

ORIGINAL ARTICLE

Comparing impacts of meditation training in focused attention, open monitoring, and mindfulness-based cognitive therapy on emotion reactivity and regulation: Neural and subjective evidence from a dismantling study

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Abstract

Commonly conducted mindfulness-based trainings such as Mindfulness-based Stress Reduction (MBSR) and Mindfulness-based Cognitive Therapy (MBCT) highlight training in two key forms of meditation: focused attention (FA) and open monitoring (OM). Largely unknown is what each of these mindfulness practices contributes to emotional and other important training outcomes. This dismantling trial compared the effects of structurally equivalent trainings in MBCT, FA, and OM on neural and subjective markers of emotional reactivity and regulation among community adults, with the aim to better understand which forms of training represent active ingredients in mindfulness trainings. Participants with varying levels of depressive symptoms were randomized to one of the three trainings. Before and after each 8-week training, $N = 89$ participants completed a modified version of the Emotional Reactivity and Regulation Task while electroencephalographic (EEG) and self-reported emotional responses to negative, positive, and neutral photographic images were collected. Examination of EEG-based frontal alpha band asymmetry during passive viewing (reactivity) and active regulation phases of the task showed that FA and MBCT trainings produced significant leftward hemispheric shifts in frontal alpha asymmetry, commonly associated with a shift toward approach-based positive affect. Self-reported emotional responses to negative images corroborated these results, suggesting salutary changes in both emotional reactivity and regulation. OM training had limited beneficial effects, restricted to the subjective outcomes. The findings suggest that MBCT may derive its greatest benefit from training in FA rather than OM. Discussion highlights the potential value of FA training for emotional health.

KEYWORDS

electroencephalography, emotion regulation, emotional reactivity, meditation, mindfulness

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1 | INTRODUCTION

Emotional reactivity, the intensity of response to emotional stimuli, is central to anxiety and mood disorders, and training in emotion regulation, the ability to alter that emotional response, is a common element in therapeutic approaches to those and other conditions. In recent years psychoeducational and psychotherapeutic models based on or incorporating mindfulness training have demonstrated efficacy in treating internalizing disorders and enhancing emotional health (Creswell, 2017; Hofmann et al., 2010). Interest in mindfulness trainings is widespread, but little is known about active ingredients of these trainings (Davidson, 2010; Ospina et al., 2007). This topic is important because mindfulness training encompasses a variety of practices, a number of which are commonly included in various mindfulness-based and mindfulness-integrated trainings. Determining active ingredients in mindfulness trainings will facilitate efforts to enhance their effectiveness and efficiency.

Training in attention is a key component of mindfulness trainings, and theory and evidence suggest that such training is a primary means by which emotional health is enhanced through mindfulness training (Bostanov et al., 2012, 2018; Hölzel et al., 2011; Tang et al., 2015). Indeed, attention lies at the core of what mindfulness means. Canonically, mindfulness has been described as a sustained, receptive attention to salient stimuli on a moment-to-moment basis—that is, in the present (Bhikkhu, 2003), a conceptualization reflected in clinical descriptions of this mode of attention that emphasize sustained attention accompanied by an attitude of acceptance or allowance of what is attended to (Bishop et al., 2004; Lindsay & Creswell, 2017). Yet the way in which receptive attention is trained differs considerably in secular mindfulness trainings such as mindfulness-based stress reduction (MBSR; Kabat-Zinn, 1990) and mindfulness-based cognitive therapy (MBCT; Segal et al., 2002). Attention may be trained to focus on specific sensory and perceptual stimuli—often termed “focused attention” (FA) training—or attention can be trained to monitor all salient events and experiences that arise in the field of awareness—termed training in “open monitoring” (OM) (Lutz et al., 2008). Because these two forms of attention training are typically both included in programs like MBSR and MBCT, it is unknown which, if either, carries responsibility for training effects. This points to the need for research that dismantles frequently deployed mindfulness programs to compare FA, OM, and their combination. The present study was designed to do this to assess independently these purported mechanisms of effect on emotional reactivity and regulation.

1.1 | Deconstructing mindfulness training

Mindfulness training (MT) encompasses a family of meditative practices that, at their core, foster attention regulation; these various means to do so have implications for emotional experience and the regulation of that experience. A crucial difference lies in how emotional stimuli—provocative sensory, kinesthetic, or cognitive events, for example—are treated when they arise. In FA, attention is disengaged from such stimuli so that focus on an affectively neutral meditative object (commonly the sensory experience of breathing) can be maintained. FA is thought to enhance attentional control in two ways: first by orienting attention to a pre-selected perceptual object, and second through conflict monitoring (also termed executive attention), which serves to prioritize among competing tasks or responses that disengage from those that are not congruent with goals. Concretely, in FA meditation, attention is directed to the chosen object while monitoring the stability of that FA. When attention is distracted by other stimuli, or wanders away from the object, this is noticed, and attention is re-oriented back to the meditative object. By fostering stability of attention, FA is believed to reduce the frequency of negative thoughts and emotions, and produce greater calmness of mind (Lutz et al., 2008).

OM meditation is, at least in its use of attention and treatment of emotional stimuli, the opposite of FA practice. Rather than sustaining attention to a single stimulus, OM involves a receptive awareness or monitoring of all stimuli that arise moment-to-moment. This includes remaining receptively or non-reactively aware of emotion-provocative stimuli, and in this deliberate exposure to them, automatic cognitive and emotional appraisals of those stimuli are diminished. An end result is believed to be greater distress tolerance, non-reactivity, and habituation to difficult cognitive and emotional events and experiences (see review in Lutz et al., 2008).

Secular mindfulness training programs, particularly MBSR and MBCT, typically introduce and promote experiential practice in FA first and then OM over the course of their eight weeks of classes (Santorelli et al., 2017; Segal et al., 2002). This combination may offer the benefits of both forms of meditation outlined above, but also makes it difficult to know whether each is an active contributor to training outcomes. A call for dismantling MT programs into more basic didactic and experiential components has come from a number of researchers over the past 15 years (Davidson, 2010; Davidson & Dahl, 2017; Ospina et al., 2007; Rappagay & Bystrisky, 2009). Several studies have examined the effects of FA and OM separately (Ainsworth et al., 2013; Uusberg et al., 2016), but to date no research to our knowledge has systematically compared them to each

other or to standard MT (e.g., MBSR, MBCT) in their effects on emotion outcomes.

1.2 | Mindfulness training effects on emotional reactivity and regulation

Previous research suggests that mindfulness trainings, particularly those following MBSR and MBCT treatment models, can dampen emotional reactivity and can boost emotion regulation capacities among healthy and clinical populations (Arch & Landy, 2015), including those for whom emotion dysregulation is a major feature, particularly individuals with major depression (Britton et al., 2012). MT effects on emotional reactivity and regulation have been explored using a variety of subjective and neurophysiological measures. Given the rapidity with which emotional reactivity and regulatory responses occur, a number of studies have investigated MT effects using neurophysiological methods, including functional magnetic resonance imaging (fMRI) and electroencephalography (EEG), designed to track quickly changing brain activity and activation in regions associated with emotion and motivation (Allen et al., 2012; Braunstein et al., 2017; Ochsner & Gross, 2014). One predominant approach has focused on hemispheric electrophysiological activity and activation in frontal regions of the brain. In particular, a long history of EEG research has uncovered patterns of frontal electrocortical asymmetry between left and right hemispheres of the brain that have been associated with both state and trait expressions of emotional reactivity, emotion regulation, and motivation in healthy and depressed populations. Indeed, a pattern of frontal asymmetry in the alpha frequency band (8–13 Hz)—namely greater left hemispheric than right hemispheric alpha band activity—is proposed to be an endophenotype of depression and depressive risk (Allen et al., 2012; Allen, Urry, et al., 2004; Keune et al., 2011). More generally, relative right-sided frontal alpha asymmetry (FAA) has been associated with withdrawal-based negative affect (e.g., sadness, fear) while relative left-sided FAA has been linked with approach-based positive affect (and approach-based negative affect, particularly anger). A small number of studies have linked FAA with underlying neural regions, including the dorsal-lateral prefrontal cortex (dlPFC), which is part of a circuit of interconnected PFC regions that contribute to emotional states. Evidence suggests that emotion-relevant (i.e., reward) information first enters the PFC via the orbital region (e.g., Rolls, 1999), from whence it is passed to the dlPFC to guide behavior (see review by Davidson, 2004). The left dlPFC in particular has been associated with approach motivation (e.g., Berkman & Lieberman, 2010; Pizzagalli et al., 2005).

Cahn and Polich (2006) concluded that the findings from MT research showing benefits for emotional health are “consistent with the hypothesis that meditation induces a significant reorganization of frontal hemispheric activity associated with emotional reactivity and outlook” (p. 201) that may be associated with alpha EEG activation. However, relatively few studies have examined the proposition that MT produces shifts in frontal alpha asymmetry (FAA), reduced emotional reactivity, more effective emotion regulation, and emotional well-being in general (Lomas et al., 2015). Research that has done so has largely focused on resting state assessments of affective style among mindfulness meditation trainees from both healthy and depressed populations.

Aiming to test the effect of an 8-week MBSR program on resting FAA among healthy adults, Davidson et al. (2003) found that compared to wait-list controls, MBSR trainees showed a leftward shift in resting alpha asymmetry from pre-training to 4-month follow-up but at central sites (C3/C4) and anterior temporal sites (T3/T4), rather than prefrontal electrode sites, and the (marginally) significant condition \times time interactions in asymmetry at these sites may have been in part driven by rightward shifts in the control condition (Travis & Arenander, 2004). In a sample of healthy elders, Moynihan et al. (2013) found that MBSR participants showed a non-significant leftward shift in FAA (at F4-F3) from pre- to post-training, while wait-list controls showed a significant rightward shift at this electrode pair. Mindfulness trials with depressed individuals have produced equally mixed results. In a small trial with recurrently depressed participants, Szumska et al. (2020) found that MBCT trainees showed no change in resting FAA from pre- to post-training relative to wait-list controls. In another small trial, Barnhofer et al. (2007) also showed no MBCT effect of resting FAA, while treatment-as-usual controls showed a rightward shift in FAA from pre- to post training. In that study, MBCT was interpreted as serving a protective function against depression relapse in those trainees. A larger-sample trial by Keune et al. (2011) found that both MBCT and wait-list participants showed a rightward shift in resting FAA. MBCT trainees however, showed comparatively lower depressive symptoms and rumination relative to wait-list participants.

