THE EFFECT OF MINDFULNESS-BASED COGNITIVE THERAPY ON EVENT-RELATED POTENTIAL MARKERS OF ATTENTIONAL BIAS IN ANXIETY

By

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This dissertation is dedicated to my beloved grandmother who passed away when I was five. She dreamed of getting an education but was never afforded the opportunity. I am honored to be the first of her grandchildren to earn my PhD.

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CHAPTER 1: Introduction[1]

1.1 Anxiety Disorders and Threat-Related Attentional Bias

Anxiety disorders, including generalized anxiety disorder (GAD), social anxiety disorder (SAD), and specific phobia, are associated with hypervigilance to potential threat in preparation for future danger, cautious or avoidant behaviors (DSM-5 American Psychiatric Association, 2013), and delayed disengagement from threat (Amir, Elias, Klumpp, & Przeworski, 2003). An estimated 31.1% of U.S. adults experience any anxiety disorder at some time in their lives ("NIMH » Any Anxiety Disorder," 2017), and globally, anxiety disorders are the sixth leading cause of years lived with disability (Baxter, Vos, Scott, Ferrari, & Whiteford, 2014).

Individuals with anxiety disorders may display threat-related attentional bias, defined as the preferential tendency to allocate attention toward or away from threatening stimuli (Mogg & Bradley, 2018). Although the 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, Lamy, Pergamin, Bakermans-Kranenburg, & van Ijzendoorn, 2007; Cisler & Koster, 2010; Mogg & Bradley, 1998). 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, Bradley, De Bono, & Painter, 1997).

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[1]Adapted with permission from Gupta, R. S., Kujawa, A., & Vago, D. R. (2019). The neural chronometry of threat-related attentional bias: Event-related potential (ERP) evidence for early and late stages of selective attentional processing. *International Journal of Psychophysiology*, *146*, 20-42.

Individuals with anxiety disorders commonly exhibit threat-related biases at automatic and strategic stages of processing (Bar-Haim et al., 2007; Beck & Clark, 1997; Cisler & Koster, 2010; McNally, 1995). Automatic processing occurs without intent, control, or awareness and does not require cognitive effort (i.e., it is capacity free) (McNally, 1995). By contrast, strategic processing is intentional, controllable, capacity-limited, and dependent on awareness (Cisler & Koster, 2010; Shiffrin & Schneider, 1977). The vigilance-avoidance model posits that anxious individuals tend to direct their attention toward threat during early, automatic stages of processing, whereas during later, more strategic stages of processing, they tend to direct their attention away (i.e., avoidance) from threat (Mogg et al., 1997; Mogg, Mathews, & Weinman, 1987). Similarly, other theories propose that compared to healthy individuals, anxious individuals exhibit a delay in disengaging from threat stimuli (Bar-Haim et al., 2007; Fox, Russo, Bowles, & Dutton, 2001).

Taken together, anxious individuals serve as an excellent model to study the components, or observable and measurable characteristics, of threat-related attentional bias: (1) facilitated attention to threat, or hypervigilance (i.e., the relative ease or speed with which attention is initially and involuntarily drawn to a threat stimulus), during early, automatic processing stages, (2) difficulty disengaging attention away from threat (i.e., the degree to which a threatening stimulus captures attention and impairs switching attention from the threatening stimulus to another stimulus), and (3) attentional avoidance of threat (i.e., automatic or strategic shifting of attention away from the spatial location of threat, even when the threatening item is no longer present) during early or late processing stages (Cisler & Koster, 2010; Gupta, Kujawa, & Vago, 2019). An automatic, non-conscious threat-detection mechanism is believed to support facilitated attention, while avoidance is thought to be more conscious, effortful, and strategic. Difficulty in disengagement is believed to be a combination of automatic and strategic processing (Cisler & Koster, 2010).

Clearly, patterns of threat-related attentional bias vary depending on the temporal stage of information processing (Gupta et al., 2019). Researchers have attempted to use behavioral tasks to investigate and differentiate the components of attentional bias and understand how they present across different stages of information processing (Cisler & Koster, 2010). However, behavioral tasks have several limitations and can be strengthened by the inclusion of physiological measures with high temporal resolution. One frequently used task is the dot-probe (MacLeod, Mathews, & Tata, 1986), in which researchers examine how attention is deployed to emotional stimuli (Gupta et al., 2019).

