$; *n.s.*, suggesting that targets and empathizers experienced emotional convergence during the emotional sharing task (Figure 5). Further analysis of the dynamics underlying the convergence of sadness levels showed that for empathizers, there was a significant increase in their sadness levels from presharing to postsharing, $\chi^2(1) = 6.46$; $p < .05$, (Figure 5), while no significant differences were found among targets, $\chi^2(1) = 1.78$, *n.s.*

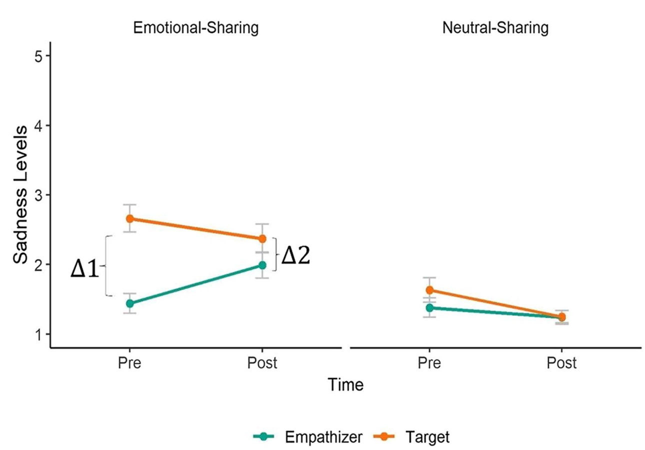
In the neutral sharing task, $\Delta 1$ gaps between empathizers ($M = 1.38$, $SD = 0.84$) and their targets ($M = 1.63$, $SD = 1.1$) were not found significantly different, $\chi^2(1) = 1.4$; *n.s.*, as well as $\Delta 2$ gaps between empathizers ($M = 1.24$, $SD = 0.61$) and their targets ($M = 1.25$, $SD = 0.54$), $\chi^2(1) = 0.0006$; *n.s.* Further analysis revealed that empathizers showed no significant changes in their sadness levels between presharing and postsharing, $\chi^2(1) = 0.39$, *n.s.*, and neither did targets, $\chi^2(1) = 3.18$; *n.s.* These findings suggest that targets and empathizers did not experience emotional convergence during the neutral sharing task.

Empathy and Distress Regulation During Emotional Sharing Task

To examine the relationship between empathy and distress relief, we conducted an exploratory stepwise regression analysis, including the three items of state empathy. These items served as possible predictors of the sadness levels among targets postsharing. Only the

Figure 5

Emotional Convergence in Sadness Levels



Note. The means and standard errors of sadness levels for targets and empathizers in each of the sharing tasks are displayed. Sadness levels were significantly higher in the emotional sharing task compared to the neutral sharing task among targets and empathizers. In the emotional sharing task, initial $\Delta 1$ gaps were found significantly different between targets and empathizers, while $\Delta 2$ gaps were not found significantly different, supporting the emergence of emotional convergence. In the emotional sharing task, empathizers showed a significant increase in sadness levels from presharing to postsharing. See the online article for the color version of this figure.

regression model including the perspective taking item ($\beta = -0.42$; $t = -2.71$) as a predictor was found statistically significant, accounting for 17.3% of the variance in the sadness levels, $F(1, 35) = 7.33$, $p = .01$, Adj $R^2 = 0.15$, (Figure 6). This result indicates that greater levels of empathy displayed by the empathizers corresponded to lower postsharing levels of sadness among the targets.

Furthermore, to examine the relationship between empathy and emotional convergence during the emotional sharing task, an exploratory stepwise regression analysis was carried out. Dyads' emotional convergence score was the dependent variable and the three state empathy items' (personal distress, perspective taking, emotional concern) scores served as possible predictors. A statistically significant regression model that accounted for 13.12% of the variance in dyads' emotional convergence, $F(1, 35) = 5.28$, $p = .028$, Adj $R^2 = 0.11$, revealed that the personal distress item ($\beta = 0.36$; $t = 2.3$) significantly predicted the levels of emotional convergence (see Figure 7).