To date, very few attempts have been made to examine state effects of mindfulness meditation on frontal EEG asymmetry (e.g., Barnhofer et al., 2010; Keune et al., 2013; Moyer et al., 2011). In particular, using emotional challenges is likely to increase signal relevant to emotional reactivity and regulation, and may produce more reliable FAA estimates than assessing resting state activity; in the latter, uncontrolled subject factors may attenuate power to detect relations between FAA and other variables (Coan et al., 2006; Smith et al., 2017). Research by

Stewart et al. (2014) found that recordings of brain asymmetry during an emotional challenge task differentiated depressed from never-depressed adults more strongly than did resting activity recordings. Thus, training-based differences in alpha asymmetry may be more apparent during emotional challenges than during rest (Keune et al., 2011). To date, only three studies have examined whether MT, using the MBCT program, alters state FAA (Keune et al., 2011, 2013; Zhou & Liu, 2017). In all three studies (two non-experimental, one experimental), brain activity was measured after rather than during emotional challenge (e.g., sad mood induction). However, these studies inform about the role in MT in recovery from emotional challenge. For example, Keune et al. (2013) found a significant leftward shift in FAA (at F4-F3) during mindfulness meditation following a negative mood induction.

We sought to test MT effects on both emotional reactivity and regulation. In the present study, EEG was recorded during passive viewing of emotional stimuli as well as during subsequent viewing with instructions to regulate emotion using mindfulness-based techniques learned during training. This permitted investigation of MT effects on both reactivity and regulation during emotional challenge.

1.3 | The present study

The primary aim of this dismantling randomized controlled trial was to compare the effects of 3 structurally equivalent mindfulness meditation trainings—FA, OM, and the parent MBCT program—on neural and subjective indicators of emotional reactivity and recovery in the face of provocative emotional stimuli. Originally designed to treat depressive relapse, MBCT has been applied successfully to a wide range of other psychological conditions in which poor emotion regulation is implicated (e.g., non-chronic depression, substance abuse, overeating, etc.; see review in Britton et al., 2018). MBCT allocates all of its psychoeducational content to addressing emotional disturbances (Britton et al., 2018).

In the present study, participants with varying levels of depressive symptoms completed a modified version of the Emotion Reactivity and Regulation Task (ERRT; Jackson et al., 2003) before and after their 8-week program while EEG was continuously recorded; self-reports of emotional state were completed at the end of each trial of the task. The ERRT is well-suited to investigate emotional reactivity and regulation, as each trial includes both initial passive viewing of emotionally provocative images (unpleasant, pleasant, and neutral) and subsequent active emotion regulation during that viewing. Thus differences in meditative training on both affective parameters can be studied.

Because both MBCT and OM training encourage exposure to emotional, cognitive, and other stimuli, we anticipated that these programs would result in the greatest changes in FAA indicative of approach motivation (or less withdrawal motivation) and more benign emotional responses in the reactivity phase of the ERRT (c.f., Britton et al., 2018). Because the emotion regulation techniques learned during these two programs foster more equanimous responses to emotional and other stimuli, we also predicted that these techniques would produce the greatest relative leftward shift in FAA from pre- to post-training. However there is an alternative hypothesis to the approach/withdrawal hypothesis that is the focus here. Specifically, research (e.g., Allen et al., 2012; Bostanov et al., 2012; Jensen et al., 2012) has found that MBCT alters neurophysiological and behavioral outcomes reflective of increased concentration and related attention abilities. Since attention is mediated by a noradrenergic network that is relatively right-lateralized in the brain (e.g., Petersen & Posner, 2012), changes in this network as a result of training could be expressed in alpha asymmetry across the brain, from anterior to posterior electrode sites. Thus, to test the specificity of training effects on FAA and the approach/withdrawal hypothesis, we also examined training effects on central and parietal alpha asymmetry (C4-C3 and P4-P3).

An additional prediction was that MBCT, OM training, or both would result in the greatest pre-post training attenuation of post-regulation, self-reported negative emotional responses to unpleasant images. Differences between MBCT and OM training on ERRT responses were also tested, but since they share the OM training component, we made no predictions about differential effects. Research on whether mindfulness training promotes positive emotion is much less abundant than that focused on negative emotion (however see Fredrickson et al., 2017; Garland et al., 2015; Geschwind et al., 2011; Lindsay et al., 2018), so no predictions were made regarding training effects on neural and subjective responses to pleasant stimuli, although these training effects were explored. This experimental study is the first known to us to dismantle a commonly administered mindfulness training (MBCT) to compare this parent program with component FA and OM training programs on important emotional outcomes measured using both objective (electrocortical) and subjective means.

2 | METHOD

2.1 | Participants

Participants were community adults in the Northeastern United States recruited through flyers at primary care

clinics, community event announcements, and internet advertisements on social media and other websites. All eligible participants were English-speaking and between the ages of 18 and 65 years. Other inclusion criteria were designed to identify those most commonly interested in using meditation-based modalities—stressed individuals with persistent mild to severe levels of depression, anxiety, and/or negative affect (Morone et al., 2017). Thus eligible participants had mild to severe levels of depression or high levels of negative affect. DSM-diagnosed emotional disturbances, namely several types of depressive disorders and anxiety disorders were acceptable.

To determine eligibility, prospective participants first underwent a phone screening, during which individuals were excluded if they reported any lifetime history of bipolar disorder, psychotic disorder, persistent antisocial behavior, self-harm behavior, borderline personality disorder, organic brain damage, or reported a regular meditation practice. Those still eligible after phone screening completed additional in-lab screening, where they were considered eligible if they did not present with extremely severe levels of depression (>48 on the Inventory of Depressive Symptoms; Rush et al., 1986; Rush et al., 1996), or persistently high levels of negative affect (>18 on past-month Positive and Negative Affect Schedule; Watson et al., 1988). Additional exclusion criteria were active suicidal ideation, Axis II personality disorder, obsessive compulsive disorder, post-traumatic stress disorder, panic disorder, eating disorder, or substance abuse disorder (all as determined by the Structured Clinical Interview for DSM-IV). Exclusion criteria also included current psychotherapy (>1 month) or a change in antidepressant medication type or dosage in the last 8 weeks. Following all screening procedures and a description of study involvement, participants provided written informed consent.

A power analysis conducted for the parent study from which the current study was a part indicated that a sample of 90 group-randomized participants ($n = 30$ for each training) would be sufficient to detect a small-medium effect ($d = 0.34$) at .80 power and $\alpha = .05$ using a 3 (condition) \times 2 (pre-post training) mixed factorial ANOVA. A total of 506 participants were screened and $N = 104$ were enrolled to account for sample attrition. See Britton et al. (2018) for an overview of participant flow through the study. Thirty-six participants were randomly assigned to each of the dismantling training conditions—FA and OM. Thirty-two participants were randomized to the MBCT condition. Data from 7 participants were removed from analyses due to technical issues during the ERRT; data from 8 participants were removed for high levels of artifact in the EEG recording. Baseline data from 89 participants were available

for intent-to-treat analyses of ERRT responses (MBCT $n = 26$; FA $n = 28$; OM $n = 35$).

2.2 | Procedure

The study was registered on clinicaltrials.gov (NCT#: 01831362) although the AA analyses were not included there. All study procedures were approved by an Institutional Review Board and supervised by an independent Data Safety Monitoring Board and NCCIH's Office of Clinical and Regulatory Affairs (OCRA). Full procedural details can be found in Britton et al. (2018) and Kriedler (2016). After providing informed consent, participants completed baseline (pre-training) assessments, including the ERRT (see Measures/Materials below) while continuous EEG was recorded. Following these assessments, participants were randomized into MBCT, FA, or OM training conditions. Due to the group-based nature of the trainings and the sequential rather than simultaneous scheduling of training courses, group randomization was used rather than individual randomization. Group randomization took the form of randomly allocating a cluster of 4–16 participants who visited the lab for baseline assessments into one of the three training arms. This was done nine times (i.e., 9 clusters) until target enrollment was reached. Once 4–16 participants were allocated to a given course, that course began. For the next 8 weeks, participants underwent their allocated meditation training and then returned to the lab for post-training assessments, including a repeat of the ERRT with continuous EEG.

2.3 | Training programs

The three training programs were structurally equivalent. Each consisting of 8 weeks of training, with 3 h of class each week, and a 1-day silent retreat during either the 6th or 7th week. The first four weeks of training centered on didactic instruction on training arm-specific meditation techniques, with the last four weeks focused on applying the learned techniques to regulate negative affect. Participants in all training programs were asked to complete 45 min of daily, at-home, audio-recorded guided meditation practice—either FA meditation, OM meditation, or both as determined by the assigned training arm.

Each training program had one male and one female instructor. The female instructor led all MBCT, FA, and OM training groups, was trained in MBSR and MBCT, and had taught 25 Mindfulness-based Stress Reduction or Mindfulness-based Cognitive Therapy courses. One male instructor co-led all FA groups and had an extensive background in concentration training in the Theravada

Buddhist tradition. Another male instructor co-led all OM trainings and also had an extensive background in Theravadin meditation practice (and specifically the Mahasi tradition). A third male instructor co-led all MBCT trainings and was trained in MBSR and Zen Buddhism. Each instructor had over 20 years of personal meditation practice experience and experience leading meditation groups.

2.3.1 | Mindfulness-based cognitive therapy

MBCT is a standardized and manualized, 8-week group-based course that emphasizes mindful attention in a client-centered format. The training incorporates aspects of both Mindfulness-based Stress Reduction (Kabat-Zinn, 2015) and Cognitive Behavior Therapy (Teasdale et al., 2000). The MBCT program includes elements of both FA- and OM-style mindfulness meditation (see below).

2.3.2 | Focused attention

This newly adapted course, derived from MBCT, trained participants in meditation practices to foster FA, or concentration. The meditation training used 6 sensory and perceptual “anchors” upon which to focus attention: one’s feet, hands, breath at the belly, breath at the chest, breath at the nostrils, and sounds. Individuals were instructed to maintain their attention on their chosen anchor, to recognize when the mind had wandered away from this anchor, and to redirect attention back to the anchor, most commonly the sensations of breathing, upon noticing the mind-wandering. This anchoring process was used throughout the variety of FA meditations taught, including sitting, walking, and movement (yoga-based) meditation.

