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ORIGINAL PAPER

Mindfulness-Based Cognitive Therapy: A Preliminary Examination of the (Event-Related) Potential for Modifying Threat-Related Attentional Bias in Anxiety

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Abstract

Objectives Mindfulness-based cognitive therapy (MBCT) can reduce anxiety and depression symptoms in adults with anxiety disorders, and changes in threat-related attentional bias may be a key mechanism driving the intervention's effects on anxiety symptoms. Event-related potentials (ERPs) can illuminate the physiological mechanism through which MBCT targets threat bias and reduces symptoms of anxiety. This preliminary study examined whether P1 ERP threat–related attentional bias markers in anxious adults change from pre- to post-MBCT delivered in-person or virtually (via Zoom) and investigated the relationship between P1 threat–related attentional bias markers and treatment response.

Methods Pre- and post-MBCT, participants with moderate to high levels of anxiety ($N = 50$) completed a dot-probe task with simultaneous EEG recording. Analyses focused on pre- and post-MBCT P1 amplitudes elicited by angry-neutral and happy-neutral face pair cues, probes, and reaction times in the dot-probe task and anxiety and depression symptoms.

Results Pre- to post-MBCT, there was a significant reduction in P1-Probe amplitudes ($d = .23$), anxiety ($d = .41$) and depression ($d = .80$) symptoms, and reaction times ($d = .10$). Larger P1-Angry Cue amplitudes, indexing hypervigilance to angry faces, were associated with higher levels of anxiety both pre- and post-MBCT ($d = .20$). Post-MBCT, anxiety symptoms were lower in the in-person versus virtual group ($d = .80$).

Conclusions MBCT may increase processing efficiency and decreases anxiety and depression symptoms in anxious adults. However, changes in threat bias specifically were generally not supported. Replication with a comparison group is needed to clarify whether changes were MBCT-specific.

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Keywords Mindfulness-based cognitive therapy · Threat-related attentional bias · Anxiety · Depression · Event-related potentials

Anxiety disorders are associated with hypervigilance to potential threat in preparation for future danger, cautious or avoidant behaviors (American Psychiatric Association, 2013), and delayed disengagement from threat (Amir et al., 2003). Individuals with anxiety disorders may also display threat-related attentional bias, defined as the preferential tendency to allocate attention toward or away from threatening stimuli (Mogg & Bradley, 2018). Although the

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accurate detection and valuation of potentially threatening information is crucial for survival, excessive deployment of attentional resources associated with threat detection can interfere with optimal functioning and may reflect a vulnerability marker for the onset and maintenance of anxiety disorders. Specifically, the attentional system of anxious individuals may be distinctively sensitive to and biased in favor of threat-related stimuli in the environment (Bar-Haim et al., 2007). In turn, these threat-related biases may play an important role in maintaining anxiety states, as anxious individuals would be more likely to detect minor potential threats in their environment, thus intensifying their anxious mood state (Mathews, 1990; Mogg et al., 1997).

Given the role of threat-related attentional bias in the etiology and maintenance of anxiety disorders (Bar-Haim et al., 2007), interventions that can modulate threat-related attentional bias may be most effective in preventing and treating anxiety (Gupta et al., 2019). One such intervention is mindfulness-based cognitive therapy (MBCT), a manualized 8-week skills-training group program (Segal et al., 2013) based on components of cognitive behavioral therapy (Beck et al., 1979) and mindfulness-based stress reduction (MBSR) (Kabat-Zinn, 1990). MBCT teaches individuals to become more aware of, and to relate differently to, their thoughts, feelings, and bodily sensations (i.e., individuals are taught to recognize thoughts and feelings as passing events in the mind rather than identifying with them or treating them as accurate readouts of reality) (Chiesa & Serretti, 2011; Kuyken et al., 2010).

Studies have shown that MBCT reduces anxiety and depression symptoms in adults with anxiety disorders (Evans et al., 2008; Kim et al., 2009). MBCT-linked changes in threat-related attentional bias may be a key mechanism driving the intervention's effects on anxiety symptoms in anxious populations (Gupta et al., 2019). A core feature of MBCT and mindfulness training in general is strengthening attention regulation through sustaining attention on a chosen object (e.g., the breath), and whenever distracted, returning attention to the object (Hölzel et al., 2011; Kuyken et al., 2010). This training may enhance the ability to inhibit elaborative processing of negative thought patterns, feelings, and body sensations (Shapiro et al., 2006) which may underlie the formation and preservation of threat-related biases. Inhibition of elaborative processes may facilitate rapid engagement and disengagement with objects of attention, thereby reducing biases associated with orienting of attention (Vago & Silbersweig, 2012).

Consistent with this possibility, studies have demonstrated that mindfulness training can mitigate and modulate attentional bias (Garland et al., 2010; Vago & Nakamura, 2011), albeit as assessed with behavioral measures such as reaction time (RT). RTs provide an indirect measure of attentional processing (Horley et al., 2004), can be confounded by post-perceptual processes such as motor responses and decision-making (Handy et al., 2001; Mueller et al., 2009), and, thus, may not be sensitive enough to reveal the mechanisms by which MBCT acts on threat-related attentional biases in anxious populations. Fortunately, the inclusion of event-related potentials (ERPs), with their temporal sensitivity and reliability across time (Cassidy et al., 2012), can illuminate the potential physiological mechanism through which MBCT may target threat-related attentional bias and reduce symptoms of anxiety (Gupta et al., 2019).

The P1 ERP is a promising neurophysiological marker to capture changes in threat-related attentional bias before and after MBCT. "P1" indicates that this component has a positive polarity and peaks approximately 100 ms poststimulus (Luck, 2014). Importantly, the P1 is sensitive to allocation of attention to stimuli (Clark & Hillyard, 1996). ERP amplitudes are generally assumed to signify the degree or intensity of the engagement of cognitive processes (Luck et al., 2000); thus, examining P1 amplitudes can reflect how much attention is allocated to threatening stimuli. In one study of interest, Mueller et al. (2009) investigated attentional biases in social anxiety disorder (SAD) and control participants using a behavioral dot-probe task in conjunction with ERPs. The dot-probe task is used to assess attentional bias in spatial orienting to threatening cues (Mogg & Bradley, 2016). Mueller et al. (2009) demonstrated that, compared to healthy controls, participants with SAD displayed enhanced P1 amplitudes to angry-neutral versus happy-neutral face pairs and decreased P1 amplitudes to probes replacing emotional (angry and happy) versus neutral faces, suggesting an early hypervigilance to angry faces and reduced visual processing of emotionally salient locations at later stages of information processing in SAD participants, respectively. These results highlight the P1 as a promising neurophysiological marker to capture attentional biases occurring at early and later stages of information processing.