Interbrain Coupling Results

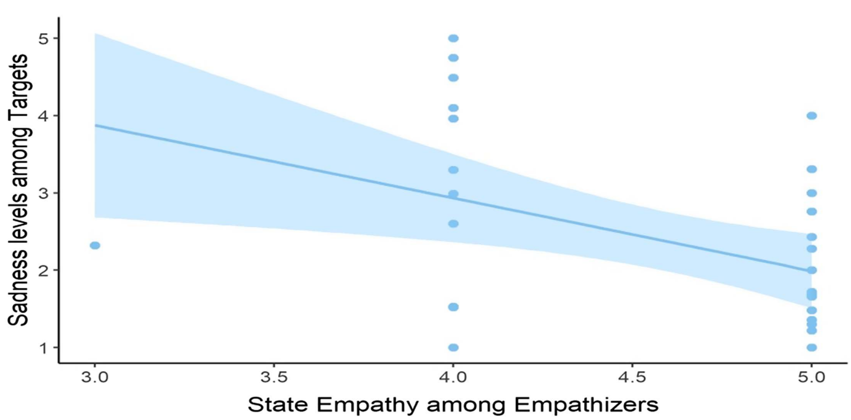
Real-Dyads and Pseudodyads

To examine whether participants exhibit differences in interbrain coupling when assigned to a real-dyad as compared to a pseudodyad, we employed an LME model, which included group assignment (pseudo/real), condition (emotional sharing/neutral sharing), and ROI combinations as fixed factors, dyad's couple number served as a random factor, and coherence (WTC) values as a dependent measure. We constructed three versions of this model, in increasing order of complexity: The first analyzed only the main effects of the fixed factors (one-way); the second added interactions of up to two levels (two-way); the third also included a possible interaction between all the fixed factors (three-way). The models were compared using Type II Wald χ^2 comparison tests and showed that the second model yielded a significantly greater predictive power than the first model, $\chi^2(71) = 112.88$; $p < .01$, whereas the third model did not provide a significantly better predictions, as compared to the second, $\chi^2(35) = 46.36$; *n.s.* Analysis of the second model revealed a significant main effect of the group assignment, $F(1, 76) = 11.45$, $p < .01$, $\eta_p^2 = 0.13$, due to overall higher interbrain coupling values among Real-dyads ($M = 0.33$, $SD = 0.04$) compared to pseudodyads ($M = 0.31$, $SD = 0.04$). The analysis also yielded a significant interaction between group assignment and ROI, $F(35, 14068) = 2.25$, $p < .0001$, $\eta_p^2 = 0.005$. Further analyses revealed 12 ROI combinations of target-empathizer coupling which significantly differed between real-dyads and pseudodyads across the conditions (for detailed comparisons see Table A3). All comparisons were corrected with the false discovery rate correction for multiple comparisons. Note that in each coupling combination, the first ROI represents the target, and the second ROI represents the empathizer (see Figure 8).

Interbrain Coupling and Distress Relief

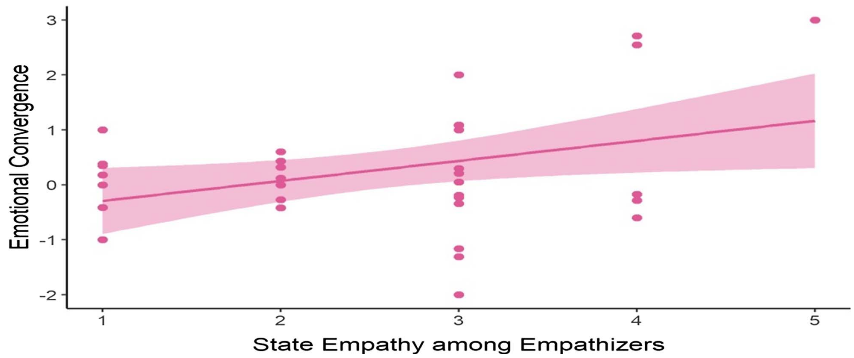
As indicated above, 12 interbrain coupling combinations showed a significant difference in the coherence values between real-dyads and pseudodyads. Only real ROI combinations that were found to be significantly different from pseudo were used in further analyses. To assess which of these 12 ROI interbrain coupling combinations may predict changes in the sadness levels of the targets, we conducted a multiple regression analysis. The regression analysis included sadness levels among targets (postsharing) as the predicted variable, and the WTC values of the 12 ROI interbrain coupling combinations, taken during the emotional sharing task, as the possible predictors. The regression model was found to be significant, $F(12, 22) = 2.94$, $p = .01$, Adj $R^2 = 0.407$, and accounted for 61.62% percent of the variance in the sadness levels. The coherence levels in six of the interbrain coupling combinations were found to be significant predictors of the sadness levels among targets. The significant predictors are as follows: L. dlPFC-R. dlPFC coupling ($\beta = -0.668$;

Figure 6
Empathy as Predictor of Sadness Levels



Note. Higher levels of state empathy, specifically perspective taking, exhibited by empathizers during the emotional sharing task were associated with reduced sadness levels among targets after sharing. While participants could rate their state empathy for perspective taking (x-axis) on a scale from 1 to 5, participants' ratings fell exclusively between 3 and 5 ($M = 4.59$, $SD = 0.551$). See the online article for the color version of this figure.