2.3.3 | Open monitoring

This training was also adapted from MBCT, but trained in open awareness of sensory, perceptual, and mental

phenomena rather than in the object focus of the FA training. As in the other trainings, participants engaged in sitting, walking, and movement meditation, among others, but this course instructed participants to be aware of salient experiences that arose in consciousness, rather than focusing on specific sensations and perceptions as in FA. To facilitate the OM training, “noting” or “labeling” of experience was used. The experiences labeled fell into 6 categories: what was seen, heard, felt kinesthetically, tasted, smelled, and thought. Initially, participants labeled their experiences out loud, then over time noted them only mentally, until finally they could monitor experiences wordlessly.

2.4 | Measures/materials

2.4.1 | Demographics

Information on age, gender, race, ethnicity, and education level was collected at the baseline assessment. Research indicates that emotional reactivity and regulation can differ by age and gender, with older adults exhibiting enhanced emotion regulation skills (Renfroe et al., 2016; Roalf et al., 2011), and men displaying a positivity bias in late positive potential (LPP) response to emotional stimuli (Syrjänen & Wiens, 2013). Racial and ethnic differences in emotion regulation strategy use have also been reported (Kwon et al., 2013). Education level was collected for exploratory purposes.

2.4.2 | ERRT (Jackson et al., 2003)

The ERRT assessed both initial reactivity to emotional stimuli and regulation of resulting emotions (see Figure 1). Originally designed to examine effects of the emotion regulation strategies reappraisal and suppression, the task includes both passive viewing and cued emotion regulation phases. In the present, passive viewing phase, participants were first shown a fixation cross on a computer screen for 3 s, after which a photographic image appeared for 4 s that participants had been pre-instructed to simply watch (without looking away or

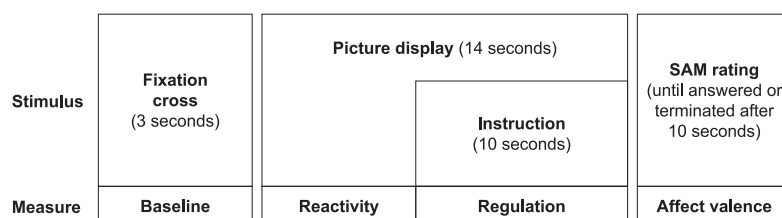


FIGURE 1 Schematic of the emotion reactivity and regulation task (ERRT)

closing eyes). In the cued emotion regulation phase, an instruction to “label,” “breathe,” or “watch” briefly appeared on the screen for all participants of any intervention (FA, OM, MBCT) while the image remained for an additional 10 s. Specifically, negative images were paired with all three instructions while all positive and neutral pictures were paired with the “watch” instruction. The “label” instruction was derived from OM practice, and instructed the participant to label or name their own emotions in response to the image. The “breathe” instruction was derived from FA practice, wherein the participant attended to the sensations of their breathing while viewing the image. “Watch” was a control, no-regulation instruction. Finally, on each trial participants provided a self-report of their affective response to the image on the valence dimension of the pictorial Self-Assessment Manikin (SAM; Bradley & Lang, 1994; see below). The next image stimulus trial began after the SAM rating was completed or after the 10 s rating period had elapsed.

The ERRT included five blocks of photographic images, with 25 images in each block. Participants received a brief rest break between each block. All images (75 negative valence, 25 positive valence, 25 neutral) were drawn from the International Affective Picture System (IAPS; Lang et al., 2008) and presented with DMDX software (Forster & Forster, 2003). Each 25-image block contained five subsets of images, each with 3 negative, 1 positive, and 1 neutral image. Images in each subset were presented pseudo-randomly, such that negative images were never presented consecutively; each negative image was followed by either a positive or neutral image.

The negative valence images were grouped into three arousal levels, using arousal ratings from Lang et al. (2008): low, moderate, and high. Low arousal images had arousal ratings <5.0 ($M = 4.44$; range = 3.52 to 4.95); moderate arousal images had arousal ratings ≥ 5.0 and <6.0 ($M = 5.55$; range = 5.00 to 5.99); high arousal images had arousal ratings ≥ 6.0 ($M = 6.56$; range = 6.00 to 7.35). There were approximately 25 negative valence images in each arousal category. The positive valence images had a mean arousal rating of 5.06 (range = 3.10 to 7.27). The neutral images had a mean arousal rating of 2.64 (range = 1.76 to 2.96). During the task participants were seated at a distance to allow for comfortable reading of instructions and image viewing; participants' own corrective lenses were worn as needed.

2.4.3 | SAM (Bradley & Lang, 1994)

The SAM is a self-report-based, pictorial measure of three dimensions of emotional response to presented stimuli

(valence, arousal, and dominance) (Greenwald et al., 1989; Hodes et al., 1985; Lang et al., 1993). Only the valence dimension of the SAM was used in this study. Participants indicated their current emotional state on a computer keyboard using a 1 (happy) to 9 (unhappy) scale; scores were reversed before analysis.

2.5 | Electrophysiological recording and data processing

EEG recording was made with 19 gold electrodes placed according to the 10–20 system, at sites Fp1, Fp2, F3, F4, F7, F8, C3, C4, T3, T4, T5, T6, P3, P4, O1, O2, Fz, Cz, and Pz, with a forehead ground and linked mastoid references. Continuous EEG was collected using a Comet AS40 amplifier (Grass Technologies Astro-Med, RI, USA) at a sampling rate of 400 Hz. Offline, EEG data were processed using custom EEGLab 14.0 (Delorme & Makeig, 2004) scripts in MATLAB (MathWorks, Natick, MA, USA). First, bad channels were detected, removed, and then interpolated using algorithms provided by EEGLab. Line artifacts (60 Hz electromagnetic noise) were removed using the *CleanLine* plugin (Mullen, 2012) and EEG channels were re-referenced to a common average reference. Thereafter, trials were segmented from stimulus onset to 14-s post-stimulus. Trials were removed using artifact detection algorithms native to EEGLab that detect nonstereotypical artifacts including abnormal amplitude values ($<-150 \mu\text{V}$ or $>150 \mu\text{V}$), improbable distributions (trials with $SD > |5|$ and kurtosis $> |5|$), improbable spectra, and linear trends. Independent components analysis was then performed on these epoched data. Artifactual independent components (e.g., blinks, horizontal eye movements) were detected and subtracted from the epoched data using the Multiple Artifact Rejection Algorithm (MARA; Winkler et al., 2014; Winkler et al., 2011)—an automatic machine learning classifier based on expert ratings of artifactual components using spectral, topographic, and temporal features of independent components. Smith et al. (2017) found that MARA improved frontal alpha asymmetry signal-to-noise ratio relative to the ADJUST automatic artifact rejection algorithm (Mognon et al., 2011). Supporting Information file 1 reports the percentage of rejected channels, trials, and independent components removed at each stage of the data-processing pipeline. Analyses of Variance detected no significant differences between training conditions nor between sessions (pre-, post-training) in the percentage rejection of channels, trials, or independent components at any stage of the processing pipeline.

Data were re-epoched into two windows consistent with the ERRT, the first a four-second passive viewing epoch beginning at stimulus onset, and the second a ten-second

epoch beginning at onset of emotion regulation instruction. We then computed power spectrum densities within these epochs with EEGLab *spectopo* function, which uses Welch's averaged, modified periodogram method (discrete Fourier transform). Trial-by-trial power spectrum densities were obtained in the 1- to 200 Hz frequency range with a .48 Hz resolution through an 800-point Hamming window (2000 ms) with 75% (1500 ms) overlap to minimize data loss. *Spectopo* returns a decibel estimation of relative power ($10 \cdot \text{Log}_{10}[\mu\text{V}^2/\text{Hz}]$), and trial-by-trial scores were converted to absolute power ($\mu\text{V}^2/\text{Hz}$) and averaged within the alpha band (8–13 Hz). Prior to analysis absolute power scores were natural log transformed as spectral power data are often positively skewed (J. B. Allen, Coan, & Nazarian, 2004). AA scores were created by subtracting log transformed left hemispheric site values from log

transformed right-sided values to create F8-F7, F4-F3, C4-C3, and P4-P3 asymmetry scores.

Absolute power within the 2–30 Hz range (.48 Hz resolution) was visually inspected. Also, signal-to-noise ratio was calculated as the ratio of the absolute power in a frequency bin divided by the surrounding ± 5 Hz, and excluding the surrounding ± 1 Hz (Cohen, 2014). Figure 2 shows a small alpha peak in the 8–13 Hz bin, maximum at parietal channels and attenuating over frontal channels. Assuming alpha power is inversely related to cortical activity (Allen et al., 2004), we highlight analyses of frontal channels as an indicator of ERRT task-related alpha asymmetry changes in emotion reactivity and regulation (e.g., Coan et al., 2001). However we report analyses at central and parietal sites to specifically test the approach/withdrawal hypothesis, which emphasizes frontal AA.

