Inside the mindful moment: The effects of brief mindfulness practice on large-scale network organization and intimate partner aggression

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Abstract

Mindfulness can produce neuroplastic changes that support adaptive cognitive and emotional functioning. Recently interest in single-exercise mindfulness instruction has grown considerably due to the advent of mobile health technology. Accordingly, the current study sought to extend neural models of mindfulness by investigating transient states of mindfulness during single-dose exposure to focused attention meditation. Specifically, we examined the ability of a brief mindfulness induction to attenuate intimate partner aggression via adaptive changes to intrinsic functional brain networks. To do so, we employed a dual regression approach to examine large-scale functional network organization in 50 intimate partner dyads (total *n* = 100) while they received either mindfulness (*n* = 50) or relaxation (*n* = 50) instruction. Mindfulness instruction reduced coherence within the Default Mode Network and increased functional connectivity within the Frontoparietal Control and Salience Networks. Additionally, mindfulness decoupled primary visual and attention-linked networks. Yet this induction was unable to elicit changes in subsequent intimate partner aggression and such aggression was broadly unassociated with any of our network indices. These findings suggest that minimal doses of focused attention-based mindfulness can promote transient changes in large-scale brain networks that have uncertain implications for aggressive behavior.

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Scientific interest in mindfulness has grown exponentially over the past two decades (Van Dam et al., 2018), but despite such popularity, mindfulness as an attribute of consciousness remains poorly understood. Although the definition is debated among scholars (Bodhi, 2013; Brown & Ryan, 2003; Dreyfus, 2010), one widely accepted definition of mindfulness with canonical roots is as follows: a sustained state of focused attention to and receptive awareness of present-moment sensations, thoughts, and emotions (e.g., Brown & Ryan, 2003). Mindfulness, as described here, is a mental faculty with the capacity to adaptively shape cognitive and emotional responses to daily lived experiences (e.g., Chiesa et al., 2011; Garland et al., 2015; Lindsay et al., 2018), and may be promoted through formal meditation exercises. Here we examined whether a brief mindfulness induction attenuated intimate partner aggression via adaptive changes in coordinated brain networks.

Converging evidence across behavioral and neuroimaging studies suggests that the cognitive and emotional benefits of mindfulness may extend to interpersonal contexts (Creswell, 2017). Emerging research shows that mindfulness is capable of promoting prosocial behavior (Berry et al., 2020), and may even inhibit antisocial behaviors (DeSteno et al., 2018; Gillions et al., 2019; Heppner et al., 2008) including intimate partner aggression, defined as the deliberate use of violence against one’s romantic partner (Chester & DeWall, 2019). The high costs of intimate partner aggression—borne by victims, witnesses, and communities—have motivated the study of its biological underpinnings (Chester et al., 2021; Verdejo-Román et al., 2019) and potential for intervention (e.g., Bair-Merritt et al., 2014; Karakurt et al., 2019). The neural circuits underlying social behaviors are highly malleable (Klimecki, 2015), and may serve as biological substrates for intervention. Investigation of brain states proceeding from mindfulness—and their potential to attenuate aggression—may simultaneously advance mechanistic understandings of mindfulness and intimate partner aggression. Accordingly, the present study examined mindful brain states in participants undergoing fMRI while engaging in a guided meditation practice (vs. active control) before completing a standardized behavioral aggression task modified to examine intimate partner aggression.

Mindfulness Inductions

Considerable research has focused on the application of mindfulness-based interventions (MBIs) spanning days, weeks, or months; however, relatively few studies have examined mindfulness inductions, or brief laboratory-delivered exercises used to promote a temporary state of mindfulness (Creswell, 2017). Mindfulness inductions have been promoted as accessible mental exercises with short-term benefits for cognitive and emotional functioning (Heppner & Shirk, 2018), and given innovations in mobile health technologies (i.e., mhealth), smartphone-delivered guided mindfulness practices have been used to provide immediate support in real-world settings (Balaskas et al., 2021; Meinlschmidt et al., 2016). While mindfulness inductions have garnered attention for their potential to improve momentary wellbeing without the geographic, monetary, and time investment demands of traditional in-person MBIs, the biological substrates of such effects remain under-researched (for review see Heppner & Shirk, 2018).

Apart from their practical merits, brief mindfulness inductions offer numerous methodological advantages for researchers seeking to elucidate the construct of mindfulness. MBIs typically include mindfulness training as one component of a multi-modal treatment package incorporating nonspecific therapeutic elements (e.g., instructor attention, group therapeutic alliance) as well as cognitive and behavioral practices unrelated to mindfulness (Canby et al., 2021). In contrast, mindfulness inductions can be delivered in a highly controlled experimental context to facilitate the isolation of specific mindfulness components. Moreover, the methodological standardization permitted by mindfulness inductions allows experimenters to reliably elicit mindful states and observe their neuropsychological substrates in a controlled laboratory setting. Nevertheless, it has been argued that mindfulness inductions cannot produce the full spectrum of cognitive effects associated with long-term mindfulness training (Leyland et al., 2019; Williams, 2010; c.f., Levi et al., 2021), and that long-term mindfulness exposure may operate via neural mechanisms distinct from those of single-dose inductions (Chiesa et al., 2013). The degree to which mechanisms of mindfulness inductions map to preexisting models of mindfulness continues to be a subject of debate; however, neuroimaging approaches may clarify the biological substrates underlying mindfulness inductions, and by extension, elucidate the larger construct of mindfulness.

Neurocognitive Mechanisms of Mindfulness

Single-dose mindfulness practices have been shown to temporarily enhance cognitive and emotional functioning with important implications for emotional, physical, and interpersonal wellbeing (Heppner & Shirk, 2019); however, the mechanisms underlying mindful brain states are under-researched. Mindfulness inductions typically operate by instructing the individual to focus their attention on a salient stimulus (i.e., the breath), referred to as an “object of focus” or “meditative object” (Lutz et al., 2015). When the mind wanders and attention is captured by distracting thoughts, the meditator is encouraged to note this attentional change and redirect their focus to the meditative object. These cognitive stages of the meditative process have likewise been mapped to distinct brain states (Hasenkamp et al., 2012).

The default mode network (DMN), anchored to the medial PFC and PCC, has been associated with both volitional and non-volitional internal mentation (Andrews-Hanna et al., 2014), but is particularly engaged during periods of unintentional mind-wandering (Hasenkamp et al., 2012). In turn, the salience network (SN), encompassing the anterior insula and dorsal anterior cingulate, has been previously associated with detection of motivationally relevant external and internal stimuli (Corbetta et al., 2008), and appears to support the detection of mind-wandering in the practice of meditation (Hasenkamp et al., 2012). Finally, the FPCN, anchored to the dorsolateral PFC and posterior parietal cortex (Uddin et al., 2019), is known to facilitate cognitive control (Seeley et al., 2007) and in the context of meditation has been shown volitionally redirect attention to the object of focus (Hasenkamp et al., 2012). MBIs have reliably been shown to induce changes in network connectivity within and between these three networks (Cooper et al., 2022; Mooneyham et al., 2016; Rahrig et al., 2022; Sezer et al., 2022); however, relatively few studies have observed mindful brain states *in vivo* (Bauer et al., 2019; Dixon et al., 2020; Hasenkamp et al., 2012; Kilpatrick et al., 2011).

To date, the majority of functional connectivity research has focused on how mindfulness practice promotes long-term plasticity “off the mat” as indexed by resting state functional connectivity (rsFC) (Dixon et al., 2020, p. 5). The preponderance of research indicates that mindfulness solicits engagement from the FPCN and SN (Fox et al., 2016; Ganesan et al., 2022)—related to executive control and interoceptive awareness, respectively—which may serve to strengthen intra-network connectivity of both of these networks (Dixon et al., 2020; Hasenkamp & Barsalou, 2012; Kemmer et al., 2015; Kilpatrick et al., 2011; Taren et al., 2017; Vago & Zeidan, 2016). The converse has been observed within the DMN, with evidence suggesting that mindfulness reduces DMN coherence, possibly as a mechanism for altering habitual modes of self-referential thought (Cooper et al., 2022). In accord with this theory, studies have previously reported reduced local connectivity in the PCC/precuneus in MBI trainees (Xiao et al., 2019) and experienced meditators (Panda et al., 2016), reduced DMN node centrality during mindful acceptance (vs. active control comparison) (Dixon et al., 2020), weaker DMN hub connectivity in experienced meditators relative to novices (Kral et al., 2022), attenuated posterior DMN synchrony following meditation training (Fingelkurts et al., 2016), and lower levels of DMN intra-network connectivity in participants scoring high in trait mindfulness (Doll et al., 2015; Harrison et al., 2019) and participants trained in mindfulness-based neurofeedback (J. Zhang et al., 2023). Aligned with these findings, researchers have previously suggested that meditation experience may effectively decouple anterior and posterior elements of the DMN (Cooper et al., 2022; Hasenkamp & Barsalou, 2012) (c.f., Jao et al., 2015).

Perplexingly, mindfulness has also been associated with *increases* in DMN intra-network connectivity (e.g., Brewer et al., 2011; Fingelkurts et al., 2016; Hasenkamp & Barsalou, 2012; Jang et al., 2011; Kwak et al., 2019). Such inconsistencies have previously been attributed to differences in methodologies and analytical approaches (Mooneyham et al., 2016; Sezer et al., 2022); however, this discrepancy is also reasonable considering the heterogeneous functions of DMN pathways (Andrews-Hanna et al., 2014; Smallwood et al., 2021). The DMN is far from monolithic and includes specialized circuitry associated with attentional shifting, self-monitoring, and abstract cognition (Bzdok et al., 2015; Fransson & Marrelec, 2008; Y. Zhang et al., 2014). Although highly integrated during rest, these specialized circuits become decoupled during cognitive tasks (Bzdok et al., 2015), an effect which may extend to mindfulness. Thus, it is conceivable that mindfulness strengthens pathways underlying self-awareness (e.g., vmPFC-PCC circuits), while reducing cohesion of the DMN at a larger scale (Cooper et al., 2022).