Figure 7
Empathy as Predictor of Emotional Convergence



Note. Elevated levels of state empathy among empathizers, particularly personal distress, during the emotional sharing task predicted higher emotional convergence in sadness levels within dyads. See the online article for the color version of this figure.

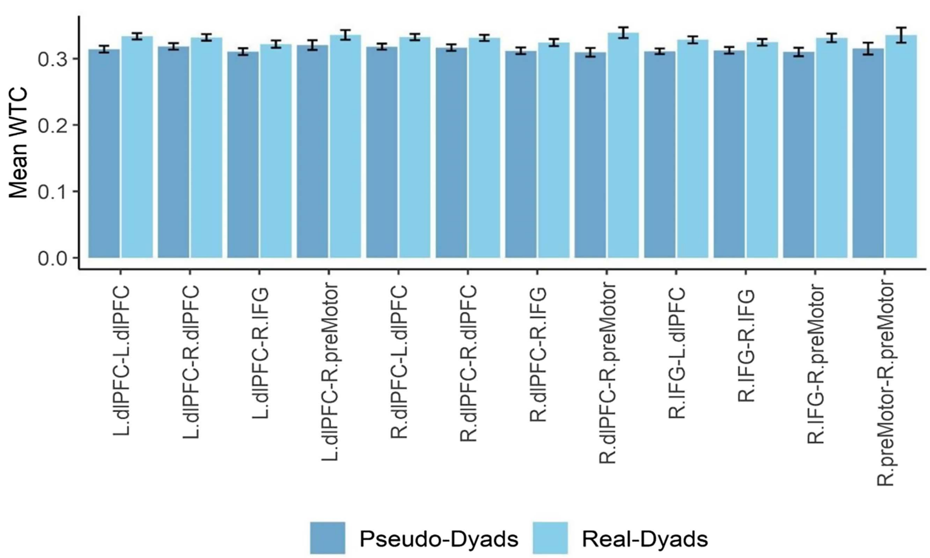
$t = -2.65$; $p = .014$), L. dlPFC-R. premotor coupling ($\beta = 0.855$; $t = 3.21$; $p = .004$), R. dlPFC-R. IFG coupling ($\beta = 0.701$; $t = 2.95$; $p = .007$), R. dlPFC-R. premotor coupling ($\beta = -0.868$; $t = -3.7$; $p = .001$), R. IFG- R. IFG coupling ($\beta = -0.47$; $t = -2.27$; $p = .033$), R. IFG- R. premotor coupling ($\beta = -0.449$; $t = -2.14$; $p = .044$).

Mediation Analysis

Based on the supportive evidence indicating a negative correlation between perspective taking (empathizers) and sadness levels (targets), and the association between dlPFC coupling (particularly, L. dlPFC-R. dlPFC) and targets' sadness levels, we proceeded to investigate the dlPFC as a potential mediator between empathy and sadness levels. We integrated these results into a mediation analysis with a bootstrapping method where dlPFC coupling served as the mediator between the independent variable of state empathy score among empathizers and sadness levels among targets after sharing.

The results indicated that the effect of empathy among empathizers on the sadness levels of the targets was partially mediated by the coherence levels in the L. dlPFC-R. dlPFC during the sharing task. As Figure 9 illustrates, the total effect of empathizers' empathy on

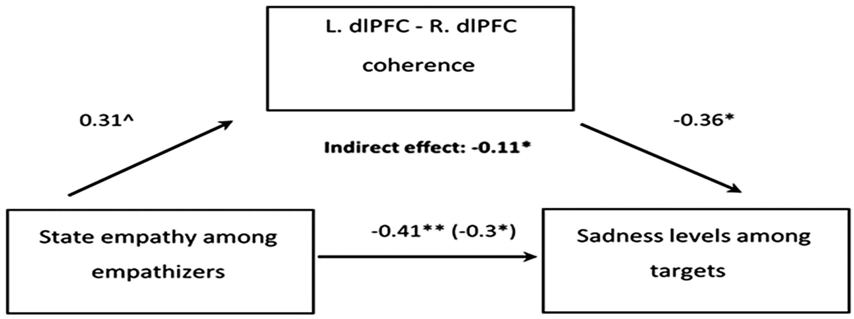
Figure 8
Twelve ROI Combinations Differ Between Real-Dyads and Pseudodyads



Note. WTC means and standard deviation values of the significantly different ROI combinations between real-dyads (light) and pseudodyads (dark). The first ROI represents the target, and the second ROI represents the empathizer. ROI = regions of interest; WTC = wavelet transform coherence; R.dlPFC = right dorsolateral prefrontal cortex; L.dlPFC = left dorsolateral prefrontal cortex; R.IFG = right inferior frontal gyrus. See the online article for the color version of this figure.