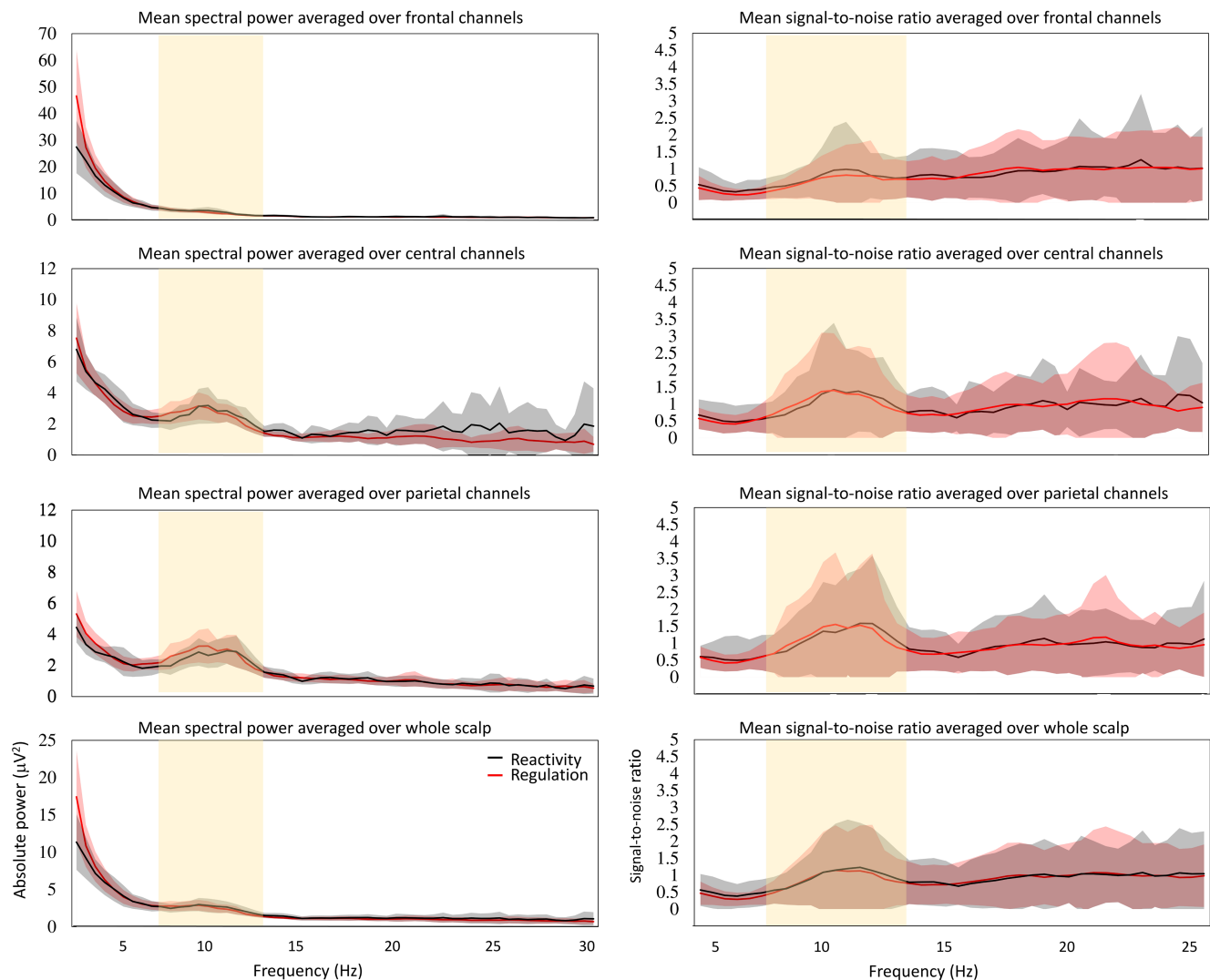


FIGURE 2 Spectral power across all scalp sites during emotion reactivity and emotion regulation tasks. All scalp sites (bottom panels), frontal channels (F3, Fz, F4, F7, F8) (top panels), central channels (C3, Cz, C4) (second panels), and parietal channels (P3, Pz, P4) (middle panels). All channels show a small (8–13 Hz in yellow) alpha peak that attenuates at frontal channels. Shading depicts ± 1 standard error

2.6 | Statistical analyses

Analyses of all AA and self-reported emotional responses were conducted with multilevel models (MLM) based on restricted maximum likelihood estimation (REML; e.g., Bryk & Raudenbush, 1992). Choice of most appropriate variance–covariance structure (unstructured, compound symmetry, toeplitz, variance components) and within-person error variance–covariance structure (first-order autoregressive) was determined through chi-square tests comparing the -2 restricted log likelihood model fit indices for each outcome. A variance components structure was used in the F8-F7 models and unstructured in the F4-F3, C4-C3, P4-P3 models, and in the SAM models, all without autoregression. R version 4.1.1. and R packages lme4 (Bates et al., 2015) and emmeans (Lenth, 2021) were used to estimate all REML mixed models. Follow-up post-hoc tests compared estimated marginal means (EMMs) across training conditions and other differences with the Tukey correction. The outcome data were kept in trial-by-trial form, permitting more strongly powered analyses. All available data were used, permitting intent-to-treat analyses. Data were pretreated as follows: Continuous predictor variable data were zero-centered and categorical data were re-scored to include zero as the lowest value. All variables showed normal distributions except FAA at F4-F3, which had a small number of outlying values. These values were winsorized to produce normally distributed data (Tabachnick & Fidell, 2007).

3 | RESULTS

3.1 | Preliminary analyses

Demographic and treatment characteristics of the sample are displayed in Table 1 according to allocated training condition. ANOVA and chi-square tests showed no condition differences in age, gender (male, female), race (Caucasian vs. others), and education level, nor the other demographic and treatment variables. The four demographic variables noted here, as well as ERRT trial number were first examined as predictors in preliminary MLM analyses of the AA outcomes measured during the reactivity and regulation portions of the ERRT. Age, race, and education level were not significant predictors in any of the models ($ps > .15$), nor was group randomized cluster ($ps > .07$), so these variables were not further considered. Gender significantly predicted some AA outcomes measured during both reactivity (passive viewing) and emotion regulation phases of the ERRT and so this variable was included in those main analyses. MLM showed that in different analyses of self-reported emotion, age and

gender were significant predictors so were retained where relevant. Trial number was not a significant predictor of AA in any model ($ps > .17$) indicating that electrocortical responses to the stimuli were stable over the course of the task.

Internal consistency of AA values was calculated for each of the 5 stimulus types at each of the 4 homologous channel pairs during the passive viewing phase at baseline (pre-training) using the Spearman-Brown formula. Across channel pairs and stimulus types, internal consistencies (ρ) ranged from .67 (F8-F7; high arousal negative) to .88 (C4-C3; moderate arousal negative) with the exception of F4-F3 (high arousal negative) where $\rho = .50$. Across all channel pairs and stimulus types the average $\rho = .74$. As expected, at pre-training, stimulus valence, and for negative stimuli, arousal level evoked differing levels of AA in the 4 s passive viewing phase, most consistently at F8-F7 (see Figure 3). At this homologous pair, there was a marginal difference between high, moderate, and low arousal negative stimuli such that high arousal stimuli evoked lower leftward FAA activation than low arousal negative stimuli and moderate arousal negative stimuli ($ps > .071$). Positive stimuli evoked higher leftward AA than high arousal negative stimuli ($p = .027$) but not from low and moderate arousal negative stimuli ($ps > .185$). Neutral stimuli evoked lower AA than positive stimuli ($p = .0002$) and low arousal negative stimuli ($p = .001$), but not from moderate and high arousal negative stimuli ($ps > .173$). Stimulus valence and arousal did not predict differing levels of AA from the P4-P3 electrode pair ($ps > .120$), F4-F3 pair ($ps > .980$), nor from the C4-C3 pair ($ps > .457$).

Finally, preliminary analyses tested for training condition differences in AA at baseline (pre-training), at all four of the homologous pairs. No baseline differences between conditions were found when examining either passive viewing and emotion regulation phases of the ERRT ($ps > .09$). Thus, AA was treated as a repeated-measures variable (pre- and post-training) in the MLM analyses to follow.

3.2 | Effects of mindfulness training on AA during passive viewing phase

To examine the effect of training condition on AA activation in the 4 s passive viewing phase of the ERRT, MLM analyses regressed AA on main and interactive effects of training condition (MBCT, FA, OM), time (pre-post training), and stimulus type (neutral, positive, and low, moderate, and high arousal negative) using alpha band data at the four homologous pairs.

For F8-F7, there were main effects of time across the passive viewing phase ($p = .0001$) and stimulus type

TABLE 1 Sample demographic and treatment characteristics by training condition

Variable	MBCT	FA	OM	<i>p</i>
Gender, <i>n</i> (% female)	21 (80.77)	19 (67.86)	27 (77.14)	.518
Race, <i>n</i> (%)				
Caucasian	25 (96.15)	28 (100)	35 (100)	.294
Ethnicity, <i>n</i> (%)				
Hispanic/Latinx	2 (7.69)	3 (10.71)	1 (2.86)	.454
Age, <i>M</i> (SD)	38.35 (12.97)	40.21 (13.89)	42.54 (12.61)	.462
Education years, <i>M</i> (SD)	16.77 (2.70)	18.00 (3.32)	16.74 (1.92)	.127
Baseline IDS, <i>M</i> (SD)	21.89 (6.37)	24.36 (6.79)	22.74 (7.74)	.425
Baseline DAS				
Depression, <i>M</i> (SD)	25.00 (8.98)	24.89 (6.80)	21.08 (5.87)	.051
Anxiety, <i>M</i> (SD)	18.27 (3.14)	20.15 (5.28)	18.06 (3.83)	.119
Stress, <i>M</i> (SD)	27.65 (5.77)	28.74 (8.42)	28.26 (6.99)	.858
Participant adherence				
Total randomized, <i>n</i>	32	36	36	.857
Classes attended, <i>M</i> (SD)	8.12 (1.11)	8.07 (1.05)	8.17 (1.30)	.944
Retreat attended, <i>n</i> (%)	22 (84.62)	25 (89.29)	32 (91.43)	.706
Meditation homework compliance				
Formal min/wk, <i>M</i> (SD)	1452.38 (675.37)	1715.38 (521.55)	1643.18 (534.68)	.229
Instructors				
Gender ratio (male: female)	1:1	1:1	1:1	
Combined meditation experience (years)	40	40	40	
Clinical degrees	1	2	1	
Ph.D.	2	1	2	
MBSR/MBCT instructor	2	2	1	
Treatment fidelity	93.9%	97.1%	88.9%	.822

Note: Treatment fidelity = percentage of weekly treatment agenda items successfully completed, as rated by 2–3 study staff. All values represent only participants whose data were analyzed in the present article; MBCT *n* = 26; FA *n* = 28; OM *n* = 35).

Abbreviations: DASS, depression anxiety and stress scales; FA, focused attention; IDS, inventory of depressive symptomatology; MBCT, mindfulness-based cognitive therapy; OM, open monitoring.