In this preliminary study, we sought to investigate (1) whether P1 threat–related attentional bias markers in anxious adults change from pre- to post-MBCT, and (2) the relationship between P1 threat–related attentional bias markers and treatment response. We hypothesized that (1) prior to MBCT, anxious participants would display larger amplitudes to angry-neutral relative to happy-neutral face pair cues and smaller P1 amplitudes to probes replacing angry relative to neutral faces in a dot-probe task, and (2) following MBCT, participants would display smaller P1 amplitudes to angry-neutral relative to happy-neutral face pair cues and larger P1 amplitudes to probes replacing angry relative to neutral faces in the dot-probe task. Exploratory analyses were performed to examine RTs in the dot-probe task pre- to post-MBCT, and given unexpected changes due to the COVID-19 pandemic, we conducted exploratory analyses on differences between in-person and virtual MBCT.

Method

Participants

The present study is a secondary aim of a larger, multimethod study investigating mechanisms by which mindfulness-based interventions (i.e., MBCT and MBSR) may improve health outcomes (NCT03571386). Eligibility was assessed using an electronic pre-screening questionnaire on REDCap. Individuals were eligible if they (1) were between the ages of 18 and 55 years; (2) had moderate to high levels of anxiety, indexed by a score of 40 or above on the State-Trait Anxiety Inventory, Trait Scale (Spielberger et al., 1983); and (3) were considered stable on anxiety, depression, or as-needed medications for at least 1 month prior to enrollment. Individuals were ineligible if they endorsed or indicated any of the following exclusion criteria on the questionnaire: (1) a diagnosis of bipolar I or II, dementia, psychotic, borderline, or narcissistic personality disorders; (2) a current history (in the past ≤ 6 months) of regular meditation practice (> 1 session per week; > 10 min per session); (3) a current history (in the past ≤ 6 months) of substance abuse and/or dependence; (4) an inability to communicate in English at a level necessary for informed consent and understanding instructions; or (5) a serious underlying systemic or comorbid disease precluding physical or cognitive ability to participate. Participants were encouraged to continue their current medications and attend appointments with their mental health practitioners or other providers over the treatment phase as they would have done otherwise. However, participants were asked not to start individual psychotherapy or a regular meditation or yoga practice aside from study-provided MBCT. Inclusion and exclusion criteria were selected to minimize confounds that could impact response to treatment. We aimed to focus on an anxious sample without other comorbidities which might affect P1 threat bias marker change. We also excluded a current history of regular meditation practice, as this could have interfered with our evaluation of P1 marker change from pre- to post-MBCT.

Participants were recruited from the greater Nashville community through ResearchMatch, the Vanderbilt University Medical Center research notification distribution listserv, and the Osher Center for Integrative Medicine at Vanderbilt. Sixty-nine participants were enrolled, 65 participants completed the pre-MBCT EEG assessment, and 50 of these participants completed the MBCT course and post-MBCT EEG (see Supplementary Materials for more information). Demographic information is provided in Table 1. Participants were required to attend at least 5 of the 8 MBCT classes and the all-day retreat to qualify for study completion. Thirteen of the 50 participants completed in-person MBCT prior to the COVID-19 pandemic and the remaining 37 participants completed virtual MBCT during

Table 1 Sample characteristics for the full sample and in-person and virtual MBCT subgroups pre- and post-MBCT. Means and standard deviations (in parentheses) are listed. Differences between the in-person and virtual group differences were explored, and resulting *t*, χ^2, *p*, and *d* values are shown. Asterisks represent $p < .05$

	Full sample ($N = 50$)	In-Person MBCT group ($n = 13$)	Virtual MBCT group ($n = 37$)	*t* or χ^2 value	*p* value
Demographics					
Age (years)	31.92 (8.75)	33.08 (7.74)	31.51 (9.15)	$t(48) = .55$	.58
Gender (% F)	78.00	84.62	75.68	$\chi^2(1) = .45$	.50
Race (%)	A: 8.00 BAA: 8.00 MTOR: 2.00 W: 82.00	A: 7.69 BAA: 7.69 MTOR: 0.00 W: 84.62	A: 8.11 BAA: 8.11 MTOR: 2.70 W: 81.08	$\chi^2(3) = .37$	.95
Ethnicity (% HL)	4.00	0.00	5.41	$\chi^2(1) = .73$	.39
Pre-MBCT					
DASS-A	12.64 (8.66)	10.15 (8.31)	13.51 (8.72)	$t(48) = -1.21$	.23 ($d = .39$)
DASS-D	18.08 (8.68)	21.08 (7.98)	17.03 (8.78)	$t(48) = 1.46$	.15 ($d = .47$)
Post-MBCT					
DASS-A	8.96 (7.75)	4.62 (4.93)	10.49 (8.03)	$t(48) = -2.47$	.02* ($d = .80$)
DASS-D	10.12 (8.74)	9.54 (6.39)	10.32 (9.49)	$t(48) = -.28$	.78 ($d = .09$)

F = female; A = Asian; BAA = Black or African American; MTOR = more than one race; W = White; HL = Hispanic or Latino; DASS-A = Depression Anxiety Stress Scale-Anxiety Subscale; DASS-D = Depression Anxiety Stress Scale-Depression Subscale

the pandemic. As shown in Table 1, the in-person and virtual MBCT groups did not differ in terms of their demographic characteristics. All participants provided written informed consent and received monetary compensation for their participation. The study was approved by the Vanderbilt University Institutional Review Board.

Procedure

MBCT Intervention In-person and virtual 8-week MBCT courses, adapted from Segal et al. (2013), were led by instructors with over 12 years of mindfulness teaching experience and qualifications to teach MBCT (see Supplementary Materials for more information). The courses were held in a group format with approximately 12 participants in each in-person group and 20 participants in each virtual group. The Zoom platform (Zoom Video Communications Inc., 2021) was used for virtual courses.

Courses included (1) a pre-program orientation, (2) a brief individual interview with the instructor, (3) eight weekly group classes (2 or 2.5 h in duration), (4) an all-day retreat during the sixth week of the program (in-person MBCT: 7.5 h; virtual MBCT: 5 h), (5) learning "formal" meditation practices (e.g., body scan meditation, gentle yoga, focused attention and open monitoring meditation, walking meditation), (6) learning "informal" meditation practices and skills for daily life (e.g., noting pleasant and unpleasant events, becoming aware of breathing and routine activities like eating, driving, walking, conversations), (7) daily homework assignments involving formal and informal practices, and (8) individual and group dialogue and inquiry processes discussing home assignments and any problems.