1.2 Behavioral Measurement of Threat-Related Attentional Bias using the Dot-Probe Task

The dot-probe task is frequently used to assess attentional bias in spatial orienting to threatening cues (Mogg & Bradley, 2016). In the task, two visual stimuli (e.g., words, faces, scenes), called cues, are briefly and simultaneously presented above and below or to the left and right of a fixation cross. One cue is emotional or threatening and the other is neutral. After the cues disappear, a probe, or target (e.g., a dot or bar), appears in the spatial location of one of the cues. Participants must quickly and accurately respond to the location or identity of the probe. Faster reaction times (RTs) to probes are observed when they occur in the attended rather than the unattended location (Navon & Margalit, 1983). Thus, participants displaying attentional bias toward threat will typically demonstrate faster RTs to probes appearing in the location of threatening, compared to neutral, stimuli (Bar-Haim et al., 2007; Van Bockstaele et al., 2014). It has been shown that anxious individuals display threat-related attentional biases in behavioral dot-probe studies (Bar-Haim et al., 2007).

However, RTs provide an indirect measure of attentional processing (Horley, Williams, Gonsalvez, & Gordon, 2004), can be confounded by post-perceptual processes such as motor responses and decision making (Handy et al., 2001; Mueller et al., 2009), and do not allow

continuous measurement of attentional processing across time (Sass et al., 2010). Thus, they should not solely be used to make determinations about how individuals are allocating their attention toward or away from threat. Fortunately, the use of event-related potentials (ERPs) allows for the examination of the time course of attention to threat with millisecond (ms) resolution (Kappenman, Farrens, Luck, & Proudfit, 2014; Kappenman, MacNamara, & Proudfit, 2015).

1.3 ERPs and Threat-Related Attentional Bias

Using ERPs, researchers have investigated the neural correlates and timing related to the processing of threat-related stimuli in attentional bias studies. Differential processing of threatening stimuli is inferred when ERP component features, such as amplitudes and latencies, differ in response to threatening, compared to neutral, stimuli. Amplitudes are generally assumed to signify the degree or intensity of the engagement of cognitive processes, and latencies are thought to measure the time course of stages of processing (Luck, Woodman, & Vogel, 2000). In ERP attentional bias studies utilizing the dot-probe task, ERPs time-locked to the presentation of cues and probes are typically analyzed separately. Amplitude or latency modulations of ERPs time-locked to cues may indicate attentional bias occurring at early stages of processing, whereas modulations of ERPs time-locked to probes may indicate attentional bias occurring at later stages of processing (Gupta et al., 2019).

Many ERP components emerging across time, including the early C1, P1, N1, N170, P2, N2, and N2pc and the later P3 and late positive potential (LPP), have been analyzed in the attentional bias literature (Gupta et al., 2019). The C1, peaking 80-100 ms poststimulus at posterior midline sites (Luck, 2014), is triggered by the appearance of a stimulus in the visual field (Clark & Hillyard, 1996; Eldar, Yankelevitch, Lamy, & Bar-Haim, 2010; Luck et al., 2000). The P1, peaking 100-130 ms poststimulus at lateral occipital sites (Luck, 2014), is sensitive to allocation of attention to stimuli (Clark & Hillyard, 1996). The N1, consisting of several subcomponents peaking between 100-200 ms poststimulus at anterior and posterior sites, is influenced by spatial