($p = .0001$). FAA activation shifted leftward from pre- to post-training (estimated margin means [EMM]) = 0.467, SE = 0.148 and EMM = 0.838, SE = 0.149, respectively, $d = 0.080$). High arousal negative stimuli (EMM = 0.444, SE = 0.162) elicited lower leftward FAA than low arousal negative stimuli across time (EMM = 0.812, SE = 0.164; $p = .017$, $d = 0.080$) and lower left FAA than positive stimuli (EMM = 0.913, SE = 0.161; $p = .0004$, $d = 0.101$). However the FAA for high arousal negative stimuli did not differ from that of moderate arousal negative stimuli ($p = .460$) nor from neutral stimuli ($p = 1.000$). Neutral stimuli (EMM = 0.468, SE = 0.161) showed lower FAA than low arousal negative ($p = .031$, $d = -0.074$) and positive stimuli ($p = .0009$, $d = -0.096$).

More importantly, a training condition \times time interaction was also found ($p = .0001$) at F8-F7 (see Figure 4). FAA in the MBCT condition marginally shifted leftward from

pre-training (EMM = 0.249, SE = 0.271) to post-training (EMM = 0.650, SE = 0.273; $p = .003$, $d = 0.087$). FAA activation also shifted left within this homologous pair in the FA condition from pre- to post-training (EMM = 0.362, SE = 0.265 and EMM = 1.168, SE = 0.262, respectively; $p < .0001$, $d = 0.175$). FAA activation among OM participants did not change from pre-training (EMM = 0.791, SE = 0.234) to post-training (EMM = 0.697, SE = 0.237; $p = .428$, $d = 0.021$). The main effect of condition was non-significant ($p = .625$), as were the condition \times stimulus type interaction ($p = .707$), the time \times stimulus type interaction ($p = .152$), and the condition \times stimulus type \times time interaction ($p = .413$). In sum, FA training and marginally, MBCT training impacted FAA across all stimulus types, again suggesting a more benign perception of all presented emotional stimuli (that is, regardless of stimulus valence).

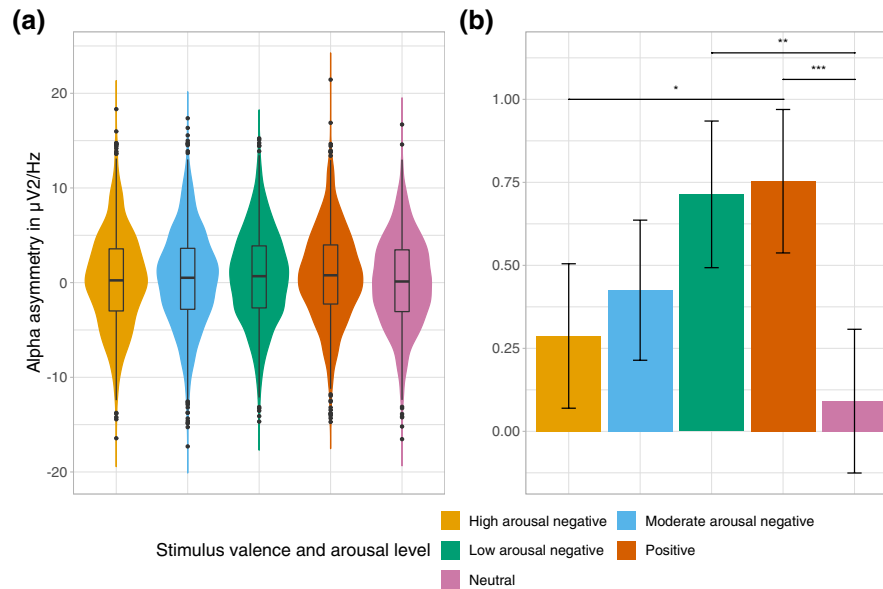


FIGURE 3 Violin plot/box plot showing data distribution (panel a) and bar chart showing estimated marginal means \pm SE (panel b) of alpha band (8–13 Hz) asymmetric activation at pre-training (baseline), for each stimulus image valence and, for unpleasant images, arousal level; values are collapsed across training conditions. The asymmetry score represents right minus left log-transformed power density from the F8-F7 electrode sites. Higher values indicate greater left-sided frontal activation. ** $p < .01$; *** $p < .001$

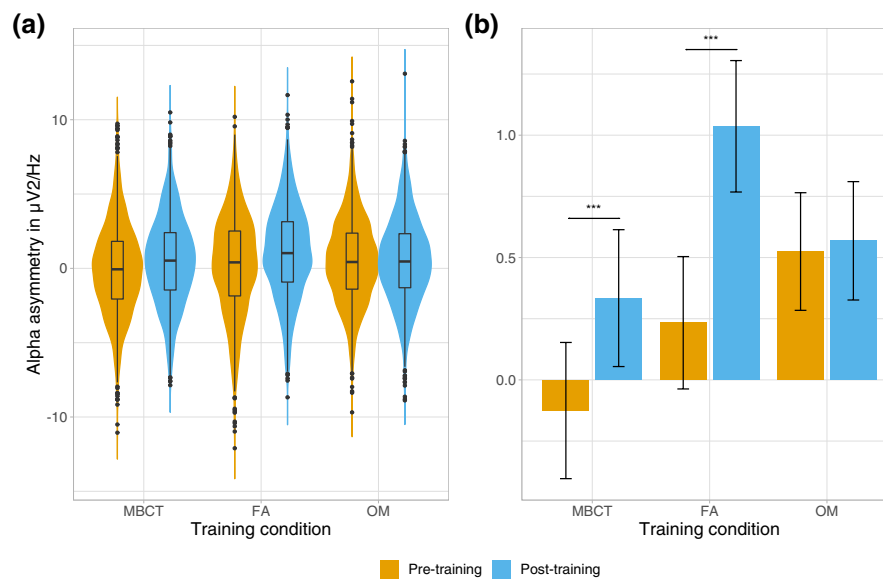


FIGURE 4 Violin plot/box plot showing data distribution (panel a) and bar chart showing estimated marginal means \pm SE (panel b) of alpha band (8–13 Hz) asymmetric activation from the F8-F7 electrode sites during ERRT passive viewing at pre- and post-training sessions for each training condition; values are collapsed across stimulus image valence and, for unpleasant images, arousal level. Higher values indicate greater left-sided frontal activation. FA, focused attention; MBCT, mindfulness-based cognitive therapy; OM, open monitoring. *** $p < .001$

Across the F4-F3 pair, a pre-post training main effect was found ($p = .0001$). From pre- to post-training, FAA activation shifted leftward (pre-training EMM = 0.258, SE = 0.162; post-training EMM = 0.519, SE = 0.162, $d = 0.082$). There was also a training condition \times time interaction effect ($p = .048$). FAA in the MBCT condition

significantly shifted leftward from pre- (EMM = 0.003, SE = 0.296) to post-training (EMM = 0.446, SE = 0.298, $d = 0.139$, $p < .0001$). We observed a similar significant effect in the OM condition (pre-training EMM = 0.413, SE = 0.256; post-training EMM = 0.582, SE = 0.257, $d = 0.053$, $p = .039$), and a marginal effect in the FA

condition (pre-training EMM = 0.360, SE = 0.287; post-training EMM = 0.531, SE = 0.286, $d = 0.054$, $p = .060$). No other main or interaction effect predictors were significant for the F4-F3 pair, all $ps > .587$.

Across the C4-C3 pair, a stimulus valence main effect was found ($p = .038$), and more importantly a condition \times time interaction was found ($p < .0001$). AA in the MBCT condition shifted leftward from pre-training (EMM = -0.386 , SE = 0.258) to post-training (EMM = 0.190, SE = 0.259; $p < .0001$, $d = 0.140$). There was no change in AA from pre- to post-training in the FA condition ($p = .295$). In the OM condition, AA shifted rightward from pre-training (EMM = 0.387, SE = 0.223) to post-training (EMM = -0.259 , SE = 0.225; $p < .0001$, $d = -0.157$). Across the P4-P3 pair, there was no condition \times time interaction ($p = .152$), though there were main effects of time ($p = .0001$) and stimulus type ($p = .009$).

3.3 | Effects of mindfulness training on AA during emotion regulation

To examine the effect of training condition and stimulus-related variables on the regulation of emotion in response to negative, positive, and neutral stimuli, MLM analyses regressed AA at each of the same four homologous pairs as above on the same main effects and interactions plus, for the negative stimuli, the emotion regulation instruction (watch, label, breathe) given at the beginning of

each trial's 10 s active viewing period. As these instructions were given in the negative emotional stimulus trials only, analyses tested the effects of condition and time for neutral, positive, and negative stimuli separately. For negative stimuli, the arousal level of each stimulus (low, moderate, high) and the regulation instruction type were also included as predictors, both as main effects and in interaction with the other predictors.

3.3.1 | Negative stimuli

First examining effects on FAA activation across the F8-F7 pair, there were main effects of time ($p = .0001$) and marginally, arousal level ($p = .062$). From pre- to post-training, across all 3 trainings, FAA activation became more left-sided (EMM = 0.211, SE = 0.152 and EMM = 0.646, SE = 0.152, respectively, $d = 0.162$). As [Figure 5](#) shows, there was also a training condition \times time interaction ($p = .0001$), such that MBCT participants showed a leftward shift in FAA activation from pre- to post-training (pre-training EMM = -0.125 , SE = 0.278; post-training EMM = 0.334, SE = 0.280; $p < .0001$, $d = 0.171$). FA trainees also showed a leftward shift (pre-training EMM = 0.233, SE = 0.270; post-training EMM = 1.036, SE = 0.269; $p < .0001$, $d = 0.300$). OM trainees did not show a pre- to post-training change in FAA activation ($p = .624$). Finally there was a marginal time \times arousal level interaction ($p = .052$). No other main or interaction effects were significant ($ps > .161$).