Dot-Probe Task A dot-probe task adapted from Mueller et al. (2009) (see Fig. 1) with simultaneous EEG recording was used to assess threat-related attentional bias prior to and following MBCT. Pairs of face stimuli were created using grayscale photographs of men and women portraying angry, happy, and neutral facial expressions from Ekman's Pictures of Facial Affect (Ekman & Friesen, 1976). All happy faces used in the present study exhibited smiles with exposed teeth, while half of the angry faces used in this study featured exposed teeth and the other half featured compressed lips. Each face pair consisted of two different identities of the same sex portraying a neutral expression and either an angry or a happy facial expression. This yielded four conditions: angry-neutral, neutral-angry, happy-neutral, and neutral-happy. Each emotional expression appeared equally often to the left or right of the neutral expression. Faces were cropped into 8 cm × 10 cm ovals and set on a black background. The centers of the faces were 18 cm apart. The faces were presented in the upper visual field and were viewed at a distance of 70 cm. The probe was a white, vertical rectangular bar measuring 6 cm × 0.4 cm and was presented on either the left or right side of the screen in the same upper visual field location as the faces. The fixation cross measured 2 cm × 2 cm with a thickness of 0.1 cm and was presented centrally on the lower part of the screen. Stimuli were set on a black background and presented on a 24-inch monitor with a Dell desktop running E-Prime (Psychology Software

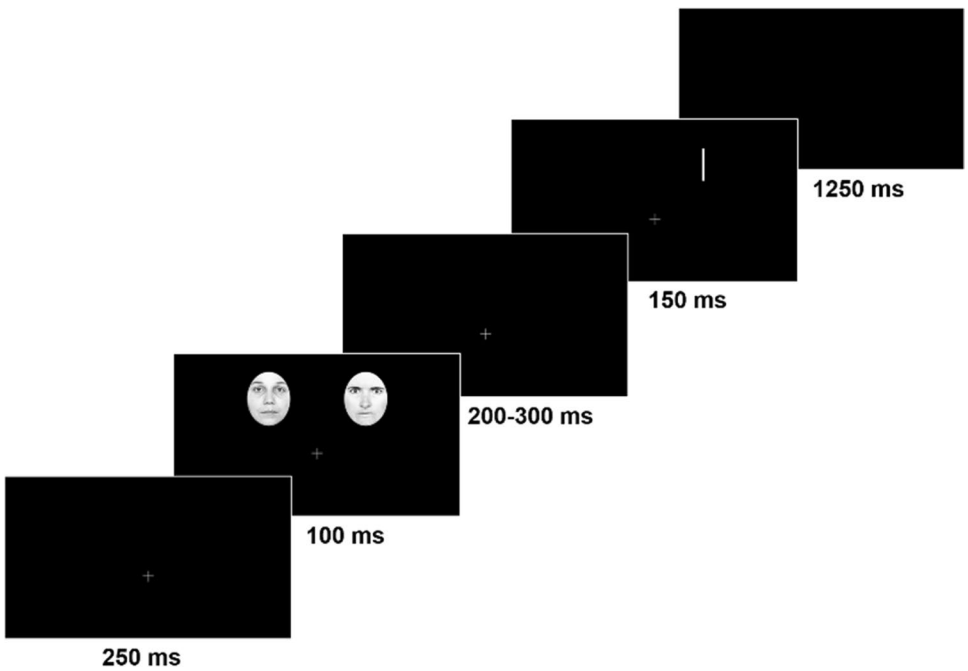

Fig. 1 Schematic of the dot-probe task

Tools, Pittsburgh, PA). Participants responded to stimuli using a Cedrus RB-844 button box (Cedrus, San Pedro, CA).

The dot-probe task began with a practice block of 16 trials followed by six blocks of 120 trials each (720 trials total). Each block was separated by a short rest break. Each trial began with the presentation of a fixation cross for 250 ms followed by presentation of the face pair cues for 100 ms. The interstimulus interval varied randomly from 200 to 300 ms (in 25 ms increments); thus, the stimulus onset asynchrony was 300–400 ms. The probe then appeared for 150 ms in either location previously occupied by a face. The intertrial interval was 1250 ms. To replicate procedures used in Mueller et al. (2009), female face pairs were presented 60% of the time, and male face pairs were presented 40% of the time. Happy and angry face pairs appeared equally often and with equal frequency in the right and left visual fields. Probes also appeared with equal frequency in the right and left visual field. All stimuli were randomized and counterbalanced across participants. For each trial, participants were instructed to focus on the fixation cross while concurrently monitoring the location of the probe. Participants were asked to press one of two buttons on the response box to indicate which side of the screen the probe was on. Response times were recorded from probe onset. Trials with incorrect responses and response times < 100 ms or > 1500 ms were excluded from behavioral analyses.

Measures

The State-Trait Anxiety Inventory, Trait Scale (STAI-T) (Spielberger et al., 1983) evaluates relatively stable aspects of "anxiety proneness," including general states of calmness, confidence, and security. Participants with moderate to high levels of anxiety, evidenced by scores of 40 or above on the STAI-T (Addolorato et al., 1999; Weinstein, 1995), were recruited.

The Depression Anxiety Stress Scale–21 Items (DASS-21) (Lovibond & Lovibond, 1995) was administered before and after MBCT. The DASS-21 anxiety scale (DASS-A), which assesses autonomic arousal, skeletal muscle effects, situational anxiety, and subjective experiences of anxious affect, was used as the primary outcome measure of anxiety. Exploratory analyses examined scores from the DASS-21 depression scale (DASS-D), which assesses dysphoria, hopelessness, devaluation of life, self-deprecation, lack of interest/involvement, anhedonia, and inertia. The DASS-A was found to have acceptable to good internal consistency both pre-MBCT (7 items; $\alpha = 0.73$) and post-MBCT (7 items; $\alpha = 0.80$), and the DASS-D also had acceptable to good internal consistency both pre-MBCT (7 items; $\alpha = 0.79$) and post-MBCT (7 items; $\alpha = 0.87$).

Data Analyses

EEG Recording and Data Reduction Prior to the COVID-19 pandemic, EEG was recorded continuously using Brain Vision Recorder (Brain Products GmbH, Gilching, Germany), BrainAmp DC (Brain Products GmbH, Gilching, Germany), and a 64-channel actiCAP (Brain Products GmbH, Gilching, Germany) with a sampling rate of 500 Hz and an FCz reference. Electrodes Fp1, Fp2, FT9, and FT10 were removed from the cap and used as EOG channels; vertical eye movements were recorded using electrodes placed above and below the left eye, and horizontal eye movements were recorded using electrodes placed near the outer canthus of each eye. Impedance of all channels was kept below 10 kΩ. During the pandemic, methodological changes were made to minimize contact time, including using only 32 scalp channels (Fp1, FT9, and FT10 were removed from the cap and used as EOG channels). The pre-pandemic 64-channel data were analyzed as 32-channel data to match the data collected during the pandemic.

Data were processed using Brain Vision Analyzer (Brain Products GmbH, Germany). Data were first filtered between 0.1 and 30 Hz via zero-phase shift band-pass (IIR Butterworth) and 60 Hz notch filters and were subsequently re-referenced offline to an average reference, yielding 29-channel EEG data (the original reference channel, FCz, was regained as a data channel). Raw data inspection was performed on the continuous EEG data to identify and mark artifacts. Ocular artifacts were corrected using the regression method (Gratton et al., 1983). When required, topographic interpolation by spherical splines was performed.