The effects of mindfulness on intra-network connectivity occur in the broader context of cross-network interactions. It is well-established that DMN activity is modulated by cross-network signaling from both the FPCN and SN, and that such internetwork coupling impacts the nature of internally-oriented cognition (Christoff et al., 2016). The FPCN, associated with executive functioning, is able to deliberately constrain internal mentation by flexibly coupling with the DMN. Likewise, accumulating evidence indicates that mindfulness facilitates top-down disengagement from mind-wandering through FPCN-DMN internetwork connectivity (Creswell et al., 2016; King et al., 2016; Kral et al., 2022). The SN has similarly been implicated in the regulation of internal mentation, although such constraints are thought to be automatic rather than volitional (Christoff et al., 2016), and MBIs have been shown to enhance SN-DMN connectivity, according to meta-analytic findings (Rahrig et al., 2022). In sum, convergent theory and evidence point to a plausible model of mindful brain states characterized by increased functional connectivity within the FPCN and within the SN, decreased functional connectivity within the DMN, and enhanced internetwork connectivity between the DMN and FPCN as well as between the DMN and SN.

While prior research has begun to disentangle these mechanisms, it remains unclear whether reorganization within and between large scale networks is an accumulative outcome of mindfulness training or if to the contrary, similar changes can be induced in transient states of mindfulness. Network connectivity modulation has notable implications for cognitive functioning (Stevens & Spreng, 2014), and elucidating the functional networks underlying MIs is an important next step to understanding mindfulness as a construct.

Neural Bases of Mindfulness and Intimate Partner Aggression

Large-scale networks are capable of flexible, dynamic reorganization, and such changes measurably impact subsequent perceptions and behaviors (Sadaghiani & Kleinschmidt, 2013). Accordingly, brain states elicited by mindfulness may plausibly influence experiences of provocation and consequent aggression. Early research has begun to explore the neural bases of intimate partner aggression using task-based fMRI paradigms (Chester et al., 2021; Chester & DeWall, 2019; Marín-Morales et al., 2022) and resting state approaches (Amaoui, Marín-Morales, et al., 2022; Amaoui, Martín-Pérez, et al., 2022). Initial findings suggest that intimate partner aggression may be linked to altered functioning of the DMN, particularly within regions underpinning social mentalization (Denny et al., 2012; Van Overwalle, 2009). For example, perpetration of intimate partner aggression has been uniquely associated with heightened dorsomedial PFC activation (Chester & DeWall, 2019) and dorsomedial PFC–ventromedial PFC connectivity (Chester et al., 2021). In contrast, DMN regions implicated in value and self-related processing—namely, the ventromedial PFC and posterior cingulate cortex–have been associated with attenuated aggression in task-based paradigms (Chester et al., 2021; Chester & DeWall, 2019). Emerging theories suggest that mindfulness programs may promote adaptive regulation by targeting similar dopaminergic vmPFC circuits involved in the negative reinforcement of harmful behaviors (Schuman-Olivier et al., 2020). Nevertheless, it remains unclear whether mindfulness may reduce intimate partner aggression via altered activity in these networks.

The Present Study

Although behavioral and neural effects have been detected following single exposure to mindfulness practice, the impact of one-time mindfulness instruction on large-scale brain networks is largely still unknown. Clarifying the biomarkers of mindfulness states will inform the mechanisms through which single-dose exposures can promote adaptive cognitive-emotional functioning and reduce harmful behaviors. The present study aimed to examine inter- and intra-network connectivity of large-scale brain networks (i.e., DMN, SN, and FPCN) during mindfulness meditation relative to relaxation in a between-subjects design. Given the paucity of research on network connectivity during single-dose mindfulness exposure, the current project goals have been framed as research aims instead of hypotheses. It warrants noting that the directional effects of the following pre-registered aims are supported by prior research centered on mindfulness training; however, there is little precedent for the use of a relaxation instruction control comparison in testing these directional effects. Nevertheless, we opted to use a relaxation control condition given that is a well-matched comparison that supports isolating the affective and cognitive neural pathways specific to mindfulness (Zeidan et al., 2010). First, we aimed to examine whether Mindfulness Instruction (MI), relative to Relaxation Instruction (RI), is associated with reduced functional connectivity within the DMN, a large-scale network associated with the maintenance of internal mentation and mind-wandering. Second, we aimed to determine if participants receiving MI, relative to RI, exhibit higher functional connectivity within networks underlying attention and cognitive control, namely the FPCN and SN. Third, given the modulatory roles of the FPCN and SN on DMN neurocircuitry, we sought to establish if MI would enhance FPCN-DMN and SN-DMN internetwork connectivity. Finally, seeking to connect these neural mechanisms of mindfulness to a behavioral outcome, we aimed to determine if neural networks targeted by mindfulness were associated with variability in self-reported and behavioral outcomes of interpartner aggression.

To test these aims, participants were randomly assigned to receive brief auditory instruction in either relaxation or mindfulness meditation, which they completed while undergoing functional magnetic resonance imaging (fMRI). We applied a data-driven approach, incorporating group independent component analysis (gICA) with dual regression, in order to identify large-scale networks differentially affected by states induced by mindfulness and relaxation instruction. Following the experimental manipulation, participants completed a standardized aggression paradigm and self-report questionnaire, designed to measure intimate partner aggression via behavioral and subjective indices.

Methods

Power Statement

The current project is a secondary analysis of the pre-registered parent trial, https://osf.io/un2fy. The sample size of 50 couples was determined by funding constraints and was not determined by an a priori analysis. As reported in Chester et al. (2021), the pre-registered sample size was later increased to N = 100 in order to detect zero-order main effects of at least r = 0.28 at 80% power ($\alpha = .05$). This effect size was based on the average effect size reported in the aggression literature (Richard et al., 2003) Although a power analysis was not performed to estimate the sample size necessary to detect within- and between-subject brain-based effects, Chen et al. (2018) have suggested that a sample size of k = 100 (n = 50/group) has a positive predictive value of .28-.14 when using permutation tests with threshold-free cluster enhancement (TFCE), the multiple comparison correction strategy used in the present study.

Participants

Data was collected as part of a larger study investigating romantic relationships (https://osf.io/un2fy; Chester et al., 2021) including 51 heterosexual couples comprised of one man and one woman who were monogamous for at least six continuous months. After excluding two participants from separate couples due to potential MRI safety issues, initial participants were 100 young adults recruited from the Richmond, Virginia community and from an introductory psychology subject pool. Eligibility was determined using an online screening questionnaire, which assessed the following exclusionary characteristics: aged less than 18 or greater than 35 years, body mass index above 30, claustrophobia, color blindness, mental or neural pathology, metallic objects in the body, left hand dominance or ambidexterity, history of head trauma, and current psychoactive medication use. Participant characteristics of this initial sample are reported in Supplemental Table S1. From this sample, functional scans were unavailable for 5 participants due to acquisition errors or excessive motion. Thus, our final sample included 95 participants randomly assigned to either the mindfulness (n = 46) or relaxation control condition (n = 49) irrespective of the condition assignment of their partner.

Procedure

Couples arrived at our MRI laboratory for a three-hour study. The two participants were separated from each other, and then separately provided informed consent, completed MRI safety screening, and then entered the MRI scanner to perform our scans in a staggered manner (i.e., one participant was scanned first, the other second). First, participants completed several structural MRI scans and three unrelated functional scans. In a model-free fMRI paradigm, participants listened to the first 7m and 20s audio recording of either a guided mindfulness meditation or relaxation practice, both delivered by a male voice. The mindfulness meditation was adapted from Segal et al. (2002) and included a series of instructions to focus attention on moment-to-moment somatic, cognitive, and emotional experience. Additionally, these participants were instructed to notice when their mind had wandered and, by focusing on their breath, return their attention to the present moment. The structurally equivalent relaxation practice instructions were adapted from progressive muscle relaxation instructions (Bernstein & Borkovec, 1973), which has previously been used as an active control comparison to mindfulness (Feldman et al., 2010). Although relaxation inductions are used less frequently compared to alternative control inductions (Heppner & Shirk, 2018; Leyland et al., 2019), they offer a well-matched comparison in terms of engagement, time, and delivery. Moreover, RI control comparisons, which have been shown to immediately reduce anxiety (Avants et al., 1990), permit the experimental isolation of mindfulness components from the broader effects of stress management (Feldman et al., 2010; Gao et al., 2018).

After this model-free functional scan, participants completed a behavioral aggression task adapted for the MRI environment (full description in Chester et al., 2021). In this task, participants engaged in a reaction time competition wherein they needed to press a button more quickly than three ostensible opponents in order to win. Participants were led to believe that their opponents, which were in reality, automated by a computer program, were either their intimate partner, a close friend, or a same-gender stranger (i.e., three order-randomized blocks that each corresponded to a different aggression target, 8 trials per block, 24 trials total). At the outset of every trial, participants set the volume of a noise blast (on a scale from 1 [low] to 4 [high]) that would be delivered to their opponents if the participant won and their opponent lost. When participants lost a given round of competition, they were punished with an aversive noise blast at the volume their opponent selected for them. However, when participants won the round their opponent received the noise blast at the volume that the participant selected. After completing this task and several unrelated functional scans, participants exited the scanner, completed a battery of questionnaires that included a measure of broader patterns of intimate partner aggression within the given couple (the Abuse Within Intimate Relationships Scale; AWIRS; Borjesson et al., 2003). Participants were then debriefed, compensated, and excused from the study.