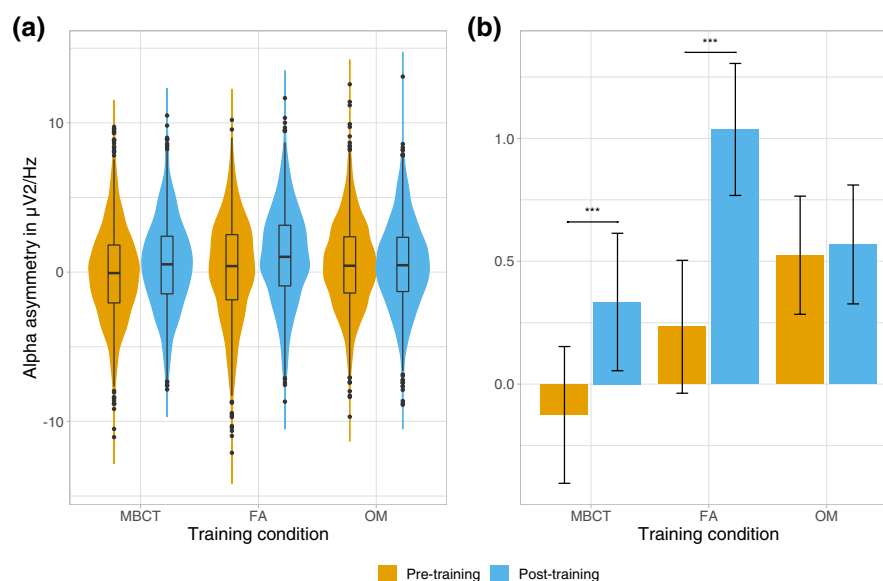


FIGURE 5 Violin plot/box plot showing data distribution (panel a) and bar chart showing estimated marginal means \pm SE (panel b) of alpha band (8–13 Hz) asymmetric activation in response to unpleasant images from the F8-F7 electrode sites during ERRT emotion regulation at pre- and post-training sessions for each training condition; values are collapsed across unpleasant image arousal level. Higher values indicate greater left-sided frontal activation. FA, focused attention; MBCT, mindfulness-based cognitive therapy; OM, open monitoring. *** $p < .001$

Across the F4-F3 pair, there was a main effect of time ($p = .0001$), and an interaction between training condition and time ($p = .0004$). The main effect of time showed that from pre- to post-training, FAA activation become more left-sided (EMM = 0.249, SE = 0.170 and EMM = 0.472, SE = 0.170, respectively, $d = 0.132$). The interaction showed that, like the results found across the F8-F7 pair, MBCT trainees showed a leftward shift in FAA activation from pre- to post-training (EMM = 0.018, SE = 0.312 and EMM = 0.347, SE = 0.312, respectively; $p < .0001$, $d = 0.195$). FA trainees also showed a leftward shift pre-training EMM = 0.220, SE = 0.301; post-training EMM = 0.527, SE = 0.300; $p < .0001$, $d = 0.183$). OM trainees did not show a pre- to post-training change in FAA activation ($p = .558$). No other main or interaction effects were significant ($ps > .161$).

Across the C4-C3 pair, there was also an interaction between training condition and time ($p = .0001$). The interaction showed that, like the results found across the F8-F7 and F4-F3 pairs, MBCT trainees showed a leftward shift in AA activation from pre- to post-training (EMM = -0.380 , SE = 0.411 and EMM = 0.256, SE = 0.412, respectively; $p < .0001$, $d = 0.257$). FA trainees did not show a shift in AA ($p = .776$), while OM trainees showed a rightward pre- to post-training change in AA activation (EMM = 0.315, SE = 0.355 and EMM = -0.386 , SE = 0.356, respectively; $p < .0001$, $d = -0.283$). There was also a significant interaction between condition \times stimulus arousal level \times emotion regulation instruction ($p = .027$), however no other main or interaction effects were significant ($ps > .144$).

Finally, across the P4-P3 pair, there was a main effect of time ($p = .0004$), and also an interaction between training condition and time ($p = .0002$). The interaction showed that, like the results found across the other three electrode pairs, MBCT trainees showed a leftward shift in AA activation from pre- to post-training (EMM = -0.055 , SE = 0.480 and EMM = 0.374, SE = 0.481, respectively; $p < .0001$, $d = 0.191$). Neither FA trainees nor OM trainees showed a significant change in AA activation ($ps > .158$). There was also a significant time \times condition \times stimulus arousal level interaction ($p = .037$), but no other effects were significant ($ps > .808$).

Overall, these results suggest a similar conclusion to that made for the emotional reactivity findings, namely that MBCT and FA trainings produced a shift in FAA activation consistent with more benign emotional response and approach orientation to all negative emotional stimuli, in most cases regardless of stimulus arousal level and type of regulation instruction given. As with emotional reactivity, OM training showed no evidence of change in neural response to the emotional

stimuli across arousal level and regulation instruction type.

3.3.2 | Positive stimuli

MLM analyses showed that across the F8-F7 pair, there was a main effect of condition ($p = .043$). A main effect of time was again found ($p = .0001$), with FAA more left-sided from pre- to post-training (EMM = 0.261, SE = 0.160 and EMM = 0.645, SE = 0.161, respectively, $d = 0.144$). Figure 6 displays a training condition \times time interaction ($p = .007$), which indicated that MBCT participants showed a shift toward more left-sided FAA activation from pre- to post-training (EMM = -0.154 , SE = 0.292 and EMM = 0.502, SE = 0.295, respectively; $p = .0001$, $d = 0.247$). FA participants also showed a significant shift in FAA activation from right to left (EMM = 0.542, SE = 0.286 and EMM = 1.055, SE = 0.281, respectively; $p = .002$, $d = 0.193$). OM participants showed no FAA activation change from pre- to post-training (EMM = 0.396, SE = 0.253 and EMM = 0.377, SE = 0.258, respectively; $p = .901$, $d = 0.007$). The main effect of training condition was not significant, $p = .246$.

Regarding the F4-F3 pair, a main effect of time was found ($p = .001$) with overall, FAA shifting to the left from pre- to post-training (EMM = 0.246, SE = 0.098 and EMM = 0.441, SE = 0.099, respectively, $d = 0.115$). Nonsignificant were the main effect of training condition ($p = .416$) and the condition \times time interaction ($p = .223$).

Across the C4-C3 pair, a training condition \times time interaction was again found ($p = .0001$), in which MBCT participants showed a leftward shift in AA activation from pre- to post-training (EMM = -0.412 , SE = 0.369 and EMM = 0.306, SE = 0.372, respectively; $p < .0001$, $d = 0.295$). FA participants did not show a significant shift in AA activation ($p = .866$), while OM participants showed a rightward shift in AA activation from pre- to post-training (EMM = 0.420, SE = 0.319 and EMM = -0.112 , SE = 0.322, respectively; $p = .0002$, $d = -0.219$). The main effects of training condition and time were not significant across this electrode pair, $ps > .420$.

Across the P4-P3 pair, only a main effect of time was found ($p = .002$) with overall, AA shifting to the left from pre- to post-training (EMM = -0.135 , SE = 0.227 and EMM = 0.113, SE = 0.228, respectively, $d = 0.112$). There was also a time \times condition interaction effect ($p = .038$), such that MBCT participants demonstrated a significant leftward shift in AA activation (pre-training EMM = -0.200 , SE = 0.416; post-training EMM = 0.340, SE = 0.420, $d = 0.244$, $p = .0002$), whereas FA participants did not (pre-training EMM = -0.234 , SE = 0.403;

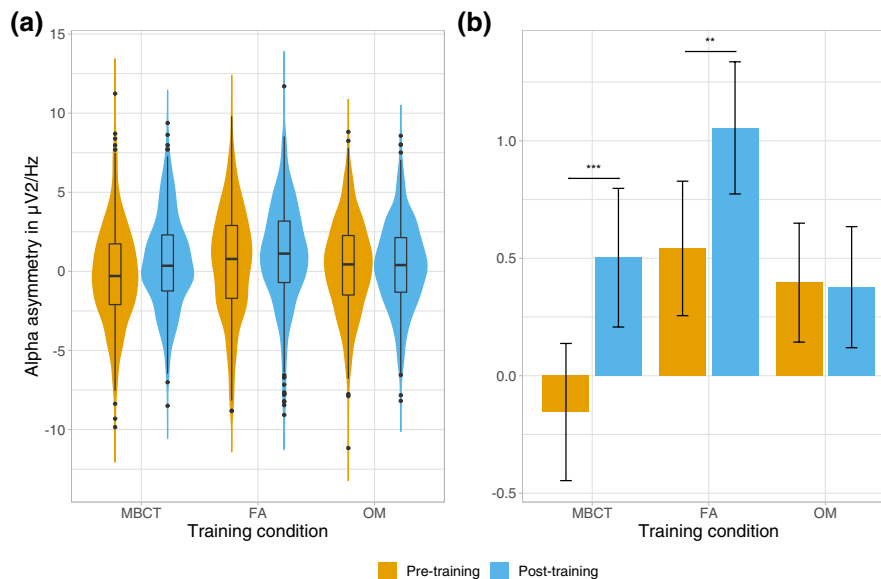


FIGURE 6 Violin plot/box plot showing data distribution (panel a) and bar chart showing estimated marginal means \pm SE (panel b) of alpha band (8–13 Hz) asymmetric activation in response to pleasant images from the F8-F7 electrode sites during ERRT emotion regulation at pre- and post-training sessions for each training condition. Higher values indicate greater left-sided frontal activation. FA, focused attention; MBCT, mindfulness-based cognitive therapy; OM, open monitoring. * $p < .05$; ** $p < .01$

post-training EMM = -0.155 , SE = 0.399 , $d = 0.035$, $p = .574$) and neither did OM participants (pre-training EMM = 0.029 , SE = 0.360 ; post-training EMM = 0.155 , SE = 0.362 , $d = 0.057$, $p = .331$). The main effect of training condition was nonsignificant ($p = .845$).

The results of these analyses of training condition effects on positive stimuli show a pattern similar to those on negative stimuli: MBCT and FA produced leftward AA activation, especially across F8-F7 electrode pairs. Results of the MLM analyses examining AA activations from the two homologous electrode pairs in response to neutral stimuli are given in [Supporting Information file 2](#).

3.4 | Effects of mindfulness training on self-reported emotional valence following regulation

To examine training and stimulus-related effects on self-reported emotional states, collected at the end of each ERRT trial, multilevel models regressed emotional valence responses onto training condition and time for each stimulus type separately. As with the analyses of AA during emotion regulation, modeling of responses to negative stimuli also included the effects of stimulus arousal level and emotion regulation instruction type. Demographic variables and trial number were included where preliminary analyses showed significant relations to self-reported emotion.