Figure 9

A Mediation Model: The dlPFC as a Mediator in the Relationship Between Empathy and Distress Relief



Note. This is a structural mediation model depicting how the association between empathizers' state empathy, particularly in the form of perspective taking, during the emotional sharing, and targets' sadness levels after the emotional sharing, is partially mediated by L.dlPFC-R.dlPFC coupling during the emotional sharing. Coefficient values are standardized. In parentheses are the standardized coefficients between empathy and sadness levels, controlling for the interbrain coupling. dlPFC = dorsolateral prefrontal cortex; R.dlPFC = right dorsolateral prefrontal cortex; L.dlPFC = left dorsolateral prefrontal cortex.
Marginally significant ^ p = .06. * p < .05. ** p < .01.

the targets' sadness levels ($b = -0.41$, $p < .01$; 95% CI [−0.83, −0.12]) was still significant when L. dlPFC-R. dlPFC coupling was added to the equation ($b = -0.3$, $p < .05$; 95% CI [−0.72, −0.02]). The indirect effect of empathizers' empathy on the targets' sadness levels was significant ($b = -0.11$, $p < .05$; 95% CI [0.31, −0.01]), as well as the mediation proportion ($b = 0.27$, $p < .05$). Therefore, L. dlPFC-R. dlPFC coupling during emotional sharing was found to partially mediate the relationship between the empathy among empathizers during emotional sharing and the sadness levels among their targets.

As there were other significant ROI predictors of the targets' sadness levels, we explored these additional ROI interbrain couplings as potential mediators in the empathy–distress relief relationship. Consequently, five mediation models were run, each incorporating a different potential mediator: L. dlPFC-R. premotor, R. dlPFC-R. IFG, R. dlPFC-R. premotor, R. IFG- R. IFG, and R. IFG- R. However, none of these mediation models produced significant results.

Furthermore, to rule out the alternative model, according to which empathy mediates the relationship between interbrain coupling and sadness levels, we carried out an additional mediation analysis which showed that the total effect of L. dlPFC-R. dlPFC coupling on the targets' sadness levels ($b = -0.45$, $p < .01$; 95% CI [−0.9, −0.17]) was still significant when empathy was added to the equation ($b = -0.36$, $p < .01$; 95% CI [−0.8, −0.09]). The indirect effect of L. dlPFC-R. dlPFC coupling on the targets' sadness levels via empathy was not significant ($b = -0.09$, *n.s.*; 95% CI [−0.3, 0]), indicating that empathy does not mediate the relationship between interbrain coupling and the target's sadness levels. All the mediation analyses were conducted using the bootstrapping method (5,000 bootstrapped samples were calculated in each analysis).

Discussion

Considering that empathy has developed evolutionarily to alleviate the distress experienced by others (Decety et al., 2016; Reeck et al., 2016; Telle & Pfister, 2016; Zaki, 2020; Zaki & Williams, 2013), it is imperative to develop a comprehensive framework that unifies empathy and emotional relief as interconnected processes. Addressing this research gap, the present study employed a novel face-to-face laboratory modeled empathic interaction involving a distressed target and an empathizer. This approach enabled the examination of interbrain coupling as a critical mechanism, allowing relief for the target sharing their personal distressing story and fostering empathy in the interacting partner.

The Emotional Sharing Task: Distress Induction Validation

To validate the efficacy of our emotional sharing task in inducing distress, we compared both self-reported sadness levels and overall negative affect (Negative Affect subscale, PANAS) to those reported in a neutral sharing task. The results confirmed that our emotional sharing task, which included the recalling and reflecting of a distressing biographical event, elevated sadness levels and negative affect among targets. Furthermore, empathizers also showed increased sadness levels in the emotional sharing task in comparison to the neutral sharing task, demonstrating that listening to someone else's distressing biographical event elevates sadness levels.