For the cue condition, data were segmented into trials where (1) angry-neutral face pairs were presented, and (2) happy-neutral face pairs were presented. For the probe condition, data were segmented into presentation of (1) angry congruent probes (i.e., probe replaced angry face in angry-neutral face pairs), (2) angry incongruent probes (i.e., probe replaced neutral face in angry-neutral face pairs), (3) happy congruent probes (i.e., probe replaced happy face in happy-neutral face pairs), and (4) happy incongruent probes (i.e., probe replaced neutral face in happy-neutral face pairs). All segments were extracted beginning 50 ms before and ending 300 ms after stimulus presentation. Cue- and probe-locked segments were baseline corrected using a relatively narrow window of − 50 to 0 ms, as the rapid nature of the task led to overlap of cue- and probe-locked potentials and deflections when using a wider baseline period of 100 ms. Artifact rejection was completed using semi-automatic inspection, individual channel mode, and the following criteria: maximal allowed voltage step: 50 μV/ms; maximal allowed difference of values in intervals: 200 μV (interval length: 200 ms); and lowest allowed activity in intervals: 0.1 μV (interval length: 100 ms). Artifact rejection also removed

trials where voltages exceeded ± 75 µV. Only trials with correct responses were used to calculate each subject's averages and the grand averages. Subject averages and grand averages were computed with individual channel mode enabled.

Primary ERP analyses focused on P1 amplitudes elicited by the face pair cues (P1-Cue) and probes (P1-Probe), as the P1 is sensitive to attentional allocation (Clark & Hillyard, 1996) and is modulated by emotional (e.g., threatening or positive) stimuli (Gupta et al., 2019). Furthermore, examining both the P1-Angry Cue and P1-Angry Congruent Probe pre- and post-MBCT allowed for examination of changes in hypervigilance toward and avoidance from threatening stimuli at early and later stages of processing, respectively. An 80–150 ms search window at electrode P8 was used to identify the P1-Cue and P1-Probe peaks, and the mean value around the peaks (50 ms) was exported from Brain Vision Analyzer. Time window and electrode site selections were based on (1) Mueller et al. (2009), who used an 80–150 ms time window at parieto-occipital sites for P1-Cue and P1-Probe peak detection and observed that P1 amplitudes were larger over the right hemisphere, and (2) Gupta et al. (2021), where a temporospatial factor combination resembling a P1-Cue peaked at 86 ms at a right hemisphere parieto-occipital site. It has been demonstrated that neurophysiological markers of attentional bias are reliably measured in the ERP waveforms (Gupta et al., 2021).

Statistical Analyses Linear mixed-effects (LME) models rather than repeated-measures analysis of variance were used to test study hypotheses because LME models are better equipped for handling dependencies in repeated-measures data (Gueorguieva & Krystal, 2004; Judd et al., 2012). All LME models used a random intercept for subject and were implemented in Matlab R2021a using the default settings. Reference conditions used for the LME model parameters were as follows: time (pre-MBCT), emotion (angry), congruency (congruent). Paired *t*-tests were performed on the pre- and post-MBCT DASS-A and DASS-D scores in jamovi (R Core Team, 2021; The jamovi project, 2021) to determine whether there were significant changes in anxiety and depression symptoms, respectively. Pre-MBCT was used as the reference condition for the paired *t*-tests. Finally, given the unexpected move from in-person to virtual MBCT due to the COVID-19 pandemic, a series of exploratory analyses were conducted to test for group differences in outcomes.

Results

MBCT Effects on P1-Cue ERP

Mean P1-Cue amplitudes and standard deviations are shown in Table 2, pre- and post-MBCT grand average ERP waveforms time-locked to the presentation of angry and happy face pair cues at electrode P8 are shown in Fig. 2, and the mean number of trials included in the grand averages are described in the Supplementary Materials. The P1-Cue LME model was used to determine the effects of time (pre-MBCT versus post-MBCT) and emotion (angry versus happy) on P1-Cue amplitudes. The interaction between time and emotion on P1-Cue amplitudes was nonsignificant (*unstandardized* $b = -0.07$, $SE = 0.32$, $t(196) = -0.22$, $p = 0.83$, $d = 0.02$). In the main effects model, there was no significant effect of time ($b = -0.06$, $SE = 0.16$, $t(197) = -0.36$, $p = 0.72$, $d = 0.03$) or emotion ($b = 0.02$, $SE = 0.16$, $t(197) = 0.14$, $p = 0.89$, $d = 0.01$) on P1-Cue amplitudes.

Table 2 Mean amplitudes and standard deviations (in parentheses) for all P1 conditions in the full sample ($N = 50$)

P1 conditions	Pre-MBCT	Post-MBCT
Angry Cue	2.62 (2.83)	2.60 (2.74)
Happy Cue	2.68 (2.81)	2.58 (2.73)
Angry Congruent Probe	1.19 (2.32)	.87 (1.97)
Angry Incongruent Probe	1.16 (2.30)	.61 (2.24)
Happy Congruent Probe	1.19 (2.42)	.64 (2.22)
Happy Incongruent Probe	1.14 (2.15)	.65 (2.11)

MBCT Effects on P1-Probe ERP

Mean P1-Probe amplitudes and standard deviations are shown in Table 2, pre- and post-MBCT grand average ERP waveforms time-locked to angry congruent, angry incongruent, happy congruent, and happy incongruent probes at electrode P8 are shown in Fig. 3, and the mean number of trials included in the grand averages are described in the Supplementary Materials. The P1-Probe LME model was used to determine the effects of time (pre-MBCT versus post-MBCT), emotion (angry versus happy), and congruency (congruent versus incongruent) on P1-Probe amplitudes. The interaction between time, emotion, and congruency was nonsignificant ($b = 0.28$, $SE = 0.41$, $t(392) = 0.68$, $p = 0.50$, $d = 0.03$). In the main effects model, there was no significant effect of emotion ($b = -0.05$, $SE = 0.10$, $t(396) = -0.51$, $p = 0.61$, $d = 0.03$) or congruency ($b = -0.08$, $SE = 0.10$, $t(396) = -0.77$, $p = 0.44$, $d = 0.04$); however, there was a significant main effect of time ($b = -0.48$, $SE = 0.10$, $t(396) = -4.65$, $p < 0.001$, $d = 0.23$) such that P1-Probe amplitudes were reduced (by −0.48 µV, on average) across conditions post-MBCT compared to pre-MBCT.

Changes in Anxiety and Depression Symptoms

Paired *t*-tests revealed that pre-MBCT DASS-A scores ($M = 12.64$, $SD = 8.66$) were significantly greater than