attention and discrimination of attended stimuli (Luck, 2014). The N170, peaking approximately 170 ms at lateral occipital sites (Luck, 2014), is regarded as a face-specific ERP component (Bentin, Allison, Puce, Perez, & McCarthy, 1996). The P2 reflects allocation of attentional resources during the processing of emotional facial expressions (Bar-Haim, Lamy, & Glickman, 2005; Eldar et al., 2010; Torrence & Troup, 2018) but can be difficult to distinguish from the N1, N2, and P3 at posterior sites (Luck, 2014). The N2 consists of several subcomponents; the posterior N2 subcomponent has been associated with discrimination and classification of visual stimuli (Luck, 2014). The N2pc, occurring 200-300 ms poststimulus at posterior scalp sites contralateral to an attended object, measures whether attention is covertly directed to a stimulus (Luck, 2014). The P3 component, peaking 350-600 ms poststimulus (Luck, 2014), includes the frontal P3a component and a parietal P3b component; both are elicited by unpredictable, infrequent stimulus changes. The LPP, a central-parietal, midline component occurring approximately 300 ms poststimulus, is larger following the presentation of emotional compared to neutral stimuli (Hajcak, Dunning, & Foti, 2009) and can be sustained for several seconds after emotional stimuli are presented (Hajcak et al., 2009).

A review on the neural chronometry of threat-related attentional bias showed that early ERP components, including the P1, N170, P2, and N2pc, are modulated by emotional (e.g., threatening or positive) stimuli in both healthy and anxious populations, suggesting that both groups display enhanced allocation of attention to emotional stimuli at earlier stages of processing. However, later components (e.g., P3) are modulated by emotional stimuli more reliably in healthy, compared to anxious, populations. Thus, healthy populations show evidence of conscious, evaluative processing of threat and emotion at later stages of processing (Gupta et al., 2019).

1.4 Mindfulness, Threat-Related Attentional Bias, and Anxiety

Given the role of threat-related attentional bias in the etiology and maintenance of anxiety disorders (Van Bockstaele et al., 2014), interventions that can modulate threat-related attentional bias may be most effective in preventing and treating anxiety. In addition, ERPs may be particularly useful measures for evaluating outcomes (Gupta et al., 2019) because of their temporal sensitivity and reliability across time (Cassidy, Robertson, & O'Connell, 2012). Mindfulness training is a promising approach to reduce attentional biases (Garland & Howard, 2013; Vago & Nakamura, 2011) and anxiety symptoms (Hoge et al., 2015, 2013).

Mindfulness has been defined as "paying attention in a particular way: on purpose, in the present moment, and nonjudgmentally" (Kabat-Zinn, 1994, p.4). Mindfulness meditation training enhances a core set of therapeutically relevant and interrelated capacities, including (1) meta-awareness, defined as the capacity of individuals to monitor and report on the current contents and processes of their mind, (2) present-centered awareness, defined as sustained attention to current mental content, as contrasted with retrospective or prospective thinking (i.e., mental time travel), (3) nonreactivity to experience, defined as suspension of habitual affective reactions to the current contents of experience, and (4) dereification, defined as reduction in the habitual attribution of objective reality (reification) to the contents of thought and perception (Lutz, Jha, Dunne, & Saron, 2015; Wielgosz, Goldberg, Kral, Dunne, & Davidson, 2019). With mindfulness training, meta-awareness is cultivated primarily through monitoring for distractions, present-centered awareness is facilitated by the moment-by-moment focus on a meditation object (e.g., the breath); nonreactivity is cultivated by adopting a nonaverse (i.e., curious, nonjudging) stance toward experience, and dereification is trained by recognizing that the thoughts are just thoughts and not reality at times when a distracting chain of thoughts captures attention and pulls it away from the mediation object (Wielgosz et al., 2019).

Mindfulness-based interventions (MBIs), such as Mindfulness-Based Cognitive Therapy (MBCT; Segal et al., 2013) and Mindfulness-Based Stress Reduction (MBSR; Kabat-Zinn, 1990) are increasingly being used to treat psychological disorders (Chiesa & Serretti, 2011; Hofmann, Sawyer, Witt, & Oh, 2010). A meta-analysis of mindfulness-based therapy (including MBCT and MBSR) for anxiety and depression found overall large effect sizes (Hedges' *g*) of 0.97 and 0.95 for improving anxiety and mood symptoms, respectively. These effect sizes were robust, unrelated to publication year or number of treatment sessions, and were maintained over follow-up (Hofmann et al., 2010).