Convergence of Distress Levels Between Target and Empathizer

Throughout the emotional sharing task, as targets shared their sad narratives and as empathizers actively engaged and listened, a convergence of their emotional states was observed. Originally characterized by a large emotional gap between the target and empathizer (reflected in their significantly different sadness levels prior to the interaction), this gap diminished by the end of the interaction (reflected in their nonsignificant sadness levels). This observed manifestation of emotional convergence may be construed as indicative of emotional synchronization taking place during emotional sharing, developing gradually through bidirectional exchange of verbal and nonverbal behaviors. Such examples may be the continuous matching of target and empathizers' motor behaviors such as facial expression (Dimberg et al., 2000; Olszanowski et al., 2019; Riehle et al., 2017) body posture (Chartrand & Bargh, 1999; Varlet et al., 2011) and vocal characteristics (Imel et al., 2014). According to the primitive contagious model (Hatfield et al., 1994), humans hold the ability to feel each other's emotional state through synchronized facial expressions, body postures, and voices as they adopt one another's muscular configuration, which provides a congruent emotional experience.

The influence of the interactants' nonverbal synchrony on emotional state has been previously shown (Tschacher et al., 2014) and may serve as a primary mechanism for emotional convergence.

Empathizer's Empathy Predicts Convergence of Distress Levels

To further understand the spontaneous emotional convergence that emerged between a target and empathizer, we explored the potential influence of the empathizer's empathy levels on the process. We found that increased levels of emotional convergence at the end of the emotional sharing task was significantly predicted by higher levels of empathizer's self-reported empathy, further indicating that the tendency of target and empathizer to emotionally converge represents a core empathic response. Among the measured forms of state empathy, it was specifically personal distress that significantly predicted the emotional convergence of sadness levels. Characterized as an empathic response, personal distress is described as a self-oriented sensation of discomfort in response to another individual's condition (Davis, 1980). It has been suggested that personal distress arises from the lack of boundaries between oneself and others (Decety & Lamm, 2006). In the context of the emotional sharing task, this lack of boundaries becomes evident between the target and empathizer. As participants engage in the task, the empathizer's experience of personal distress becomes a bridge for the convergence of emotional states, fostering a shared emotional experience.

Empathizer's Levels of Empathy Predict Target's Distress Relief

To further understand whether a meaningful relationship between state empathy and distress relief exists, we explored if the empathizer's empathy levels would significantly predict the target's sadness levels following the emotional sharing. We found that the target's sadness levels were significantly negatively predicted by the empathizer's levels of empathy during the emotional sharing task. Among the measured forms of state empathy, it was specifically perspective taking, a form of cognitive empathy, which significantly predicted targets' sadness levels. Cognitive empathy involves components such as mentalizing (Tamir & Thornton, 2018) and refers to understanding someone's perspective (Shamay-Tsoory, 2011). It is possible that it is primarily cognitive empathy (i.e., perspective taking), as opposed to emotional empathy (i.e., emotional concern and personal distress), that is most effective in contexts where interpersonal emotion regulation is needed to alleviate distress. This distinction in the effectiveness of cognitive versus emotional empathy in interpersonal emotion regulation contexts has been previously documented in the literature. In line with this, it was shown that in the context of romantic dyads, higher levels of trait cognitive empathy and not trait affective empathy predicted better emotion regulation by a romantic-partner (Levy-Gigi & Shamay-Tsoory, 2017). Also, in a study exploring the process of adaptive empathy, where empathizers select emotion regulation strategies based on real-time feedback to reduce the distress of a target person, it was found that cognitive empathy abilities, but not affective empathy abilities were positively associated with learning about the effectiveness of emotion regulation strategies (Kozakevich Arbel et al., 2021).

Consistent with our findings that emotional and cognitive empathy differentially impact emotion regulation, similar patterns are observed in intrapersonal contexts. Research indicates that higher levels of perspective taking correlate with decreased emotion dysregulation (Contardi et al., 2016; Okun et al., 2000). Conversely, elevated levels of affective empathy are linked to increased empathic stress (Powell, 2018). The tendency of emotional empathy to involve direct and shared emotional experiences (Bernhardt & Singer, 2012; Decety & Jackson, 2004) may lead to more intense and frequent emotional responses (Eisenberg & Okun, 1996; Eisenberg, 2000). Such heightened emotional reactivity can compromise cognitive control (Mueller, 2011) essential for managing emotions effectively. Thus, while cognitive empathy may mitigate emotional dysregulation, higher levels of emotional empathy could exacerbate empathic stress, impacting both personal and relational emotional management. Furthermore, given that many forms of adaptive emotion regulation strategies are reliant upon similar processes and neural architecture to those that support cognitive empathy (Morawetz et al., 2022) it could be the case that higher cognitive empathy is associated with improved efficiency of the cognitive control processes that also underlie the ability to regulate other's emotions.