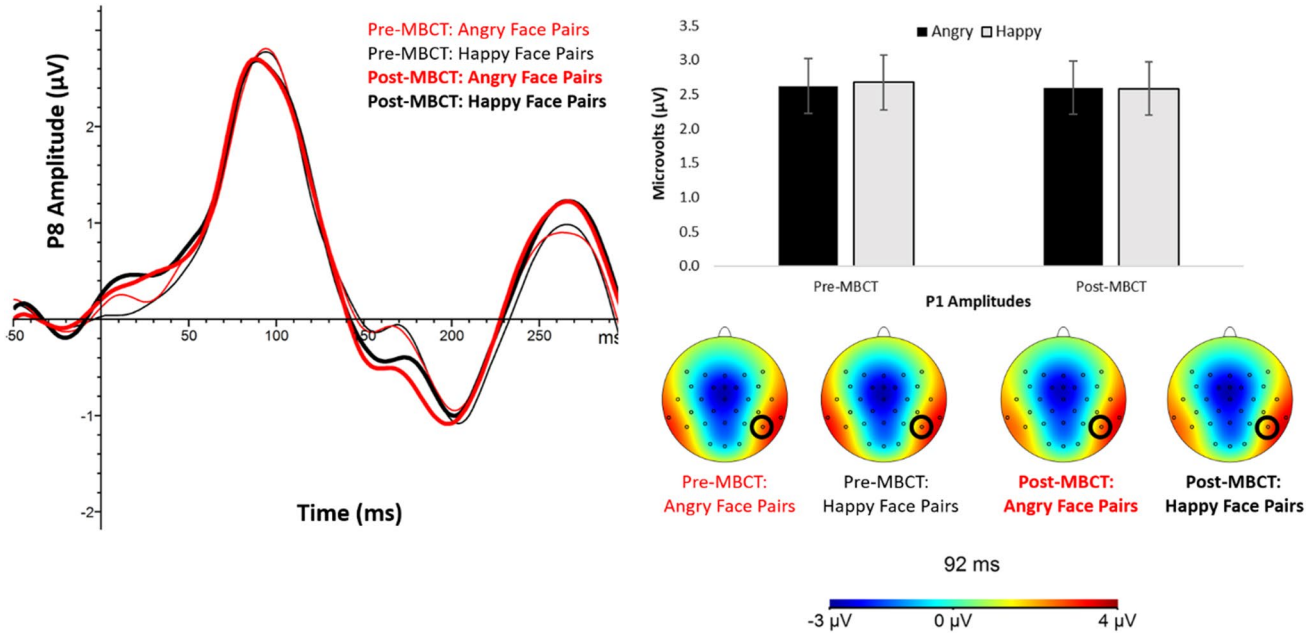

Fig. 2 P1-Cue ERPs and scalp distributions for the full sample ($N = 50$). Left: Pre- and post-MBCT grand average ERP waveforms time-locked to the presentation of angry and happy face pair cues at electrode P8 (indicated with black circles on scalp distribution figures). Right: Mean P1 amplitudes as a function of time and emotion (error bars represent standard error of the mean) and scalp distribution figures for each condition at the approximate peak time point (92 ms)

post-MBCT DASS-A scores ($M = 8.96$, $SD = 7.75$), $t(49) = 2.88$, $p < 0.01$, $d = 0.41$, *mean difference* = 3.68, *SE difference* = 1.28. Similarly, pre-MBCT DASS-D scores ($M = 18.08$, $SD = 8.68$) were significantly greater than post-MBCT DASS-D scores ($M = 10.12$, $SD = 8.74$), $t(49) = 5.66$, $p < 0.001$, $d = 0.80$, *mean difference* = 7.96, *SE difference* = 1.41.

P1-Angry Cue and Anxiety and Depression Score Analyses

The P1-Angry Cue and DASS-A/DASS-D LME models were used to investigate the effects of time (pre-MBCT versus post-MBCT) and P1-Angry Cue amplitudes on DASS-A and DASS-D scores, respectively. In the P1-Angry Cue and DASS-A model, the interaction between time and P1-Angry Cue amplitudes was nonsignificant ($b = -0.30$, $SE = 0.46$, $t(96) = -0.65$, $p = 0.52$, $d = 0.06$). However, in the main effects model, there was a significant effect of time ($b = -3.67$, $SE = 1.24$, $t(97) = -2.95$, $p < 0.01$, $d = 0.29$) on DASS-A scores such that scores were reduced (by − 3.67 points, on average) post-MBCT compared to pre-MBCT. There was also a significant effect of P1-Angry Cue amplitudes ($b = 0.65$, $SE = 0.32$, $t(97) = 2.05$, $p = 0.04$, $d = 0.20$) on DASS-A scores such that higher P1-Angry Cue amplitudes overall were associated with higher DASS-A scores across both pre- and post-MBCT time points.

To determine whether these results were restricted to the DASS-A, the model was also applied to the DASS-D data. The interaction between time and P1-Angry Cue amplitudes was nonsignificant ($b = 0.47$, $SE = 0.51$, $t(96) = 0.94$, $p = 0.35$, $d = 0.09$). In the main effects model, there was no significant effect of P1-Angry Cue amplitudes ($b = 0.57$, $SE = 0.34$, $t(97) = 1.68$, $p = 0.10$, $d = 0.17$) on DASS-D scores; however, there was a significant effect of time ($b = -7.95$, $SE = 1.37$, $t(97) = -5.81$, $p < 0.001$, $d = 0.58$) on DASS-D scores such that scores were reduced post-MBCT compared to pre-MBCT.

P1-Angry Congruent Probe and Anxiety and Depression Score Analyses

The P1-Angry Congruent Probe and DASS-A/DASS-D LME models were used to investigate the effects of time (pre-MBCT versus post-MBCT) and P1-Angry Congruent Probe amplitudes on DASS-A and DASS-D scores, respectively. In the P1-Angry Congruent Probe and DASS-A model, the interaction between time and P1-Angry Congruent Probe amplitudes was nonsignificant ($b = -0.49$, $SE = 0.61$, $t(96) = -0.80$, $p = 0.43$, $d = 0.08$). In the main effects model, there was no significant effect of P1-Angry Congruent Probe amplitudes ($b = 0.62$, $SE = 0.40$, $t(97) = 1.53$, $p = 0.13$, $d = 0.15$) on DASS-A scores; however, there was a significant effect of time ($b = -3.48$,