MRI Acquisition and Preprocessing

MRI data were collected using a Phillips Ingenia 3.0 Tesla scanner and 32-channel headcoil. We acquired functional neuroimaging data using echo planar whole-brain BOLD imaging with a T2*-weighted gradient with a 3D shim; field of view (FOV) = 224mm (right-left) x 224mm (anterior-posterior) x 188.75mm (superior-inferior); echo time (TE) = 28ms; repetition time (TR) = 2.5s; slice thickness = 3.5mm, 40 interleaved slices, flip angle = 90°. After including dummy scans used for signal equilibration, the duration of the mindfulness and relaxation induction scan was 7m 20s). High resolution structural brain images were acquired using a coplanar magnetization-prepared rapid gradient-echo (MPRAGE) sequence for the purposes of registration to native space with a T1-weighted gradient; FOV = 240mm (superior-inferior x 259mm (anterior-posterior) x 160mm (right-left); slice thickness = 1mm; TE = 3.7ms, TR = 8.1s; 160 sagittal slices; flip angle = 6°. Analysis of Functional NeuroImages (AFNI) software was used to conduct all preprocessing steps. Time series datasets were despiked to compensate for motion artifacts, corrected for head motion (3dvolreg), and warped out to common stereotactic reference space (Montreal Neurological Institute; MNI). Functional volumes then underwent pre-whitening and interleaved slice-timing correction. Finally, volumes were spatially smoothed to uniform 6mm full-width half maximum Gaussian kernel and underwent temporal high-pass filtering (80s cutoff).

Independent Component Analysis

Following pre-processing, large-scale functional connectivity (FC) indices were obtained using independent component analysis (ICA), a data-driven approach to identifying spatial properties of temporally coherent networks (Beckmann et al., 2005). Specifically we conducted group ICA using FSL MELODIC 3.0 software. First, participants' functional scans were registered to their structural scans using MELODIC’s boundary-based registration method (12 dof). Preprocessed functional volumes underwent multi-session temporal concatenation with automatic dimensionality estimation. The number of independent components was estimated automatically by the principal component analysis (PCA) process of the MELODIC software, which labeled components as signal or noise.

Components of interest were identified from group ICA using spatial correlation with reference networks from Yeo’s seven network cortical parcellation ($r \geq .15$; threshold previously reported in Kilpatrick et al., 2011) via the FSL utility fslcc. Among the total independent components (n = 137) estimated by the PCA process, this procedure yielded a total of 17 networks corresponding with one of the seven reference networks, which include the Visual, Somatomotor, Dorsal Attention, Ventral Attention, Limbic, Frontoparietal, and Default networks. Component signals were visually inspected to ensure that the majority of the component’s signal was within the low frequency spectrum. Standardized z-scores obtained from individual subject components were extracted for second-level analysis.

Defining Neural Networks and Regions of Interest

All components meeting the correlation threshold (n = 17) were sorted into one or more reference networks and visually inspected to determine the functional nodes contained within each component (see Supplemental Table S2). In order to address study aims, which concerned functional connectivity trends among large-scale networks, components were further organized into superordinate networks according to the following schema:

1. ***Default Mode Network***. Investigation of large-scale networks suggests that the DMN may be parceled into three functionally dissociable subnetworks: the *Midline Core network*, the *Dorsomedial Prefrontal Cortex (DmPFC) subsystem*, and the *Medial*

Temporal Lobe subsystem (Andrews-Hanna et al., 2010). The Midline Core, containing the posterior cingulate and anterior medial PFC, is canonically associated with self-referential thought and "hot" cognition (i.e., emotionally evocative cognitions) (Andrews-Hanna et al., 2010). Operating in tandem with the Midline Core, the DmPFC subsystem supports complex meta-cognitive functions, and is preferentially engaged during evaluation of one's own mental state as well as the mental states of others (Denny et al., 2012; Van Overwalle, 2009). Finally, the Medial Temporal Lobe subsystem—comprised of regions within the ventromedial PFC, posterior inferior parietal lobule, parahippocampal cortex, retrosplenial cortex, and hippocampal formation—supports self-related cognition through episodic recall and simulation (Rugg & Vilberg, 2013).

2. ***Frontoparietal Control Network.*** Parcellation studies suggest that the FPCN may be more aptly conceived as two functionally distinct networks, referred to as the *Dorsal Frontoparietal Network* (Dorsal FPCN) and the *Lateral Frontoparietal Network* (Lateral FPCN) respectively (Uddin et al., 2019). The Dorsal FPCN is primarily associated with the deployment of visuospatial attention (Corbetta & Shulman, 2002), with core regions including the superior parietal lobule, intraparietal sulcus, middle temporal complex, and the putative eye fields (Uddin et al., 2019). In contrast, the Lateral FPCN has been linked to functions conventionally associated with executive control, namely goal-oriented cognition, task-switching, and inhibition (among others) (Kam et al., 2019). Core regions comprising the Lateral FPCN include structures of the rostral and dorsolateral PFC as well as the anterior inferior parietal lobule (Uddin et al., 2019).
3. ***Salience Network.*** Predominant structures of the Salience Network (SN) include the bilateral anterior insula and anterior/mid-cingulate cortex. However, this network has also

been associated with subcortical structures often ascribed to the limbic system, namely the amygdala, hypothalamus, substantia nigra/ventral tegmental area, and certain nuclei of the thalamus (Uddin et al., 2019). Notably, some parcellations (e.g., Yeo et al., 2011) do not recognize the SN as a functionally independent network; rather, SN structures are consolidated under the "ventral attention network" label.

Statistical Analyses

Dual Regression

Following multi-subject ICA analysis, between-subject rsFC comparisons were calculated using a dual regression approach (Filippini et al., 2009). Using multiple linear regression, this approach estimates single-subject spatial maps (one per group) used for between-subject inferential testing. First, group-average spatial maps (obtained through ICA) are regressed into subject-level 4D space-time datasets in order to estimate temporal dynamics specific to each group-level map. Then, units of temporal variance are regressed into the same 4D dataset to obtain subject-specific spatial maps, one per group level spatial map. This series of calculations results in pairs of estimates (i.e., regression weights) indexing the functional cohesion of each spatial map for each group. Using these pairs of rsFC estimates, we then evaluated group differences in network rsFC using a two-group unpaired t-test via the FSL utility randomise with 5000 permutations and cluster-mass thresholding ($z = 2.3$) at FWE-corrected $p < .01$ to account for multiple comparisons. Group-level analysis of spatial maps then estimated group differences in subnetworks of the DMN, FPCN, and SN in terms of voxel-wise differences in amplitude and shape effects.