Furthermore, empathy may alleviate distress in others by fostering a sense of "felt understanding," wherein a target acknowledges that their interaction partner has genuinely grasped and responded to fundamental aspects of their emotional experience (Reis et al., 2004, 2017). While felt understanding is reported to diminish stress and boost positive affect among partners in close relationships (Gable et al., 2004; Lippert & Prager, 2001; Lun et al., 2008), among strangers, felt understanding also decreases negative affect (Seehausen et al., 2012). This may be because feeling understood activates neural regions previously associated with reward and social connection (Morelli et al., 2014).

Our findings that distress relief was associated with empathy levels during the emotional sharing task are in line with the previous studies which have also demonstrated empathy's role in reducing other forms of distress, such as physical pain (Goldstein et al., 2016, 2018). For example, in a study examining pain relief through social touch, Goldstein et al. (2016) found a significant negative relationship between the toucher's empathy and the pain experience of their female partner, suggesting that empathy between partners may explain the pain-alleviating effects of social touch. Moreover, according to the biosocial model (Linehan, 1997), providing an empathic response to a distressed other who is sharing his pain-related feelings, promotes a feeling of validation and acceptance which directly contributes to reduction in negative affect, and consequently a reduction in pain (Edmond & Keefe, 2015).

Interbrain Coupling of IFG, Premotor Cortex, and DLPFC Predicts Target's Distress Relief

The neuroimaging results showed that increased interbrain coupling in regions of the targets and empathizer's observation execution system and emotion regulation network (L. dlPFC-R. dlPFC, R. dlPFC-R. premotor, R. IFG- R. IFG, R. IFG- R. premotor), significantly predicted sadness levels among targets during the emotional sharing task. Interbrain coupling in the IFG and premotor cortex, central regions of the observation execution system (Iacoboni et al., 2001; Lestou et al., 2008; Wade & Hammond, 2015), were significant predictors of target distress relief. As these areas enable individuals to understand others' actions and intentions through the generation of congruent representations of the other in the self (IFG; Jabbi & Keysers, 2008) and are activated both in observation and imitation (premotor; Carr et al., 2003, Leslie et al., 2004), it is possible that interbrain coupling within these regions represents blurring of the boundaries between the self and other (Hove, 2008). This blurring can evoke a sense of oneness (Swann et al., 2012) and as a result, the target may begin to feel more like the empathizer, less sad. The target may also experience distress relief through the activation of the observation execution system as it has been shown that alignment (as seen in mimicry) induces positive affect by activating reward related processes in the brain (Kühn et al., 2010).

While involvement of the observation execution system may facilitate distress relief in the target, it may also promote empathy in the empathizer. For example, previous functional magnetic resonance imaging (fMRI) research demonstrated the engagement of the premotor cortex when participants viewed images of individuals in distressing situations and were instructed to empathize (Nummenmaa et al., 2008).

Furthermore, the involvement of the observation execution system may play a role in the execution of the emotional sharing task itself. Previous studies examining interbrain coupling of the right IFG have shown that it is involved in successful joint attention tasks (Koike et al., 2016; Saito et al., 2010), face-to-face synchrony motor tasks (Marton-Alper et al., 2023), and shared goal achievement requiring temporal coordination of actions (Newman-Norlund et al., 2008).

Greater interbrain coupling within the dlPFC also significantly predicted distress relief of targets (reduced sadness levels). The current literature on emotion regulation points to both the right and left dlPFC as key players in exerting emotional regulation processes (Kroes et al., 2019; Lorenz et al., 2003; Ochsner et al., 2012; Rêgo et al., 2015) that are primarily through top-down cognitive mechanisms (Dörfel et al., 2014; Drabant et al., 2009; Morawetz et al., 2017; Zhao et al., 2021), as the dlPFC is also part of the executive network (Morawetz et al., 2020).

In line with our results that the activation of the left dlPFC is associated with distress regulation, previous studies have shown the left dlPFC to be involved in the regulation of pain perception (Brighina et al., 2011, Lorenz et al., 2003; Nahmias et al., 2009; Seminowicz & Moayedi, 2017). A recent meta-analysis of fMRI studies using psychophysiological interaction analysis showed convergent connectivity between the amygdala and right dlPFC during the down-regulation of negative emotions (Berboth & Morawetz, 2021), showing that the activation of the right dlPFC may potentially impact emotional regulation during our emotional sharing task through its communication with subcortical brain regions. Furthermore, in a study using bihemispheric transcranial direct current stimulation (tDCS) over the dlPFC to assess emotional reactions elicited by pain observation, both left-cathodal/right-anodal and left-anodal/right-cathodal tDCS decreased hostility, sadness, and self-pain perception, suggesting a common role for left and right dlPFC in personal distress modulation (Rêgo et al., 2015). Intriguingly, an fMRI study by Morawetz et al. (2016) linked both the IFG and dlPFC to distinct processes in emotional regulation, whereby the IFG selects a single goal-appropriate reappraisal from multiple options held in working memory (represented in the dlPFC), and then inhibits the dlPFC upon selection completion.