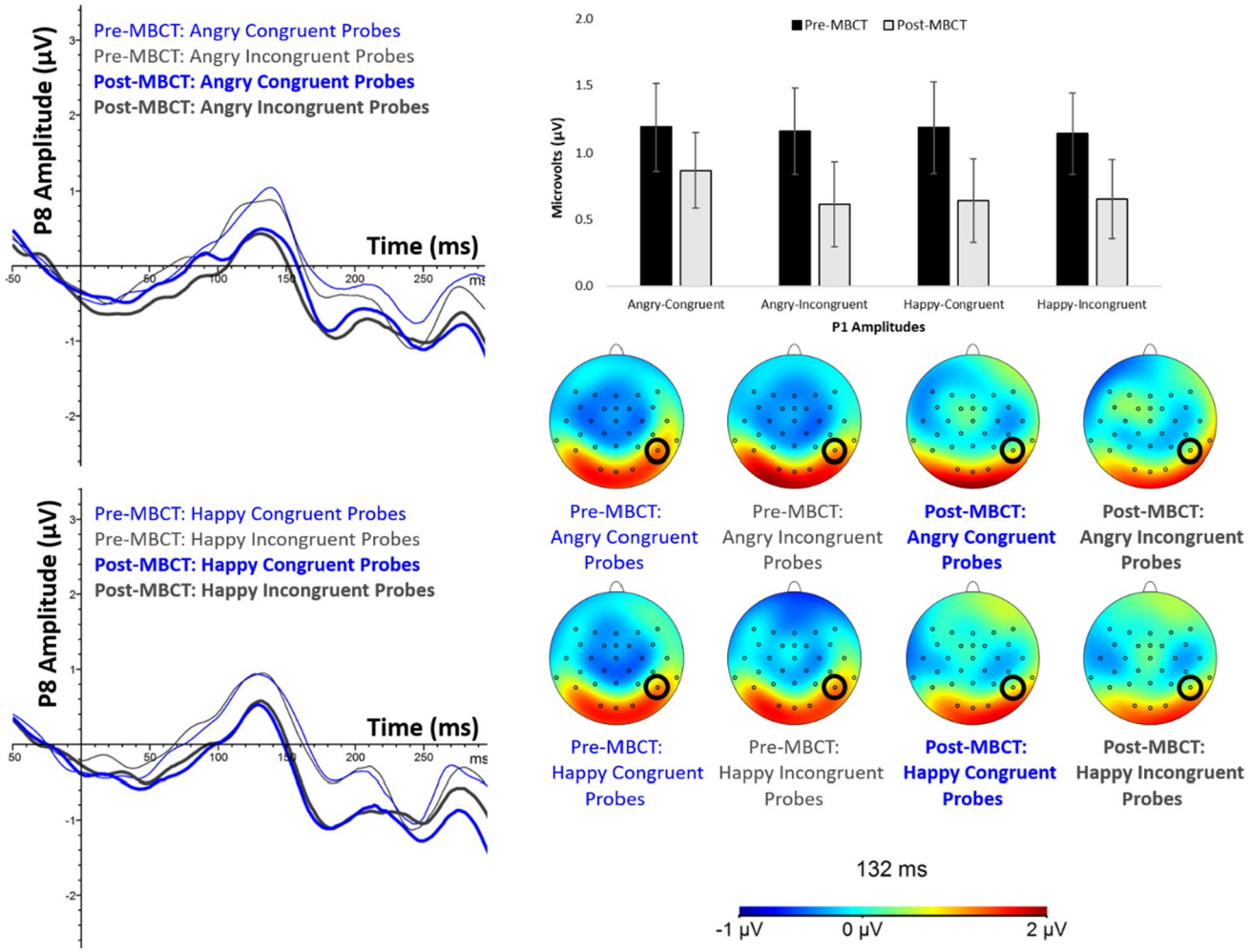

Fig. 3 P1-Probe ERPs and scalp distributions for the full sample ($N = 50$). Left: Pre- and post-MBCT grand average ERP waveforms time-locked to the onset of angry congruent and angry incongruent probes (top) and happy congruent and happy incongruent probes (bottom) at electrode P8 (indicated with black circles on scalp distribution figures). Right: Mean P1-Probe amplitudes as a function of time, emotion, and congruency (error bars represent standard error of the mean) and scalp distribution figures for each condition at the approximate peak time point (132 ms)

$SE = 1.26$, $t(97) = -2.77$, $p < 0.01$, $d = 0.28$) such that DASS-A scores were reduced post-MBCT compared to pre-MBCT.

The model was also used to investigate the effects of time and P1-Angry Congruent Probe amplitudes on DASS-D scores. The interaction between time and P1-Angry Congruent Probe amplitudes was nonsignificant ($b = -0.05$, $SE = 0.69$, $t(96) = -0.07$, $p = 0.94$, $d = 0.01$). In the main effects model, there was no significant effect of P1-Angry Congruent Probe amplitudes ($b = 0.31$, $SE = 0.43$, $t(97) = 0.73$, $p = 0.47$, $d = 0.07$) on DASS-D scores; however, there was a significant effect of time ($b = -7.86$, $SE = 1.40$, $t(97) = -5.61$, $p < 0.001$, $d = 0.56$) such that DASS-D scores were reduced post-MBCT compared to pre-MBCT.

MBCT Effects on Behavioral (RT) Data

Mean RTs to probes are shown in Fig. 4. The RT LME model was used to explore the effects of time (pre-MBCT versus post-MBCT), emotion (angry versus happy), and congruency (congruent versus incongruent) on RTs. The interaction between time, emotion, and congruency was nonsignificant ($b = -2.03$, $SE = 7.29$, $t(392) = -0.28$, $p = 0.78$, $d = 0.01$). In the main effects model, there was no significant effect of emotion ($b = -0.77$, $SE = 1.82$, $t(396) = -0.42$, $p = 0.67$, $d = 0.02$) or congruency ($b = 3.16$, $SE = 1.82$, $t(396) = 1.73$, $p = 0.08$, $d = 0.09$) on RTs; however, there was a significant effect of time ($b = -3.68$, $SE = 1.82$, $t(396) = -2.02$, $p = 0.04$, $d = 0.10$) such that RTs were reduced (by −3.68 ms, on average) overall post-MBCT compared to pre-MBCT.

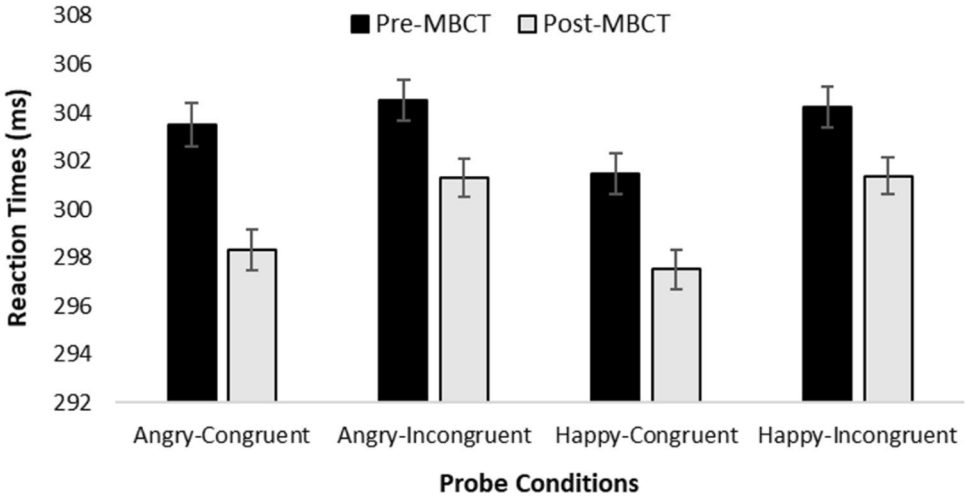

Fig. 4 Mean reaction times to probes as a function of time, emotion, and congruency in the full sample ($N = 50$). Error bars represent standard error of the mean

Exploratory Tests of In-Person (n = 13) Versus Virtual (n = 37) MBCT Group Differences

Table 1 presents descriptive statistics for pre- and post-MBCT DASS-A and DASS-D scores in the in-person and virtual MBCT groups. Exploratory independent-samples *t*-tests were performed in jamovi (R Core Team, 2021; The jamovi project, 2021) to determine whether there were significant group differences, and in-person was used as the reference condition. Pre-MBCT DASS-A and DASS-D group comparisons did not reach significance. However, small to moderate effects were observed, such that the in-person group reported relatively higher pre-MBCT DASS-D scores than the virtual group, *mean difference* = 4.05, *SE difference* = 2.77, but the virtual group reported relatively higher DASS-A scores, *mean difference* = −3.36, *SE difference* = 2.78. Post-MBCT, in-person group DASS-A scores were significantly lower than virtual group DASS-A scores, *mean difference* = −5.87, *SE difference* = 2.38, but the groups did not differ on DASS-D scores, *mean difference* = −0.79, *SE difference* = 2.84.