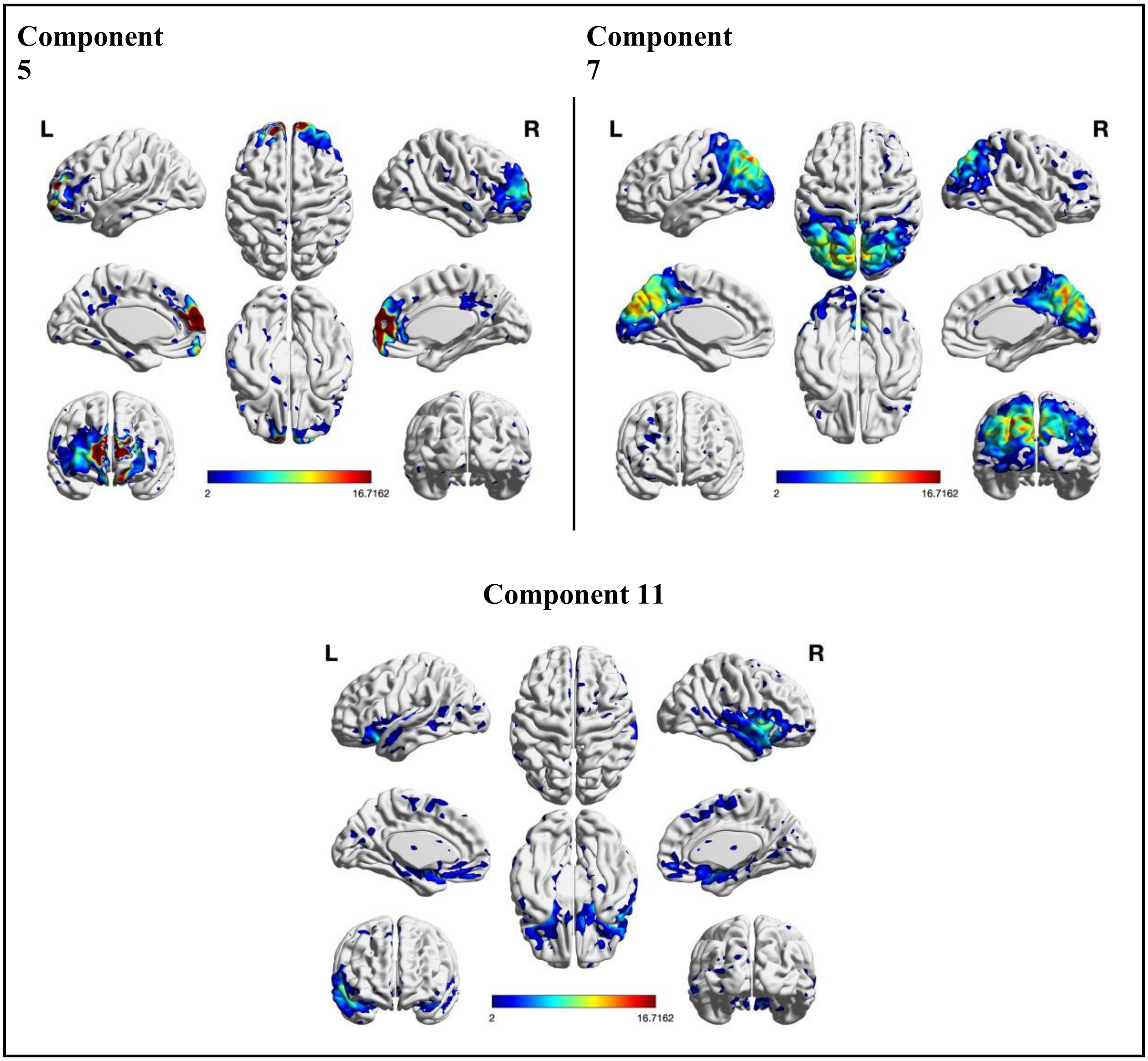
Network Modeling

Individual-level time series associated with the 17 spatially-independent components were used to perform network analysis (Smith, 2012). First, pairwise correlations between component time series were estimated using the FSLNets toolbox (http://fsl.fmrib.ox.ac.uk/fsl/fslwiki/FSLNets), from which lambda regularized ($\rho = 0.1$) partial correlations were calculated and transformed via Fisher's transformation. Network matrices (17 x 17) for each participant were then used to generate a group mean functional connectome, in which functional connectivity matrices were organized hierarchically. Finally, group differences in between-network connectivities were examined using cross-subject GLM with nonparametric permutation inference (via the FSL utility randomise).

Results

Mindfulness Induction's Effect on Connectivity Within the Default Mode Network

Aim 1 of the present study sought to determine if mindfulness instruction (MI) elicited lower functional connectivity within DMN components relative to relaxation instruction (RI). In support of Aim 1, we found significant group differences (MI<RI) in intrinsic functional connectivity within components localized to the bilateral posterior cingulate cortex/precuneus (component 7; peak $z = 6.96$, FWE $p = .0002$), and the bilateral parahippocampal cortex (component 11; peak $z = 5.57$, FWE $p = .002$). Group differences (MI<RI) were also found within the bilateral anterior medial PFC (component 5; peak $z = 5.20$, FWE $p = .015$), although this test exceeded FWE correction at $p < .01$. In sum, MI reduced intra-DMN connectivity relative to RI (Figure 1).


Component 5

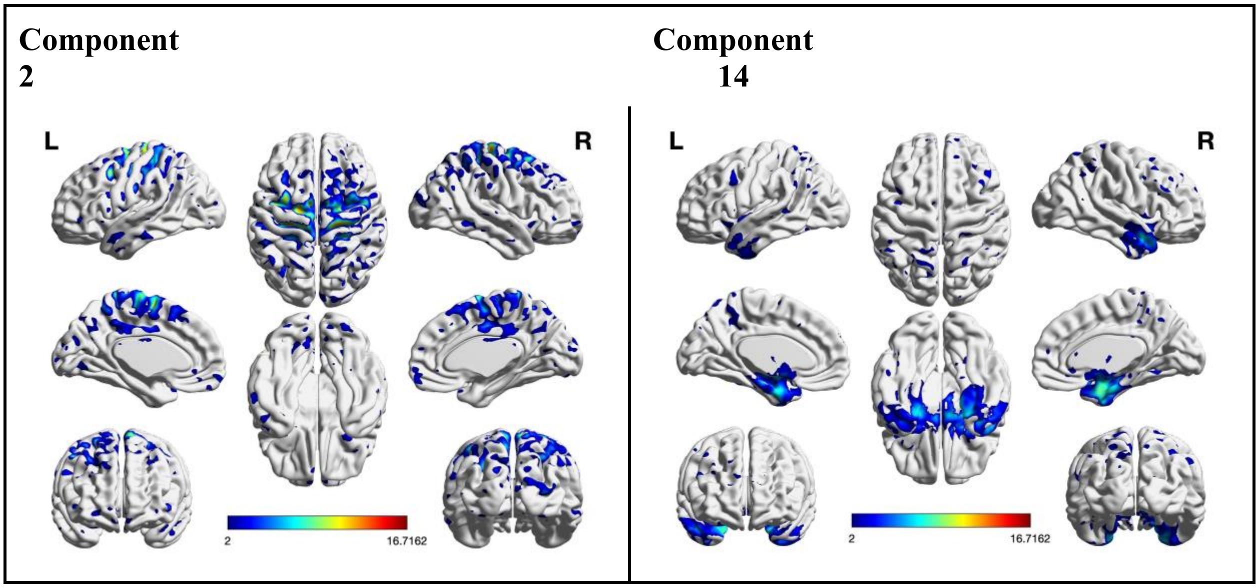
Component 7

Component 11

Figure 1. MI reduced DMN intrinsic connectivity relative to controls (MI<RI), as indicated by dual regression and two-group unpaired t-tests. Statistical maps are shown within the bilateral posterior cingulate cortex/precuneus (component 7; peak $z = 6.96$, FWE $p = .0002$), the bilateral parahippocampal cortex (component 11; peak $z = 5.57$, FWE $p = .002$), and the bilateral anterior medial PFC (component 5; peak $z = 5.20$, FWE $p = .015$). Components 5, 7, and 11 were spatially correlated with Yeo's (2011) Default Network at levels exceeding $r > .15$.

Mindfulness Induction's Effect on Connectivity Within the Salience Network

In support of Aim 2, MI enhanced intrinsic functional connectivity within SN components (Figure 2), concentrated in the inferior/superior parietal lobule (component 2; peak $z = 5.28$, FWE $p = .001$). Group differences were identified within the subcortical limbic structures (component 14; peak $z = 5.13$, FWE $p = .041$), although this test exceeded the preregistered alpha of FWE $p < .01$.


Component 2

Component 14

Figure 2. MI enhanced SN intrinsic connectivity relative to controls (MI>RI), as indicated by dual regression and two-group unpaired t-tests. Statistical maps are shown within the inferior/superior parietal lobule (component 2; peak $z = 5.28$, FWE $p = .001$) and within subcortical limbic structures (component 14; peak $z = 5.13$, FWE $p = .041$). Components 2 and 14 were spatially correlated with Yeo's (2011) Somatosensory Network and Limbic Network, respectively ($r > .15$).

Mindfulness Induction's Effect on Connectivity Within the Frontoparietal Control Network

In support of Aim 2, MI enhanced FPCN connectivity relative to RI (component 10; peak $z = 5.30$, FWE $p = .0004$), concentrated within the medial FPCN, anterior cingulate cortex, and superior/middle frontal gyrus (component 10) (Figure 3). Although this component was primarily associated with Yeo's FPCN network ($r = .35$), it showed partial overlap with Yeo's DMN component ($r = .17$).

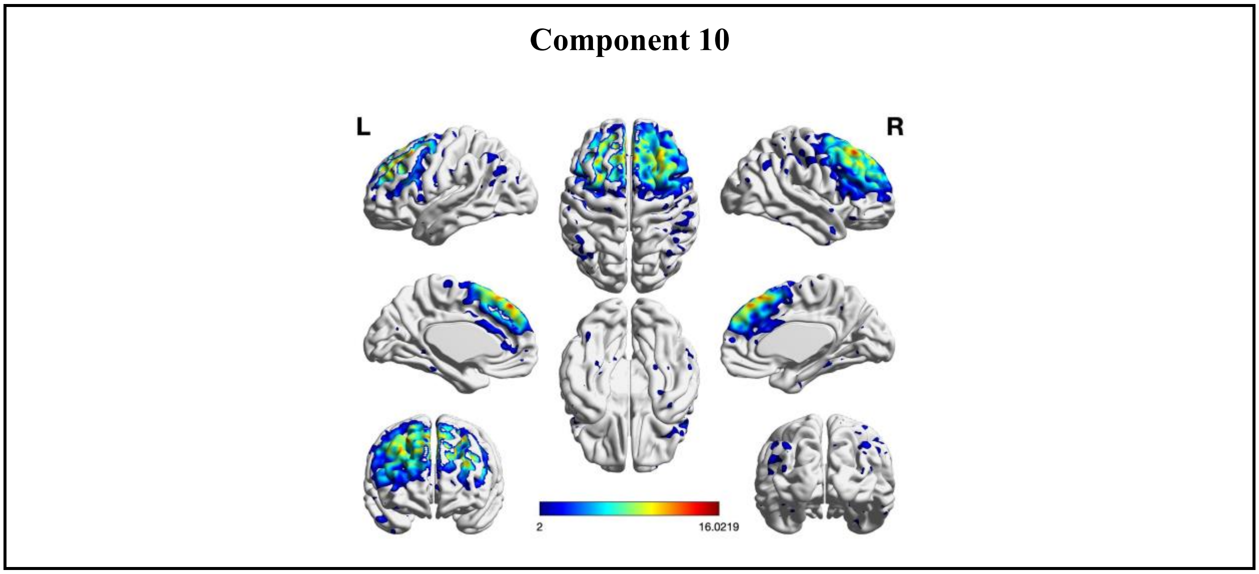

Component 10

Figure 3. Mindfulness increased FPCN intrinsic connectivity relative to controls (MI>RI), as indicated by dual regression and two-group unpaired t-tests. Statistical maps are shown within the medial FPCN (component 10; peak $z = 5.30$, FWE $p = .0004$). Component 10 was spatially correlated with Yeo's Frontoparietal Network ($r > .15$).