While numerous intrabrain studies have demonstrated the dlPFC's role in distress regulation, the question remains, how might interbrain coupling of the dlPFC between target and empathizer contribute to distress reduction in the target? One possibility is that the attunement of the empathizer to the emotions of the target contributes to dyadic coupling which allows coregulation of affective states during the emotional sharing. Furthermore, interbrain coupling between empathizer and target within the dlPFC might reflect the extent of cooperation to coregulate as previous hyperscanning studies that have linked dlPFC coupling with successful cooperative interactions between two individuals (Nguyen et al., 2020, 2021; Reindl et al., 2018). Further supporting the dlPFC's role in emotion regulation are the results of our mediation analysis, where interbrain coupling levels in the L. dlPFC-R. dlPFC partially mediated the effect that state empathy levels had on target distress relief. While the dlPFC is commonly known for its role in emotion regulation, it has been also previously involved in the formation of cognitive empathic responses (Naor et al., 2018; Powell, 2018; Weisz & Cikara, 2021). Interbrain coupling in the L. dlPFC-R. dlPFC might serve a mechanistic role in the link between empathic processes and distress regulation in the target. It is thus possible that during empathetic interactions, the IFG plays a critical role in enabling the participants to share emotions and diminish the distinction between their individual experiences. At the same time, interbrain coupling within the dlPFC regions may support the collaborative regulation of emotions between the target and the empathizer.

Constraints on Generality

The relevance of our study's findings to broader theoretical frameworks on dyadic interpersonal emotion regulation (Simons et al., 2017) may have certain limitations. While attempts were made to make the emotional sharing task as ecological as possible, it should be acknowledged that the "role assignment" of empathizer and target makes the conversation less spontaneous and less like real life. Second, we address the generalizability of our sample. While our sample included culturally different participants with different native tongues (Hebrew and Arabic), it did exclude participants diagnosed with a medical condition. Therefore, our behavioral and neural findings should be limited to nonclinical populations. Furthermore, the applicability of our study's findings is confined to individuals who are unacquainted, rather than closely acquainted, such as significant others or friends. The results should be treated with caution when extending to other relationship contexts. For this reason, future research should investigate emotion regulation and empathy processes in different dyadic and group contexts.

Conclusion

Our study reveals the emergence of emotional convergence during emotional sharing, where empathy assumes a pivotal role in shaping the sharing experience. Notably, we observed that interbrain coupling in the IFG, premotor cortex and in the dlPFC is associated with the extent of distress experienced after sharing. These findings suggest that interbrain coupling may serve as a mechanism of connectedness during emotional sharing, contributing to the emergence of attuned responses and ultimately influencing the levels of distress the target experiences. Since we did not explore the specific communication signals (e.g., facial expressions, prosody) contributing to these associations, future research can characterize the relationship between distinct behavioral signals and their contributions to reducing distress. Finally, it is imperative to investigate causality to ascertain whether the observed interbrain coupling genuinely influences the distress of the target.

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(*Appendix follows*)

Appendix

Montreal Neurological Institute (MNI) Coordinates for fNIRS Optodes

Table A1
MNI Coordinates for fNIRS Optodes

Hemisphere	Optode	MNI coordinate *X*	MNI coordinate *Y*	MNI coordinate *Z*
Right	S1	23.2	−23.0	28.6
Right	S2	−8.9	−62.9	63.3
Right	S3	18.1	−62.5	64.2
Right	S4	41.7	−54.6	70.2
Right	S5	14.9	−76.3	115.9
Left	S6	19.7	28.6	27.0
Left	S7	42.3	51.6	71.4
Left	S8	18.4	61.8	69.3
Left	S9	−12.2	62.5	68.2
Left	S10	21.2	68.6	124.7
Right	D1	5.1	−48.6	38.5
Right	D2	30.8	−41.9	45.2
Right	D3	5.6	−72.1	89.7
Right	D4	31.7	−68.6	97.1
Left	D5	34.9	45.2	49.5
Left	D6	5.0	51.4	42.7
Left	D7	30.5	64.9	96.8
Left	D8	4.2	67.0	95.3

Note. All optodes are attributed to the Brite-24 fNIRS system (Artinis Medical Systems, Elst, Netherlands). MNI = Montreal Neurological Institute; fNIRS = functional near-infrared spectroscopy.