Finally, we repeated analyses both in the virtual group only ($n = 37$) and with group (in-person versus virtual) as a covariate, and results were generally consistent with findings from the full sample barring a few instances (see Supplementary Materials). We also examined participants classified as treatment responders ($n = 16$) to determine whether this subgroup displayed P1-Cue, P1-Probe, and RT threat bias changes, but no significant effects emerged (see Supplementary Materials).

Discussion

The goal of this preliminary study was to investigate (1) whether P1 threat–related attentional bias markers in anxious adults change from pre- to post-MBCT, and (2) the relationship between P1 threat–related attentional bias markers and treatment response. Exploratory analyses were performed to examine RTs in the dot-probe task pre- to post-MBCT, and given unexpected changes due to the COVID-19 pandemic, we conducted exploratory analyses on differences between in-person and virtual MBCT. Primary findings indicated an overall reduction of P1-Probe amplitudes, anxiety and depression symptoms, and RTs following MBCT; however, it is possible that these changes may be due, in part, to repeated assessments. Additionally, larger P1-Angry Cue amplitudes were associated with higher levels of anxiety across both pre- and post-MBCT time points. Surprisingly, no significant changes in the P1-Angry Cue were observed following MBCT.

Contrary to our hypotheses, ERP results suggested that anxious participants did not display hypervigilance to threat cues pre-MBCT or a reduction in hypervigilance post-MBCT. Participants also did not appear to display avoidance from threat pre-MBCT or reduced avoidance post-MBCT. The observation that anxious participants did not display pre-MBCT P1 threat–related biases at the level of the cues and probes was surprising and did not match the early hypervigilance/later avoidance findings described in Mueller et al. (2009). However, Mueller et al. specifically focused on participants with SAD; in the present study, participants with moderate to high levels of anxiety were recruited using the STAI-T, which evaluates relatively stable aspects of "anxiety proneness," including general states of calmness, confidence, and security (Spielberger et al., 1983). It has been shown that modulations of ERP components in response to threatening and emotional stimuli are particularly apparent in socially anxious populations (Gupta et al., 2019), and the lack of focus on SAD specifically may have contributed to the difference in findings. Additionally, even though biases occur in all anxiety disorders, including generalized anxiety disorder (GAD), social phobia, specific phobia, and panic

disorder (Cisler & Koster, 2010), attentional biases present differently across these disorders. For example, patients with panic disorder display attentional bias for a wide range of threat words, including panic-threat, social-threat, and general-threat, whereas patients with social phobia display a trend toward specific attentional bias for social-threat words primarily (Maidenberg et al., 1996) and faces such as the ones used by Mueller et al. (2009) and in the present study. Even within high trait anxiety populations, biases can present in an inconsistent fashion. Using RT data, Zvielli et al. (2014) showed that, in a sample of 106 high trait anxious individuals, 34% of participants expressed attentional bias toward threat stimuli, 20.8% of participants expressed attentional bias away from threat stimuli, and 34% of participants displayed attentional bias toward some categories of threat stimuli and away from others. This may explain why no clear biases to the cues and probes were apparent in this study.

P1-Probe amplitudes were reduced across conditions post-MBCT compared to pre-MBCT, suggesting that participants allocated less attention to probes following MBCT. Mindfulness has been described as a self-regulatory strategy to facilitate rapid engagement and disengagement with objects of attention without further elaboration (Vago & Silbersweig, 2012); therefore, the reduced attentional allocation suggests that MBCT may be associated with more efficient probe processing. Practice effects, referring to the phenomenon that individuals perform better at cognitive function tests with repeated testing (Wesnes & Pincock, 2002), could also explain these results. Participants may have required fewer attentional resources to perform the dot-probe due to familiarity with the task post-MBCT. However, prior research on repeated P1 assessments in oddball and Sternberg tasks indicated that peak amplitudes were stable across time and did not significantly decrease (Cassidy et al., 2012; Morand-Beaulieu et al., 2022), suggesting that P1-Probe amplitude reductions observed in this study may indeed have resulted from MBCT effects.

Exploratory analyses were performed to examine RTs in the dot-probe task pre- to post-MBCT. There was a main effect of time such that RTs were faster post-MBCT compared to pre-MBCT. Similar to the P1-Probe findings, the faster RTs post-MBCT suggest that participants were able to engage and disengage with the probes more efficiently after MBCT, leading to faster responses. However, faster RTs could also stem from practice effects arising from familiarity with the task at post-testing. Indeed, prior research on repeated RT assessments in dot-probe tasks has shown faster RTs at repeated administrations over shorter time frames (Aday & Carlson, 2019; Wise et al., 2022).

Anxiety and depression symptoms were significantly reduced following MBCT. These findings are consistent with other studies which have shown that MBCT can reduce anxiety and depression symptoms in adults with anxiety disorders (Evans et al., 2008; Kim et al., 2009). Interestingly, changes in P1-Angry Cue markers of early hypervigilance to threat and P1-Angry Congruent Probe markers of later avoidance from threat were not associated with anxiety (or depression) symptom changes. However, higher P1-Angry Cue amplitudes overall were associated with higher anxiety scores across both pre- and post-MBCT time points. This suggests that participants who displayed larger P1-Angry Cue amplitudes, indexing greater attention and hypervigilance to angry faces, also had higher levels of anxiety. Indeed, anxiety levels may affect the direction of attentional bias (Gupta et al., 2019). Williams et al. (1988) proposed that individuals with high trait anxiety disposition allocate attention to threat more readily, thereby facilitating threat appraisal, increasing arousal, and decreasing the likelihood of disengagement from threat. By contrast, individuals with low trait anxiety may disengage from threat more readily, ignore potential threat, thereby reducing autonomic arousal, and decrease threat potential of incoming sensory information. Heterogeneous tendencies for threat-related attentional bias in high- and low-trait anxious individuals should be accounted for in future studies.

Exploratory analyses were performed on the virtual MBCT sample alone, and results were generally consistent with findings from the full sample, barring a few instances. Anxiety symptoms were not significantly reduced following virtual MBCT. Additionally, higher P1-Angry Cue amplitudes were associated with higher depression scores across both pre- and post-MBCT time points, suggesting that participants who displayed greater attention to angry faces also had higher levels of depression. This was an unexpected finding, as hypervigilance to threat is not commonly associated with depression (Mogg & Bradley, 2005). Additionally, RTs were not significantly faster following virtual MBCT.