Mindfulness Induction's Effect on Between-Network Functional Connectivity

Aims 3-4 were not supported, as DMN-SN and DMN-FPCN connectivity did not differ significantly between induction groups. Follow-up exploratory network modeling revealed that mindfulness decreased functional coupling between visual (component 4) and FPCN (component 10) networks (MI $z = -8.900$; RI $z = -3.625$; FWE $p = .016$; Figure 4). Additionally, mindfulness decreased functional coupling between visual (component 4) and dorsal attention (component 7) networks (MI $z = 3.588$; RI $z = 8.436$; FWE $p = .019$; Figure 5). In both cases, effects exceeded our preregistered levels of significance (FWE $p < .01$).

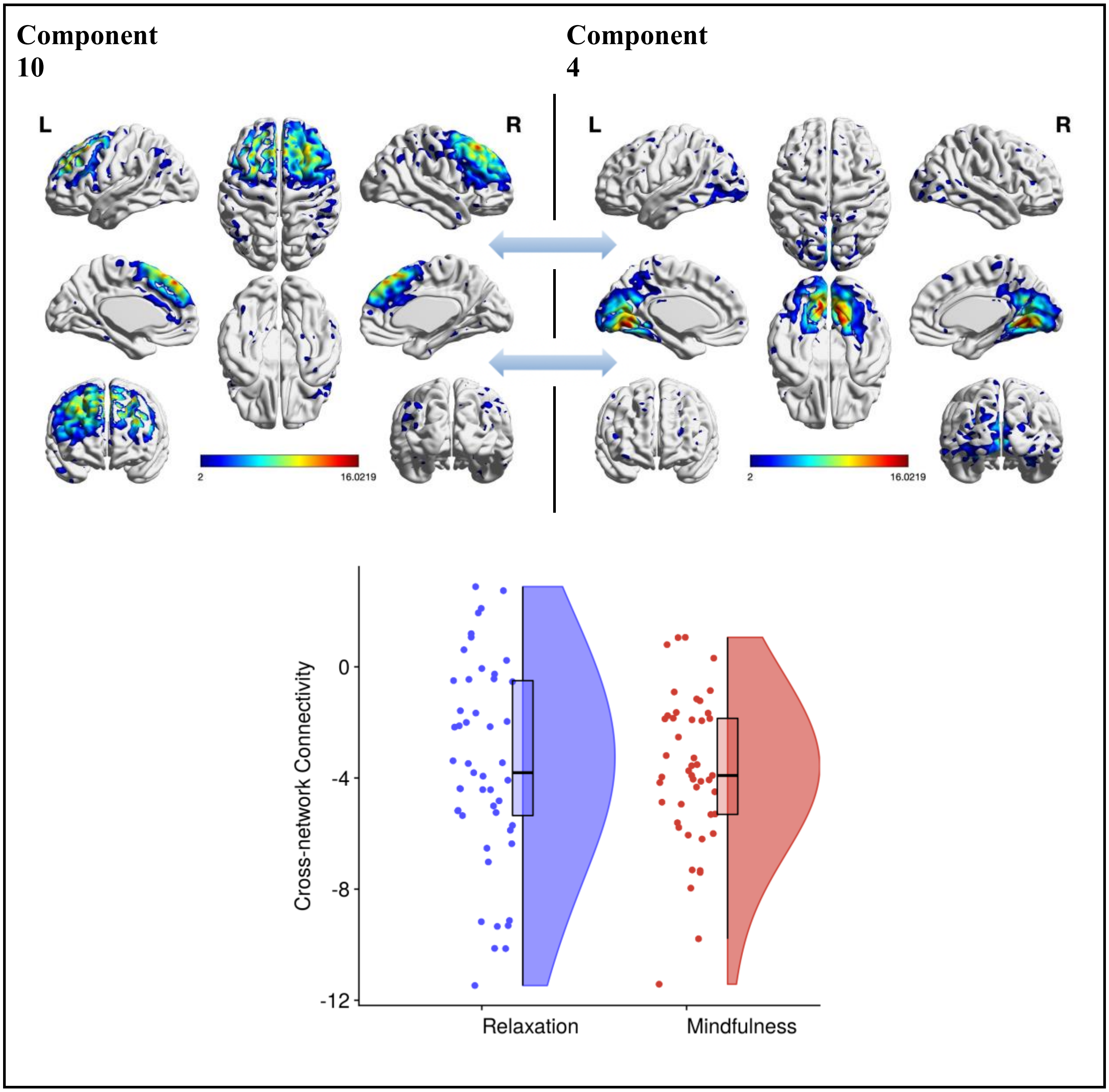


Figure 4. Boxplots depict the distribution of connection strengths between component 10 and component 4. Mindfulness instruction increases functional decoupling (MI *z* = -8.900; RI *z* = -3.625; FWE *p* = .016) between nodes of the frontoparietal network (component 10) and visual network (component 4). Blue arrows indicate negative functional coupling (i.e., decoupling) between nodes.

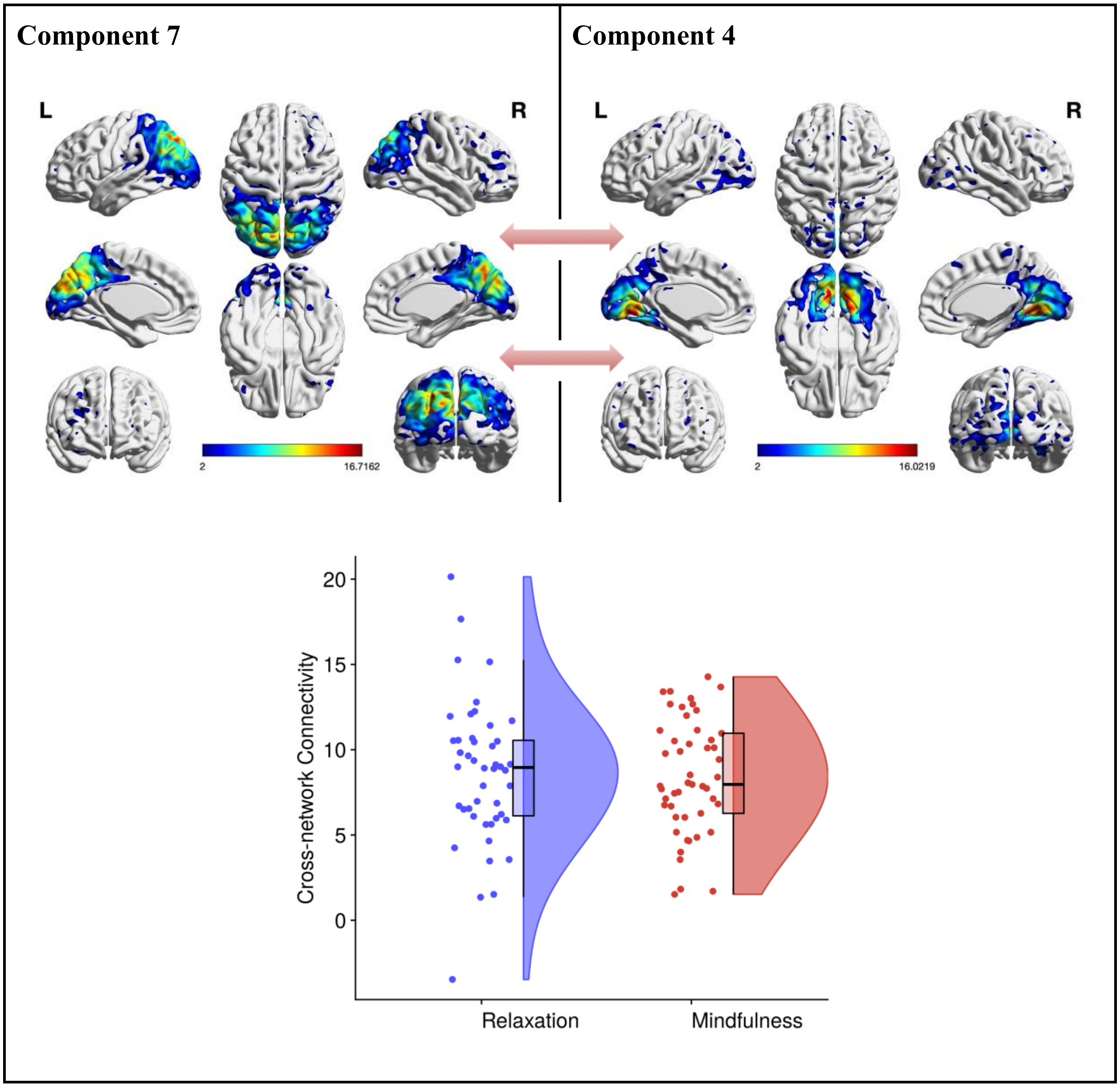


Figure 5. Boxplots depict the distribution of connection strengths between component 7 and component 4. Mindfulness instruction decreases functional connectivity (MI z = 3.588; RI z = 8.436; FWE p = .019) between nodes of the dorsal attention network (component 7) and visual network (component 4). Red arrows indicate positive functional coupling between nodes.

Effects on Intimate Partner Aggression

Intimate partner aggression was operationalized as the volume of noise blasts (1 – low to 4 – high) that participants chose to administer to their partner during the MRI aggression task, averaged across all eight partner aggression trials. Using multilevel modeling that nested participants' data within their respective intimate couple, the fixed effect of the mindfulness instruction did not alter subsequent intimate partner aggression, $\beta = .07$, $SE = .09$, $t = 0.76$, $p = .449$. Further, behaviorally measured and self-reported intimate partner aggression (i.e., AWIRS scores) were unassociated with any of the intrinsic functional connectivity estimates we acquired from the 17 independent components we extracted (Supplemental Table S3), even when analyses were constrained to the mindfulness condition (Supplemental Table S4).