3.4.1 | Negative stimuli

An MLM analysis on SAM-rated levels of emotional valence in response to negative stimuli revealed main effects of time ($p = .0001$), stimulus arousal level ($p = .0001$), emotion regulation instruction type ($p = .024$), sex ($p = .020$) and trial number ($p = .0001$). Overall, self-reported valence increased (became less unpleasant) from pre- to post-training ($M = 3.661$, SD = 1.458 and $M = 4.285$, SD = 1.649 , respectively, $d = 0.401$). Emotional valence changed toward lower unpleasantness according to level of stimulus arousal (low EMM = 3.821 , SE = 0.143 ; moderate EMM = 4.085 , SE = 0.142 ; and high EMM = 4.473 , SE = 0.143 ; all p differences $< .0001$, $d(\text{low-moderate}) = -.220$; $d(\text{moderate-high}) = -.323$). Emotional valence was higher (less unpleasant) when participants were asked to regulate through labeling emotions while looking at emotional stimuli than when asked to simply watch them (EMM = 4.173 , SE = 0.143 and EMM = 4.108 , SE = 0.143 , respectively; $p = .033$, $d = 0.062$). Instructions to breathe (EMM = 4.11 , SE = 0.143) produced similar emotional responses as label instructions ($p = .074$, $d = -0.065$) and watch instructions ($p = .947$, $d = 0.009$). Female participants reported more unpleasant emotion levels than male participants (EMM = 3.798 , SE = 0.141 and EMM = 4.455 , SE = 0.241 , respectively, $p = .016$, $d = 0.547$). Levels of emotional valence in response to negative images decreased (became more unpleasant) over trials at pre- and post-training, though the relation was small ($b = -0.003$).

A training condition \times time interaction was found ($p = .0001$), yet participants in all 3 training conditions reported varying degrees of change in emotional valence toward less unpleasantness in response to negative stimuli (see Figure 7). MBCT trainees showed a small decrease in reported unpleasantness from pre- to post-training (EMM = 4.037, SE = 0.237 and EMM = 4.291, SE = 0.238, respectively; $p < .0001$, $d = 0.211$). FA participants (EMM = 3.656, SE = 0.220 and EMM = 4.304, SE = 0.219, respectively; $p < .0001$, $d = 0.538$) and OM trainees (EMM = 3.854, SE = 0.206 and EMM = 4.617, SE = 0.206, respectively; $p < .0001$, $d = 0.633$) reported larger declines

in perceived unpleasantness. No other main effects or interactions were significant (all $ps > .057$).

3.4.2 | Positive stimuli

Modeling of emotional valence in response to positive stimuli showed main effects for age ($p = .001$) and trial number ($p = .0001$); older respondents reported more pleasantness ($b = 0.024$) and as with negative stimuli, emotional pleasantness decreased over trials ($b = -0.007$). A condition \times time interaction ($p = .0001$; see Figure 8) showed that

FIGURE 7 Violin plot/box plot showing data distribution (panel a) and bar chart showing estimated marginal means \pm SE (panel b) of SAM emotional valence levels to unpleasant images at pre- and post-training sessions for each training condition. Higher values indicate higher pleasant emotional valence. FA, focused attention; MBCT, mindfulness-based cognitive therapy; OM, open monitoring; SAM, self-assessment manikin. *** $p < .001$

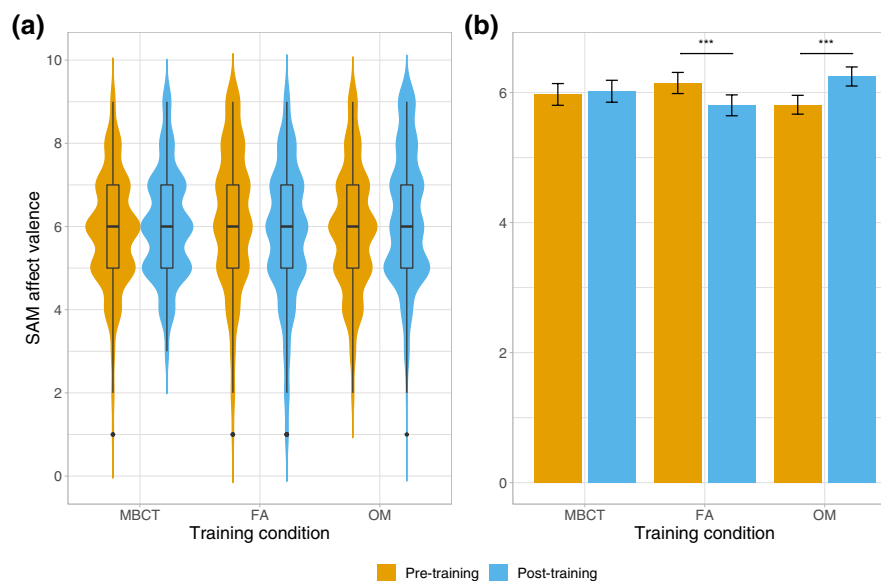
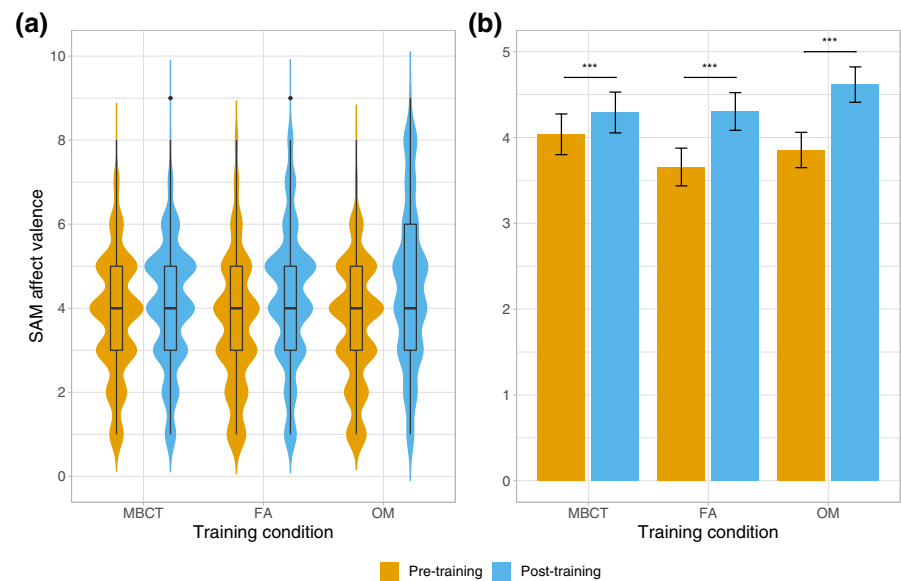


FIGURE 8 Violin plot/box plot showing data distribution (panel a) and bar chart showing estimated marginal means \pm SE (panel b) of SAM emotional valence levels to pleasant images at pre- and post-training sessions for each training condition. Higher values indicate higher pleasant emotional valence. FA, focused attention; MBCT, mindfulness-based cognitive therapy; OM, open monitoring; SAM, self-assessment manikin. *** $p < .001$

MBCT participants' reported emotional valence did not change from pre- to post-training ($EMM = 5.97$, $SE = 0.167$ and $EMM = 6.02$, $SE = 0.169$, respectively; $p = .544$, $d = 0.039$). FA trainees showed a significant decrease in emotional valence—that is, less pleasantness on the SAM after training ($EMM = 6.15$, $SE = 0.163$ and $EMM = 5.80$, $SE = 0.161$, respectively; $p < .0001$, $d = -0.275$). OM participants showed an increase in emotional pleasantness across time ($EMM = 5.81$, $SE = 0.145$ and $EMM = 6.25$, $SE = 0.147$, respectively; $p < .0001$, $d = 0.347$). The main effects of training condition and time were nonsignificant ($ps = .966$ and $.298$, respectively).

In sum, these findings on self-reported emotion show that participants in all 3 training conditions reported less unpleasant emotional responses to negative stimuli following training, particularly those in FA and OM conditions. FA training produced less positively valenced responses to positive stimuli after training while OM trainees reported more positive responses to positive stimuli. However, these effect sizes for positive stimuli were small. Results of the MLM analyses examining emotional responses to neutral stimuli are given in the [Supporting Information file 2](#). Across conditions, labeling emotion instructions to regulate emotional responses were more effective in reducing unpleasant emotion than either breathing or simply watching negative stimuli, though the effect sizes were small.

4 | DISCUSSION

Mindfulness trainings are typically multimodal, making the search for active ingredients of their effects on emotional and other outcomes challenging. This dismantling study compared one of these multi-component trainings, namely mindfulness-based cognitive therapy (MBCT), with two structurally equivalent programs that trained in one of two of the major forms of mindfulness meditation taught in MBCT: FA and OM. The effects of these programs on two major affective parameters (Davidson & Irwin, 1999; Jackson et al., 2003) were examined—initial reactivity to emotionally evocative imagery and explicit, intervention-trained efforts to regulate emotional responses to that imagery using the validated ERRT (Jackson et al., 2000).

The primary prediction of the study was that MBCT and OM training would result in lower reactivity to, and better regulation of responses to emotionally evocative visual stimuli. Support for the prediction concerning MBCT was found, while support for OM training was not. Unexpectedly, FA training produced leftward shifts in FAA equal to, and in some analyses, more strongly than MBCT.

Examining initial reactivity to evocative images, interestingly, these shifts occurred regardless of stimulus type (unpleasant, pleasant, neutral) and arousal level (high, medium, low; unpleasant images only). Examining regulation of emotional responses to the images, FA and MBCT again produced quite consistent leftward shifts in FAA from pre- to post-training, particularly at electrode pair F8-F7. Paralleling the passive viewing phase, these FAA changes were found for unpleasant, pleasant, and neutral images and regardless of arousal level (unpleasant images), as well as regulation instruction (watch, breath, label). OM training did not result in shifts in FAA across stimulus type, arousal level, and regulation instruction across either electrode pair. In the self-reported ratings of emotional state made at the end of each ERRT trial, participants in all three training conditions showed decreases in unpleasant emotion in response to negative stimuli from pre- to post-training. FA participants also showed a decrease in pleasant emotional valence, while OM participants showed an increase in pleasant emotion in both positive and neutral image trials. We interpret these positive stimulus results with caution, however, given the small effect sizes associated with FA and OM conditions.

In general these results suggest that MBCT and FA participants became more approach-oriented in response to emotional stimuli, with effect sizes generally larger for FA training. As a consequence of training, participants in both conditions appeared to become less emotionally reactive to evocative negative stimuli and better able to regulate the emotions that did arise. We anticipated that either or both MBCT or OM would be most likely to produce the neural changes observed, as both programs were designed to foster exposure to emotional and other perceptual stimuli. OM training did not produce consistent changes across neural and self-report outcomes, and salutary changes were restricted to self-reported emotional valence outcomes.