Exploratory analyses were also conducted to test for in-person versus virtual MBCT group effects. The groups differed in terms of their anxiety symptoms; specifically, post-MBCT, anxiety scores for the in-person versus virtual group were significantly lower. Elevated post-MBCT anxiety observed in the virtual group may have resulted from pandemic-related physical health and psychosocial burdens, including interpersonal, occupational, and financial strain (Kujawa et al., 2020). Indeed, the pandemic has been associated with high rates of anxiety and depression (Hyland et al., 2020; Rajkumar, 2020).

As a final exploration, participants classified as treatment responders post-MBCT were analyzed to determine whether this subgroup displayed P1-Cue, P1-Probe, and RT threat bias changes, but no significant effects emerged (see Supplementary Materials). Thus, although this subgroup demonstrated positive reliable DASS-A change, they did not appear to display changes in threat bias following MBCT. Additionally, clinical significance of treatment outcomes

in the present study were compared with outcomes from a study examining the effects of MBCT on participants with GAD (Evans et al., 2008). Participants in the Evans et al. (2008) study appeared to have made greater treatment gains (see Supplementary Materials). Differences between virtual compared to in-person MBCT, heterogeneity in our anxious sample, and potential variability in instruction may have affected our treatment outcome results.

Limitations and Future Research

This study has many strengths; first, it examined changes in attentional bias following MBCT in anxious adults using neural measures. Additionally, the relationship between neural markers and treatment response was examined. However, there are a number of limitations which should be acknowledged.

First, the present study lacked a comparison group. This study was a preliminary test of whether MBCT may be associated with changes in threat-related attentional bias. In future studies, we plan to employ an active control group structurally equivalent to MBCT and control for non-specific effects (e.g., interaction with a facilitator, perceived social support, treatment outcome expectations) (Shallcross et al., 2015). This would help clarify whether the reduction in P1-Probe amplitudes, anxiety and depression symptoms, and RTs following MBCT specifically resulted from the intervention. We were also unable to conduct fidelity assessments for virtual MBCT due to pandemic-related changes in resource availability (see Supplementary Materials).

Second, the present study only examined early ERP markers of threat-related attentional bias (i.e., P1-Cue and P1-Probe) in anxious participants who did not have a current history of regular meditation practice. Thus, it is unclear whether changes in threat-related bias occurred at later stages of processing. A systematic review by Chiesa et al. (2011) suggested that early phases of mindfulness training are associated with improvements in top-down, voluntary, goal-directed attention (i.e., conflict monitoring and orienting), whereas later phases are associated with improved bottom-up, stimulus-driven attention (i.e., alerting and exogenous stimulus detection) (Corbetta & Shulman, 2002; Jha et al., 2007). Indeed, many studies investigating the effects of short-term mindfulness meditation on bottom-up stimulus driven attentional processes such as alerting have not found significant effects, but studies examining long-term meditators have detected changes in early components of attention (Jha et al., 2007; Tang et al., 2015). Thus, MBCT may modulate later ERP markers of threat-related attentional bias sensitive to top-down attentional control and elaborative processing, such as the P3 and LPP (Hajcak et al., 2009), but not early ERP markers of threat-related bias capturing bottom-up, stimulus-driven attentional processes, such as the P1 (Schiff et al., 2006). The rapid nature of the dot-probe task used in the present study made it particularly well-suited for examining early, but not later, ERP components of attentional bias. In future studies, it will be advantageous to study later ERP markers of threat-related attentional bias using dot-probe paradigms with longer stimulus presentation times or other attentional bias tasks, such as the emotional Stroop and emotional spatial cueing paradigms (Gupta et al., 2019).

Third, the lack of significant threat-related bias findings also brings into question whether changes in threat-related attentional bias are a key mechanism driving symptomatic improvements. Two early models of mindfulness (Hölzel et al., 2011; Vago & Silbersweig, 2012) have suggested that mindfulness meditation may exert its effects through a variety of mechanisms, including attention regulation, body awareness, emotion regulation, and change in perspective on the self. Several studies have demonstrated mindfulness-induced improvements in aspects of emotion regulation, and psychological disorders characterized by problems in emotion regulation, including anxiety disorders, can benefit from the enhancement of emotion regulation capacities (Hölzel et al., 2011). Chiesa et al. (2013) conducted a review suggesting that mindfulness training is associated with top-down emotion regulation (i.e., cognitive reappraisal) in short-term practitioners and bottom-up emotion regulation (i.e., reduced reactivity) in long-term practitioners. This again suggests that MBCT may be better able to modulate voluntary, endogenous processes in novices. Future studies should investigate whether MBCT modulates later ERP markers of emotional regulation, such as the LPP (Hajcak et al., 2009).

Fourth, while anxiety symptoms were significantly reduced in the full sample, this reduction did not reach significance in the virtual sample. Some aspects of virtual MBCT delivery may have been responsible for these findings. For example, participants were given the option to keep their personal video on or off during the classes, and this may have discouraged class engagement and participation and encouraged distraction. The video format may also have caused hesitancy in participating in larger group discussions. However, one major confound is that the virtual courses took place during the COVID-19 pandemic. The pandemic has been associated with high rates of anxiety and depression (Hyland et al., 2020; Rajkumar, 2020), and this may explain why the virtual MBCT group displayed elevated anxiety symptoms compared to the in-person MBCT group and a non-significant reduction in these symptoms post-MBCT.

Finally, due to unforeseen circumstances, 8 participants made changes to their medication and therapy regimens (e.g., starting new medications, stopping current medications, changing medication dosages, starting therapy for pain or injury) over the course of the study. Analyses were reapplied with these participants excluded (see Supplementary

Materials), and results were generally consistent with findings from the full sample, barring a few instances. Higher P1-Angry Cue amplitudes were associated with higher DASS-A scores, but this result did not reach significance. Additionally, RTs were not significantly faster following MBCT.

In conclusion, MBCT is a promising intervention to improve engagement and disengagement processes, thus leading to more efficient probe processing and responses to probes, in addition to reducing symptoms of anxiety and depression in anxious adults. However, changes in threat-related attentional bias specifically were generally not supported. Inclusion of a comparison group in future work will help clarify whether the changes observed in the present study specifically resulted from the MBCT intervention.

Supplementary Information The online version contains supplementary material available at https://doi.org/10.1007/s12671-022-01910-x.

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Author Contribution RSG: Collaborated on study design, collected data, performed analyses, acquired funding, wrote original draft, and reviewed and edited subsequent drafts. AK: Provided project administration and supervision, advised on methodology and analyses, and reviewed and edited drafts. DMF: Collaborated on study design and reviewed and edited drafts. HK: Developed and advised on statistical analyses and reviewed and edited drafts. DRV: Collaborated on study design, provided project administration and supervision, and reviewed and edited drafts. All authors approved the final version of the manuscript for submission.

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Data Availability The de-identified data supporting the findings of this study are accessible in https://osf.io/6453s/. Public access to the data is restricted and subject to approval by the PI of the parent clinical trial upon reasonable request.

Declarations

Ethics Approval and Consent to Participate All study procedures were reviewed and approved by the Vanderbilt University Institutional Review Board. Informed consent was obtained from all participants included in the study.

Conflict of Interest Dr. David Vago is the research lead at RoundGlass.

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