Discussion

A wealth of research on mindfulness meditation has been amassed over the last several decades with a predominant focus placed on *outcomes* of mindfulness, either in terms of clinical benefits, behavioral manifestations, or neuroplastic effects (Berry et al., 2020; Fox et al., 2014, 2016; Khoury et al., 2013; Rahrig et al., 2022). While such outcomes and their purported mechanisms have been thoroughly documented, the *experience* of mindfulness in *real time* has been largely overlooked (c.f. Dixon et al., 2020; Hasenkamp & Barsalou, 2012; Kilpatrick et al., 2011). Acknowledging the challenges of characterizing subtle phenomenological experiences such as mindfulness (Brown & Cordon, 2009; Brown & Ryan, 2003), we have sought to bridge this gap through the neuroimaging-based investigation of mindful brain states. The present pre-registered study sought to characterize mindful states via plastic organization of large-scale brain networks. While substantial neuroimaging research has focused on meditation experts and mindfulness trainees (Hölzel et al., 2011; Marchand, 2014; Tang et al., 2015), relatively few studies have observed neural plasticity extending from early or single-dose exposure to mindfulness. This research gap is noteworthy given the substantial influx of brief, low-intensity practices made accessible by smartphones (Heppner & Shirk, 2018). As revealed through data-driven analyses, we found that one-time instruction in focused attention meditation induced functional reorganization within and between large-scale brain networks. Such effects were detected within theoretically anticipated networks, namely the default mode network (DMN), salience network (SN), and frontoparietal control network (FPCN); however, observations likewise extended to networks featured less frequently in the mindfulness literature, including the visual network (VN) and dorsal attention network (DAN). Theoretical implications are discussed herein with consideration to both within-network and between-network effects.

Within-Network Connectivity

Relative to relaxation instruction (RI), mindfulness instruction (MI) enhanced intra-network functional connectivity of salience (SN) and frontoparietal control networks (FPCN) while reducing intra-network functional connectivity of the default mode network (DMN). These three networks, collectively referred to as the ‘triple network’ (Menon, 2011), have been implicated in the cognitive outgrowths of mindfulness, which—as commonly theorized—include attentional control, emotion regulation, and self-awareness (Vago & Silbersweig, 2012). It is disputed whether mindfulness induction in novices can exert changes in the domains of emotion regulation or self-awareness (Leyland et al., 2019; Williams, 2010); however, one meta-analysis suggests that even a single session of mindfulness may immediately impact attentional mechanisms (Leyland et al., 2019), and that attentional enhancement may confer short-term cognitive and emotional benefits. The neuroimaging findings reported here may elucidate the neural pathways by which attentional focus influences other aforementioned targets of mindfulness downstream.

MIs elicit mindful states by guiding the meditator to continuously monitor their attention and redirect their focus in the instance of mind wandering. This iterative practice promotes multiple cognitive skills, namely attentional awareness and redirection, ostensibly supported by the SN and FPCN. In alignment with this neurocognitive framework, our analysis indicated that MI, relative to RI, evoked greater connectivity within network 10, a network comprising sections of both the dACC and dorsolateral PFC. MI additionally elicited greater connectivity within the inferior parietal cortex, a region often classified under the salience network (Yeo et al., 2011). Collectively these findings suggest that MI may facilitate within-network communication of the SN and FPCN. Further, such transient brain states–ostensibly associated with attentional control–may be accessible at even early stages of meditation practice.

We found that compared to RI, MI reduced functional connectivity within DMN networks localized to the anterior medial PFC (amPFC), posterior cingulate cortex (PCC), and the parahippocampal gyrus. Our findings are consistent with prior studies linking trait mindfulness (Doll et al., 2015; Harrison et al., 2019) and mindfulness training (Fingelkurts et al., 2016; J. Zhang et al., 2023) to reduced DMN coherence, particularly within posterior components of the DMN (Dixon et al., 2020; Xiao et al., 2019) and between posterior and anterior DMN regions (Cooper et al., 2022). While the DMN has been shown to support a diversity of functions (Laird et al., 2009; Smallwood et al., 2021), it has most prominently been implicated in self-referential cognition, particularly during moments of "mind wandering" (i.e., off-task mentation) (Christoff, 2012; Christoff et al., 2009). Similarly, DMN engagement has been observed during self-reported periods of mind wandering in expert meditators (Hasenkamp et al., 2012). Associated with the midline core subsystem of the DMN, the anterior medial PFC (component 5) is consistently engaged during self-related tasks (Andrews-Hanna et al., 2014), while the medial temporal subsystem—containing the parahippocampal gyrus (component 11)—facilitates autobiographical mentation (i.e., past memories and future simulation) (Rugg &

Vilberg, 2013). In turn, the PCC/precuneus (component 7) mediates DMN neural circuits underlying these and other forms of self-referential processing (Fransson & Marrelec, 2008).

While self-referential and autobiographical cognitions are undeniably important (Heatherton, 2011), such thoughts can become distracting, distressing, or disruptive to daily functioning (Hamilton et al., 2015). In this vein, such forms of perseverative cognition have been linked to abnormal patterns of DMN activation and functional connectivity (Hamilton et al., 2015). Our findings offer a potential mechanism through which MIs may facilitate disengagement from self-immersed states of mind wandering via the decoupling of DMN neurocircuitry (Andrews-Hanna et al., 2020). However, the DMN includes diverse specialized subcircuits (Andrews-Hanna et al., 2020), and further research is needed to ascertain how reorganization within and between discrete DMN subnetworks maps onto cognitive functions associated with mindfulness. Advancing such research questions may likewise inform how specialized neural circuits within the DMN contribute to the wide varieties of conscious thought, ranging from rumination to creative thinking and insight (Frewen et al., 2020).

Between-Network Connectivity

Network modeling revealed key differences between MI and RI in regards to cross-network connectivity. More specifically, MI showed comparatively stronger anti-correlations between the visual network (VN) and FPCN, as well as relatively reduced connectivity between nodes of the VN and Dorsal Attention Network (DAN). Notably, VN-related effects are scarcely reported in the mindfulness literature (e.g., Doll et al., 2015; Kilpatrick et al., 2011). Indeed, prominent mechanistic accounts of mindfulness contend that practice enhances interactions between three large scale brain networks, the DMN, SN, and FPCN, collectively referred to as the ‘triple network’ (Menon, 2011). However, triple network inter-connections were not implicated in these findings; rather, MI appeared to weaken or reduce coherence between the VN and networks associated with attention and executive functioning (i.e., the DAN and FPCN, respectively). Considering that attention processes and visual perception are inextricably linked (Pessoa et al., 2013), we argue that the relationship between mindfulness and visual processing warrants greater exploration.

Buddhist scholars have long recognized the constructed nature of perceptual events, meaning that (visual) perceptions are influenced by prior experiences (Anālayo, 2019). An overarching aim of meditation practice is to perceive the nature of experience with greater clarity, or “bare awareness” (Anālayo, 2019). It may be argued that “bare awareness”, as used here, strictly refers to post-perceptual mechanisms in the vein of reducing subjective appraisal, reactivity, etc. However, Anālayo (2019) asserts that these mental faculties may extend to low-level perceptual processes, a concept likewise supported by recent research in the field of visual perception (Niedenthal & Wood, 2019). Research has shown that low-level perceptual mechanisms may be modulated by emotion (particularly fear; Lapate et al., 2014); personality style (Yovel et al., 2005), culture (Blais et al., 2008), and even racial bias (Charbonneau et al., 2020; Carter et al., 2005). More germane to the topic at hand, one study of Tibetan Buddhist monks demonstrated that focused attention meditation could acutely improve visual performance on perceptual rivalry tasks (Carter et al., 2005). Nevertheless, the literature offers little mechanistic explanation for the effects of mindfulness on visual perception.

One surprising source of insight derives from research of simple visual hallucinations within the scope of meditation practice (Lindahl et al., 2014). Meditation-induced light experiences (i.e., hallucinations) are frequently mentioned in traditional Buddhist texts (for review see Lindahl et al., 2014) and reported by Buddhist practitioners in qualitative research

(Lindahl et al., 2014, 2017). It has been suggested that by concentrating attention on a single sensory object (e.g., the breath), focused attention may be analogous to sensory deprivation experiences (Lindahl et al., 2014). Importantly, deprivation of visual sensation has shown to accelerate neuroplasticity, particularly within the visual cortex (Boroojerdi et al., 2000), which may precipitate simple visual hallucinations. However, this neuroplastic potential may speculatively extend to other cortical areas and cognitive skill sets. This sensory deprivation theory may explain why brief focused attention instruction was able to acutely induce functional connectivity changes between the VN and attentional networks. At minimum, this theory highlights the need to consider sensory processes as potentially integral to the mechanisms of mindfulness, and by extension, the phenomenology of meditative brain states.