Previous efforts to examine AA among mindfulness trainees have largely been limited to the study of resting state activity, with mixed results (Davidson et al., 2003; Moynihan et al., 2013). Research among MBCT trainees with recurrent major depression and at risk for relapse has also shown a relative leftward shift after emotional challenge relative to non-randomized controls (Keune et al., 2011, 2013). The present findings extend those results in several ways. First, we showed that salutary electrocortical changes among MBCT and FA trainees occur *during* the processing of emotional stimuli. It has been proposed that FAA indicates a capability to regulate emotions during challenging circumstances (Coan et al., 2006; Reznik & Allen, 2018), and thus studying FAA using emotional challenges, rather than resting state measures, is likely to be more revealing of emotional processes

and individual differences in those processes (Smith et al., 2017). The present study showed that capability may be altered by mental training, creating divergent responses in electrocortical activation.

A second extension of previous research is to show that programs focused on FA instruction and practice or instruction that combines FA and OM meditation instruction and practice (MBCT) may be more emotionally beneficial than programs focused on OM alone. While all three programs showed decreases in self-reported emotional valence (less unpleasantness) in the face of unpleasant images after regulation efforts, FA and MBCT trainees most consistently showed FAA shifts indicative of greater approach orientation to provocative emotional stimuli.

It is unclear why the neural and self-report findings yielded somewhat different conclusions about the three meditative trainings, although this is not unusual in mindfulness training studies (e.g., Barnhofer et al., 2007; Isbel et al., 2019) nor in FAA studies examining current mood states, like this one, rather than affective dispositions (Grimshaw & Carmel, 2014). Here, the neural findings showing a leftward shift in FAA and the emotion regulation instructions (“breathe” vs. “label”) favored FA over OM while self-reported valence findings favored the latter: OM showed the largest decrease in negative affect to negative stimuli and was the only condition to show a (small) increase in positive emotions in response to positive stimuli. It is unclear why the salutary OM training effects were restricted to self-reported emotional valence outcomes. OM is often considered a more advanced practice than FA, and it is possible that without the stabilization of attention accrued through FA (c.f., Bostanov et al., 2012), OM practice for novice trainees may result in unhealthy over-exposure to psychological contents. Anecdotally, new meditation practitioners commonly report that opening to thoughts and emotions in a receptive, accepting way can be distressing when mental content previously unattended to—sometimes willfully—is on full display. Buddhist traditions extoll the benefits of OM practice (Shankman, 2008), and in preceding it with FA, MBCT may help to harness its potential for benefit. Conversely, it is also possible that MBCT derives its benefits from the FA training embedded in it, rather than from OM.

Interestingly, FA showed a small pre-post training decline in positive emotion, as indicated by less positive reported affect after viewing pleasant images. Other studies in non-clinical samples have also found that FA-style meditation (with attention to the breath) reduced the emotional intensity of positive (and negative) stimuli (e.g., Arch & Craske, 2006). Taylor et al. (2011) and Brefczynski-Lewis et al. (2007) found that focused breath awareness during emotional picture-viewing reduced the emotional intensity across all valences (positive, negative,

and neutral) stimuli, and that this reduction was associated with deactivations in the amygdala, a brain region associated with emotional reactivity and response. These results suggest that FA may produce states of equanimity, even-mindedness, or impartiality, considered a primary outcome of some forms of meditation training as it may protect one from “emotional agitation” (Bodhi, 2005), and in the case of positive stimuli, overexcitement, a desire to prolong those stimuli, or even addiction (Desbordes et al., 2015). However when over-trained, or trained without the balancing effects of OM, FA can result in excessive “dullness,” emotional blunting, and anhedonia (Britton, 2019; Lutz et al., 2007).

A third extension that the present study makes to existing literature is to demonstrate the benefits of FA training. While training in FA is an important part of MBCT, MBSR, and other secular interventions, few experiments have examined its effects on emotion processing when instructed as a sole meditative technique. Practices that include FA are theorized to be associated with a calming of mental (and physiological) activity (e.g., Anālayo, 2019). Relatedly, quasi-experiments using functional magnetic resonance imaging show a dampening of neural activity associated with emotional reactivity to negative auditory and visual stimuli (Brefczynski-Lewis et al., 2007; Lee et al., 2012). Such dampening is thought to be important for maintaining emotional stability and attentional focus (Lutz et al., 2008). To our knowledge, the present study represents the first research to show that FA meditation alters a neural marker of emotional reactivity and regulation, and just as strongly as a commonly used mindfulness meditation program (MBCT).

This study provides a fourth extension to current research, by contrasting the approach/withdrawal hypothesis—here reflected in training-based changes in emotion processing—with a lateralization hypothesis reflecting changes in attention ability as a result of training. Contrasting results from frontal electrode sites with sites from central and parietal regions indicated strongest evidence of AA at frontal sites. Yet additional research is needed to test the robustness of this findings, as statistical means were not deployed to examine AA differences between frontal, central, and parietal regions, nor were analyses conducted that combined these regions to examine broad lateral shifts in AA. Prior research on AA provides little guidance on this issue, as many AA studies have focused on frontal electrode sites, leaving open the possibility that AA is observable at more posterior sites. Thus, while our findings lend support to the idea that certain kinds of mindfulness training (MBCT, FA) promote approach motivation in the face of emotional stimuli, the results do not contradict research showing increased attention ability through mindfulness training (e.g., Bostanov et al., 2012),

and well-powered research is called for to further contrast the approach/withdrawal and lateralization hypotheses.

4.1 | Limitations and future directions

This dismantling study had the strengths of a randomized trial with a well-powered sample size, both additional advances over prior work in this area. Additionally, all participants received treatment, avoiding the possibility of demoralization, exacerbation of depressive or other symptoms, or study drop-out among those participants allocated to a waitlist or no-treatment control condition (Coelho et al., 2007). However, this active treatment presents a limitation of the study as well. Without a passive control condition, the possibility remains that the changes observed were at least in part due to non-specific factors associated with the trainings.

A second limitation concerns generalizability. Comparison of the baseline IDS scores to scale norms showed that on average, participants were mildly depressed (IDS-QIDS, 2020). However, participants had a wide range of depressive symptom severity, some with diagnosed depressive or anxiety disorders and some not. This heterogeneity makes the findings most applicable to distressed community adults rather than to either mentally very healthy or very unhealthy populations. In fact, the present sample was chosen to represent the population that most frequently engages in mindfulness-based meditation, namely those with mild to severe levels of depression, anxiety, and negative affect.

Third, study participants were naive to meditation, and the findings can only reflect early-stage emotional responses to the techniques instructed in and practiced. Those responses could change with further practice (Keune et al., 2013). Finally, the study examined changes in those responses from pre-to-post-training only. Without a follow-up assessment, we do not know whether those changes were sustained. Indeed, using the same study sample as that reported on here, Cullen et al. (2021) found a deterioration of self-reported emotional health gains between post-training and a 20-week follow-up point. Theory and previous research suggest that ongoing practice in meditative techniques learned during training is key to maintaining training-induced changes (Brown et al., 2015; Mathew et al., 2010).

Given the novelty of this research, replication efforts are needed before the main findings reported here can be considered conclusive. This is particularly important given the mixed evidence for salutary FAA shifts in prior MT research. Future research could also improve upon the study design to include a passive control condition to rule out non-specific treatment effects, as well as practice

logs and follow-up assessments to determine how training effects can best be sustained. Research is also needed to determine whether MBCT is more beneficial for improving emotional reactivity and regulation in the recurrently depressed population for which the program was designed. Examining the effectiveness of FA training in this population may also be warranted, given the positive findings concerning that training in this study.

Dismantling studies of mindfulness training should also examine effectiveness for emotional reactivity and regulation using brain imaging (e.g., functional magnetic resonance imaging; fMRI) and other assessments to examine underlying neural systems (e.g., Smith et al., 2018). Dorsal-lateral prefrontal cortex (dlPFC) and nearby regions underlie the frontal channels used here to calculate FAA (Davidson, 2004; c.f., Okamoto et al., 2004), and left dlPFC in particular has been associated with approach motivation (e.g., Berkman & Lieberman, 2010). Further, fMRI studies suggest that emotional responses are dampened via dlPFC through inhibitory control of negative affective stimuli (Wager et al., 2008). Finally, mindfulness experience has been associated with higher levels of left dlPFC activation (Allen et al., 2012; Brefczynski-Lewis et al., 2007) and with elevated inhibitory control in the face of negative affective stimuli (Allen et al., 2012; Isbel et al., 2019; Quaglia et al., 2019). Such research offers promise to reveal important neural pathways from meditation training-induced FAA to emotional and motivational states and traits (c.f., Smith et al., 2017).

4.2 | Conclusions

Mindfulness practice comes in a variety of forms and little is known about which specific practices are most conducive to positive emotional outcomes. This dismantling study found that the frequently used MBCT program, which combines training in FA and OM meditation, and FA training alone, were more beneficial in altering a neural indicator or emotional reactivity and emotion regulation than a program focused on OM, although the latter showed some benefits for self-reported emotional response among distressed individuals new to mindfulness meditation. These findings help to advance our understanding of how best to deploy mindfulness training for such individuals, and support the use of FA and MBCT for those suffering from depressive and related symptoms.

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AUTHOR CONTRIBUTIONS

Kirk Warren Brown: Conceptualization; data curation; formal analysis; resources; software; visualization; writing – original draft; writing – review and editing. **Daniel Berry:** Data curation; formal analysis; software; visualization; writing – original draft; writing – review and editing. **Kristina Eichel:** Data curation; writing – original draft; writing – review and editing. **Polina Beloborodova:** Formal analysis; software; visualization; writing – review and editing. **Hadley Rahrig:** Visualization; writing – original draft; writing – review and editing. **Willoughby Britton:** Conceptualization; funding acquisition; investigation; methodology; project administration; resources; software; supervision; writing – original draft; writing – review and editing.

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SUPPORTING INFORMATION

Additional supporting information may be found in the online version of the article at the publisher's website.

Supplementary File 1

TABLE S1 Means and (Standard Deviations) of the percentage of channels, trials, and independent components rejected in data pre-processing

Supplementary File 2

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