Table A2
MNI Coordinates for fNIRS Channels

Channel	ROI association	MNI coordinate Centerpoint *X*	MNI coordinate Centerpoint *Y*	MNI coordinate Centerpoint *Z*
S1–D1	dlPFC R	14.15	−35.8	33.55
S1–D2	dlPFC R	27	−32.45	36.9
S2–D1	IFG R	−1.9	−55.75	50.9
S2–D3	IFG R	−1.65	−67.5	76.5
S3–D1	IFG R	11.6	−55.55	51.35
S3–D3	IFG R	11.85	−67.3	76.95
S4–D2	IFG R	36.25	−48.25	57.7
S4–D4	Premotor R	36.7	−61.6	83.65
S6–D5	dlPFC L	27.3	36.9	38.25
S6–D6	dlPFC L	12.35	40	34.85
S7–D5	IFG L	38.6	48.4	60.45
S7–D7	Premotor L	36.4	58.25	84.1
S8–D6	IFG L	11.7	56.6	56
S8–D8	IFG L	11.3	64.4	82.3
S9–D6	IFG L	−3.6	56.95	55.45
S9–D8	IFG L	−4	64.75	81.75

Note. All channels are attributed to the Brite-24 fNIRS system (Artinis Medical Systems, Elst, Netherlands). fNIRS = functional near-infrared spectroscopy; ROI = regions of interest; IFG R = right inferior frontal gyrus; dlPFC R = right dorsolateral prefrontal cortex; IFG L = left inferior frontal gyrus; dlPFC L = left dorsolateral prefrontal cortex; MNI = Montreal Neurological Institute.

(*Appendix continues*)

Table A3

Interbrain Coupling Differences of Real-Dyads Compared to Pseudodyads

Target empathizer ROI	Real-dyad	Pseudodyad	Significance
L. dlPFC-L. dlPFC	$M = 0.33$ $SD = 0.04$	$M = 0.31$ $SD = 0.04$	$\chi^2(1) = 18.78$ $p < .0001$
L. dlPFC-R. dlPFC	$M = 0.33$ $SD = 0.04$	$M = 0.32$ $SD = 0.04$	$\chi^2(1) = 8.61$ $p < .05$
L. dlPFC-R. IFG	$M = 0.32$ $SD = 0.05$	$M = 0.31$ $SD = 0.04$	$\chi^2(1) = 6.68$ $p < .05$
L. dlPFC-R. premotor	$M = 0.34$ $SD = 0.04$	$M = 0.32$ $SD = 0.04$	$\chi^2(1) = 6.84$ $p < .05$
R. dlPFC-L. dlPFC	$M = 0.33$ $SD = 0.04$	$M = 0.32$ $SD = 0.04$	$\chi^2(1) = 10.87$ $p < .01$
R. dlPFC-R. dlPFC	$M = 0.33$ $SD = 0.04$	$M = 0.32$ $SD = 0.04$	$\chi^2(1) = 10.4$ $p < .01$
R. dlPFC-R. IFG	$M = 0.32$ $SD = 0.05$	$M = 0.31$ $SD = 0.04$	$\chi^2(1) = 7.97$ $p < .05$
R. dlPFC-R. premotor	$M = 0.34$ $SD = 0.05$	$M = 0.31$ $SD = 0.04$	$\chi^2(1) = 26.2$ $p < .0001$
R. IFG-L. dlPFC	$M = 0.33$ $SD = 0.05$	$M = 0.31$ $SD = 0.04$	$\chi^2(1) = 15.04$ $p < .01$
R. IFG-R. IFG	$M = 0.32$ $SD = 0.04$	$M = 0.31$ $SD = 0.04$	$\chi^2(1) = 7.8$ $p < .05$
R. IFG-R. premotor	$M = 0.33$ $SD = 0.04$	$M = 0.31$ $SD = 0.04$	$\chi^2(1) = 13.33$ $p < .01$
R. premotor-R. premotor	$M = 0.34$ $SD = 0.05$	$M = 0.32$ $SD = 0.04$	$\chi^2(1) = 6.84$ $p < .05$

Note. Means, standard deviations and numeric values of WTC values, significance estimates, and *p* values are displayed. All comparisons were corrected with the false discovery rate (FDR) correction for multiple comparisons. ROI = regions of interest; IFG = inferior frontal gyrus; dlPFC = dorsolateral prefrontal cortex; IFG R = right inferior frontal gyrus; dlPFC R = right dorsolateral prefrontal cortex; IFG L = left inferior frontal gyrus; dlPFC L = left dorsolateral prefrontal cortex; WTC = wavelet transform coherence.

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