Links to Intimate Partner Aggression

Against our expectation, the meditative brain state we induced exerted no effect upon subsequent intimate partner aggression. This null result casts doubt on the ability of a single-dose mindfulness interventions to affect such hostile behavior. Our findings align with other research reporting null effects of mindfulness on aggression reduction (Rahrig et al., 2021). Here, mindfulness instruction was shown to alter connectivity within the DMN. Previous literature suggests a mechanistic role of DMN neurocircuitry in intimate partner violence. Lab-based measures of intimate partner aggression have been correlated with activity in core DMN regions, either during provocation or during aggression decision making (e.g., Chester et al., 2021; Chester & DeWall, 2019). Further, convicted perpetrators of intimate partner violence have been shown to exhibit aberrant DMN activation when considering moral dilemmas involving their female partners (Marín-Morales et al., 2022). In other contexts (i.e, social rejection), MIs have been shown to attenuate affective reactivity to provocation via altered prefrontal cortical functioning (Martelli et al., 2018). However, behavioral and neural evidence suggests that interpersonal aggression may be cognitively distinct from other forms of harmful behavior (Amaoui, Marín-Morales, et al., 2022; Amaoui, Martín-Pérez, et al., 2022; Marín-Morales et al., 2022). For example, previous research suggests that perpetrators of interpartner violence may respond to moral dilemmas with neurotypical activation—localized to the DMN—but that such responses are absent when dilemmas involve interpartner aggression (Marín-Morales et al., 2022). Such studies illustrate how interpartner violence may be resistant to change, possibly due to a host of cognitive and socio-environmental factors (e.g., moral disengagement, history of trauma, etc.). Harmful behaviors are the product of associative learning, and undermining persistent mindsets requires time and internalized motivation (FeldmanHall & Dunsmoor, 2019), which cannot necessarily be induced by a single mindfulness practice.

Limitations and Future Directions

While the results reported here are consistent with empirical and theoretical accounts of the neural bases of mindfulness, their interpretation is nevertheless limited in the absence of supporting behavioral or subjective metrics. Probing subjective experiences embedded in mindfulness meditation remains a challenging obstacle for researchers. Although few in number, select studies have attempted novel phenomenological approaches in which discrete meditative experiences are subjectively reported by participants undergoing fMRI acquisition (Hasenkamp et al., 2012; Weng et al., 2020). Such studies underscore that the state of meditation is not *static*, but *dynamic* in nature. In even a brief mindfulness session, a novice (and even experienced) practitioner may cycle through multiple periods of focused attention interspersed with moments of unintentional mind wandering. In this respect, dynamic measures of functional connectivity are better suited to capturing momentary interactions among networks (Chang & Glover, 2010;

Hutchison et al., 2013). Dynamic functional connectivity approaches can ascertain how discrete patterns of connectivity, representing various cognitive states, unfold over time. In the context of mindfulness, dynamic functional connectivity has been leveraged to estimate frequency of mind wanderings occurring during a focused attention meditation (Mooneyham et al., 2017). It is plausible that this approach may be capable of characterizing a broad range of cognitive states associated with mindfulness. In the scope of healthcare, such cognitive states may become an informative tool for healthcare providers and meditation instructors who aim to maximize the benefits of mindfulness-based programs.

A second limitation concerns the study design and risk of order effects. In the study protocol mindfulness/relaxation induction was always delivered prior to the behavioral aggression task, which always preceded the self-report questionnaire. Prior psychometric investigations of the Taylor Aggression Paradigm (TAP) suggest that administration of the TAP has little to no demonstrable effect on self-reported aggression scores (Chester & Lasko, 2019). Nevertheless, the TAP has been shown to systematically provoke anger in participants (e.g., DeSteno et al., 2018; Stanger et al., 2016), and we cannot entirely rule out the possibility that the behavioral aggression task incidentally introduced systematic variability in the present sample.

Conclusion

While the preponderance of mindfulness research focuses on the neuroplastic outcomes of long-term mindfulness-based or -integrated programs, the results reported here suggest that changes in neurocircuitry may occur during brief practice of mindfulness. Findings are consistent with prior studies associating trait and state mindfulness with increased functional connectivity within FPCN and SN networks and reduced coherence within DMN networks. Additionally, we provide initial evidence that mindfulness may promote decoupling between visual areas and attention networks, although such effects may be confined to early stages of practice. Despite these robust effects upon large-scale network activity and organization, we were unable to observe any attenuating influence of a brief mindfulness intervention upon intimate partner aggression. Collectively these results suggest that minimal doses of mindfulness may promote transient changes in neural circuitry shown to facilitate adaptive self-regulation. Nevertheless, it remains unclear whether they have any meaningful consequences for human aggression.

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Open Practices Statement

Procedures for the broader study that these data were derived from are pre-registered and publicly available (https://osf.io/un2fy). The current project comprised a secondary analysis (see pre-registered aims 1-4; https://osf.io/ydrja) aimed to test the experimental effects of MI on functional neurocircuitry. In extension of aims 1-4, subsequent analyses were performed to examine the relations between intrinsic functional connectivity (IFC) patterns and trait mindfulness, among other self-reported variables (e.g., trait empathy, inclusion-of-partner-in-self; https://osf.io/ruwma). Analyses did not support hypothesized relations between IFC, and these self-reported variables and these results are not enumerated in the current report. As detailed by Finkel and colleagues (2015), we cannot publicly share these sensitive dyadic data, yet we will share such de-identified data with competent professionals who request it.

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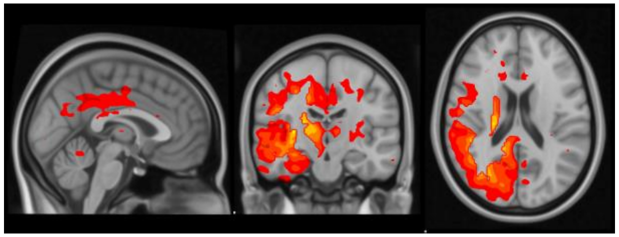
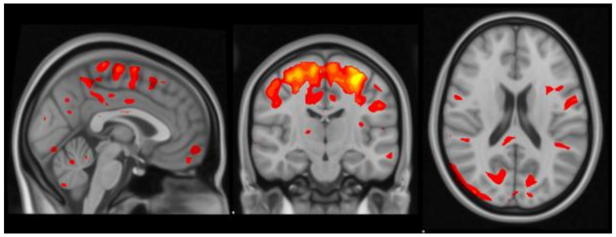
Supplemental Table 1.

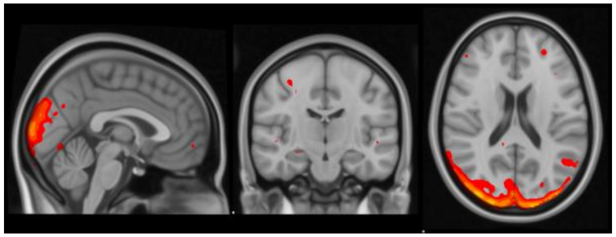
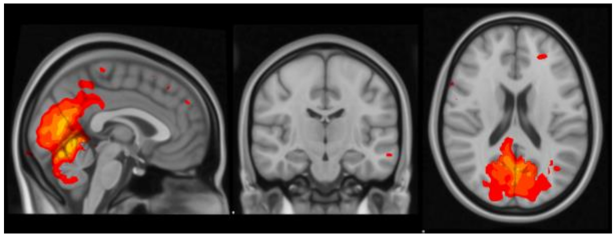
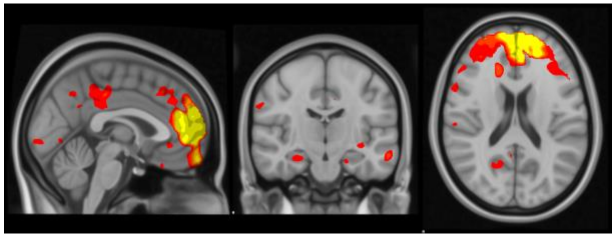
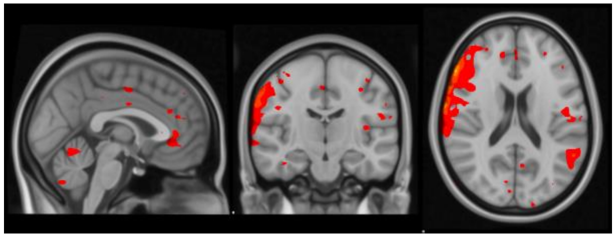
Original sample demographics

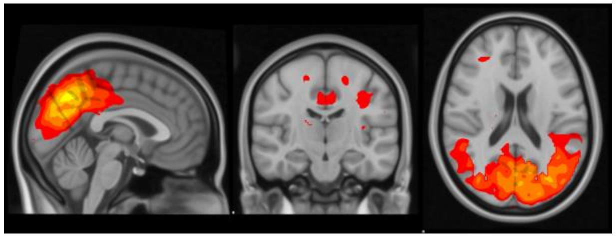
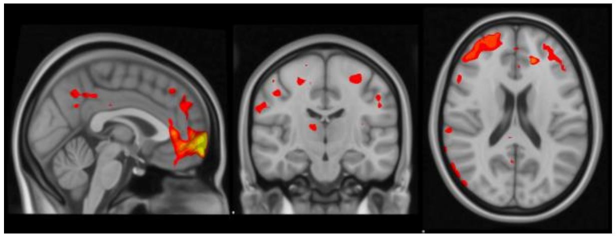
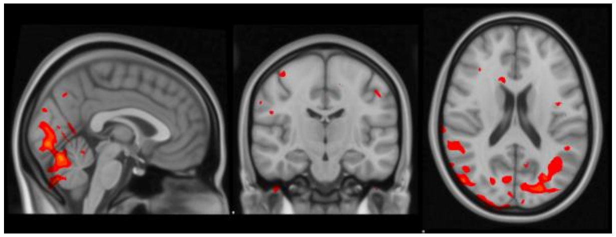
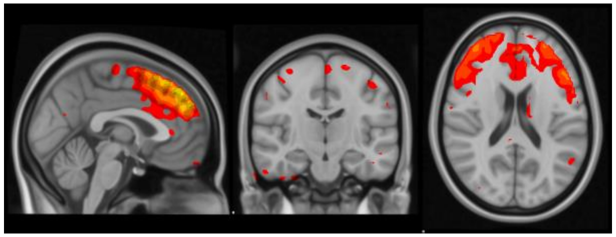
Participant Sample (*n* = 100)	
	M (*SD*)
Age (*range* = 18 - 35)	21.61 (3.73)
Biological Sex (%)	
Female	51%
Male	49%
Race	
African American	7%
Asian American	22%
Native American	1%
White	45%
Other	22%
Missing	3%
Ethnicity	
Hispanic	19%
Non-Hispanic	78%
Missing	3%

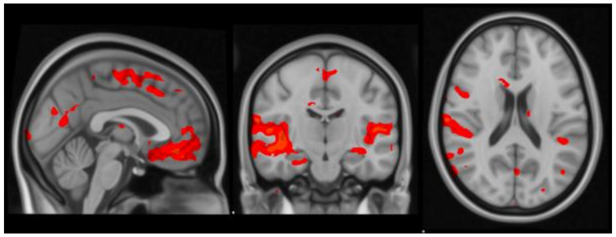
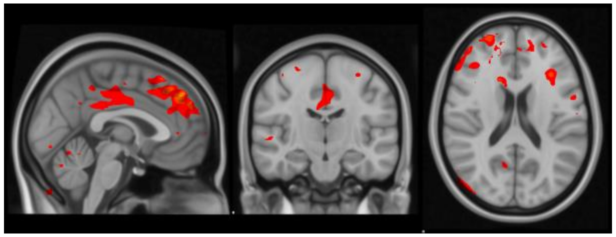
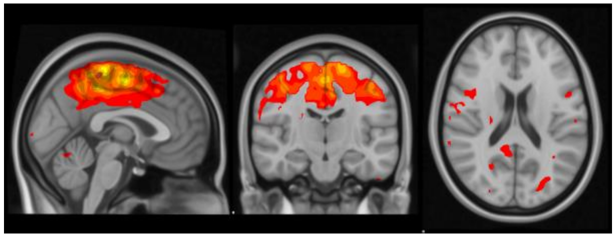
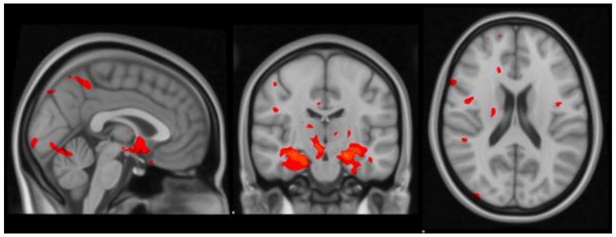
Supplemental Table 2.

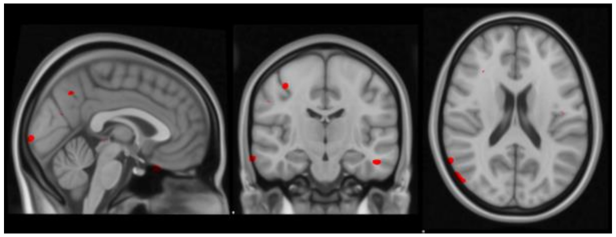
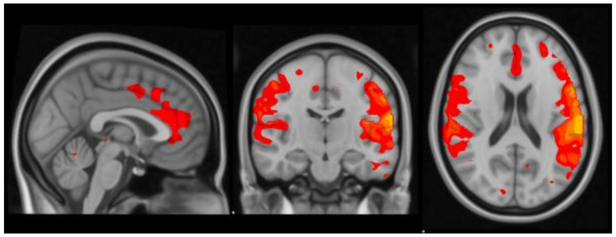
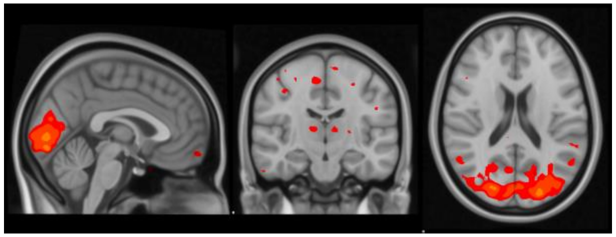
Results of group independent component analysis (ICA) and dual regression comparing functional coherence between Mindfulness Instruction (MI) to Relaxation Instruction (RI).

Component #		Network Label(s)	Peak MNI coordinates	Z-score					
				MI > RI			RI > MI		
				Min	Max	*p*	Min	Max	*p*
1		Visual (*r* = .25)	41, -35, 7	-4.77	4.84	.056	-4.84	4.78	.0012***
2		Somatosensory (*r* = .20) Dorsal Attention (*r* = .16)	-27, -19, 55	-3.81	5.28	.001**	-5.28	3.81	.41

3		Visual (*r* = .43)	35, -91, 17	-4.59	3.67	.71	-3.68	4.59	.007**
4		Visual (*r* = .52)	9, -61, 1	-6.34	4.55	.79	-4.55	6.34	.0004***
5		Default (*r* = .25)	-5, 63, 11	-5.20	4.64	.38	-4.64	5.20	.015*
6		Somatosensory (*r* = .21) Ventral Attention (*r* = .16) Frontoparietal (*r* = .21)	59, 27, 19	-4.36	4.94	.079	-4.94	4.36	.28

7		Visual (*r* = .32) Dorsal Attention (*r* = .26) Default (*r* = .19)	1, -67, 37	-6.96	5.51	.11	-5.51	6.96	.0002***
8		Frontoparietal (*r* = .23) Default (*r* = .22)	-9, 47, 3	-4.58	5.23	.053	-5.23	4.60	.0176*
9		Visual (*r* = .34)	-27, -71, -41	-5.31	3.94	.56	-3.95	5.31	.0002***
10		Frontoparietal (*r* = .35) Default Mode (*r* = .17)	-3, 41, 45	-4.98	5.30	.0004***	-5.31	4.98	.037*

11		Somatosensory (*r* = .18) Ventral Attention (*r* = .22) Limbic (*r* = .15) Default (*r* = .21)	41, 13, -1	-5.57	4.69	.25	-4.69	5.57	.002*
12		Frontoparietal (*r* = .24) Default (*r* = .18)	35, 51, 27	-5.33	4.56	.049*	-4.56	5.33	.0016*
13		Somatosensory (*r* = .31) Dorsal Attention (*r* = .32) Ventral Attention (*r* = .15)	19, -29, 67	-6.33	3.81	.077	-3.81	6.33	.0002*
14		Limbic (*r* = .24)	21, 1, -27	-4.10	5.13	.041*	-5.13	4.10	.076

15		Limbic (r = .28)	-33, 19, -35	-5.76	4.03	.96	-4.03	5.76	.0002*
16		Somatosensory (r = .28) Ventral Attention (r = .32) Default (r = .18)	-63, -19, 23	-4.76	4.58	.33	-4.58	4.76	.0006*
17		Visual (r = .53)	-35, -91, -15	-3.94	4.56	.021*	-4.59	3.94	.38

Note. Components were labeled according to Yeo's 7-network cortical parcellation (Yeo et al., 2011) with all components exceeding spatial correlation of $r > .15$. Spatial correlations with each corresponding network label are reported. Peak MNI values are derived from group independent component analysis (ICA) results. Minimum and maximum *z*-scores are reported for the second-level analysis comparing network coherence between participants in the mindfulness instruction (MI) and relaxation instruction (RI) groups.

*$p < .05$, **$p < .01$, ***$p < .001$

Supplemental Table 3.

Associations Between Intimate Partner Aggression and Resting State fMRI Components

Component	fMRI Aggression Task	AWIRS
1	.01	.00
2	-.03	-.05
3	.00	-.06
4	.00	-.02
5	.00	.00
6	-.04	.09
7	.00	-.05
8	-.01	.00
9	.01	-.03
10	.00	.00
11	.02	-.06
12	.02	-.02
13	.03	.06
14	.00	-.06
15	.03	.03
16	.00	-.07
17	.00	.03

Note. Values reflect unstandardized regression coefficients from multilevel models that nested participants within their respective intimate couple, modeling random intercepts for each participant alongside the random effect of couple and the fixed effect of each component. AWIRS analyses employed a generalized multilevel linear models that specified a binomial test family with a logit link function (as the scale was coded 0 = no past overt IPA, and 1 = past over IPA, as in Chester et al., 2021). fMRI = Functional Magnetic Resonance Imaging, AWIRS = Abuse Within Intimate Relationships Scale. $^{*}p < .05$, $^{**}p < .01$, $^{***}p < .001$

Supplemental Table 4

Associations Between Intimate Partner Aggression and Resting State fMRI Components, Participants in Mindfulness Condition Only

Component	fMRI Aggression Task	AWIRS
1	.20	-.08
2	-.32*	.00
3	.03	.04
4	-.19	-.06
5	.07	-.01
6	-.18	-.01
7	.13	-.21
8	-.11	-.02
9	.03	-.04
10	-.10	-.19
11	.19	-.09
12	.21	-.14
13	.25	.08
14	.12	-.11
15	.05	-.12
16	-.02	.06
17	.05	-.15

Note. Values for the fMRI Aggression Task reflect zero-order correlation coefficients (multilevel models were no longer required as only one participant per couple completed each induction). Values for the AWIRS reflect unstandardized regression coefficients calculated by generalized linear models that specified a binomial test family with a logit link function (as the scale was coded 0 = no past overt IPA, and 1 = past over IPA, as in Chester et al., 2021). fMRI = Functional Magnetic Resonance Imaging, AWIRS = Abuse Within Intimate Relationships Scale.
**p* < .05, ***p* < .01, ****p* < .001