MBCT is a manualized 8-week skills-training group program (Segal et al., 2013) based on components of cognitive behavioral therapy (Beck, Rush, Shaw, & Emery, 1979) and MBSR. 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). It has been shown that MBCT can reduce anxiety and depressive symptoms in adults with anxiety disorders (Craigie, Rees, Marsh, & Nathan, 2008; Evans et al., 2008; Kim et al., 2009). Additionally, MBCT may facilitate early detection of negative thinking patterns, feelings, and body sensations (Teasdale et al., 2000), which could underlie the formation and preservation of threat-related attentional biases, and consequently, may allow individuals to disengage from these habitual, automatic, and dysfunctional cognitive routines (Chiesa & Serretti, 2011), thus mitigating threat-related attentional biases. Reduction of threat-related biases may subsequently lead to a reduction in anxiety and mood symptoms in anxious populations.

1.5 Summary and Current Studies

Threat-related attentional biases, composed of facilitated attention to threat, difficulty disengaging attention away from threat, and attentional avoidance of threat, have clear

evolutionary advantages; however, these biases may also be responsible for contributing to the etiology and maintenance of anxiety disorders. While behavioral tasks alone lack the sensitivity to examine the components of threat-related attentional bias arising at different stages of information processing, inclusion of ERPs allows for the examination of the neural chronometry, or time course of threat-related attentional bias, with millisecond resolution.

It has been shown that early ERP components, including the P1, N170, P2, and N2pc, are modulated by emotional (e.g., threatening or positive) stimuli in both healthy and anxious populations, suggesting that both groups display enhanced allocation of attention to emotional stimuli at earlier stages of processing. However, later components (e.g., P3) are modulated by emotional stimuli more reliably in healthy, compared to anxious, populations. Thus, healthy populations show more evidence for conscious, evaluative processing of threat and emotion at later stages of processing.

As threat-related attentional biases may be implicated in the etiology and maintenance of anxiety disorders, they could provide an effective target for intervention, and ERPs may be particularly useful measures for evaluating outcomes. 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) and may effectively target and mitigate threat-related attentional biases. Importantly, changes in threat-related attentional biases may be a key mechanism driving MBCT effects on anxiety and mood symptoms.

A variety of cue- and probe-locked ERP components have been examined in dot-probe studies; however, the choice of which components to focus on to capture attentional bias is inconsistent across the literature. Additionally, the scoring and labeling of ERP components in attentional bias studies varies widely, and a special method is required to more systematically

select ERP components sensitive to early and later stages of processing in dot-probe tasks. The first study (**Chapter 2**) used temporospatial principal component analysis (PCA) to systematically identify the timing and scalp distributions of ERPs elicited to cues and probes in a dot-probe task in adults with moderate to high levels of anxiety, highlighting promising neurophysiological markers for future attentional bias research.

The PCA results from **Chapter 2** helped inform cue- and probe-locked components to examine in the second study (**Chapter 3**), which sought to (1) determine whether an 8-week MBCT intervention can modify ERP markers of threat-related attentional bias in anxious populations, potentially reflecting reductions in threat-related attentional biases due to the mindfulness intervention, and (2) investigate the relationship between ERP threat-related attentional bias markers and treatment response. The goal was to illuminate a potential physiological mechanism through which MBCT may target early and late stages of threat-related attentional bias and reduce symptoms of anxiety.

CHAPTER 2: Study 1 - A Preliminary Investigation of ERP Components of Attentional Bias in Anxious Adults using Temporospatial Principal Component Analysis[2]

2.1 Introduction

Dot-probe ERP studies with anxious populations have examined a wide range of components yielding a variety of results (see Gupta et al., 2019). Several of these studies have focused on early components such as the P1. For example, Helfinstein, White, Bar-Haim, & Fox (2008) observed that individuals with high social anxiety displayed higher mean P1 amplitudes to angry-neutral face pairs compared to individuals with low social anxiety, suggesting increased sensory processing of faces in individuals with high levels of social anxiety. Similarly, Mueller et al. (2009) demonstrated that, compared to healthy controls, participants with social anxiety disorder (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.

However, other early components have also been examined. For example, Eldar et al. (2010) demonstrated that, compared to non-anxious individuals, anxious individuals displayed enhanced occipital P2 amplitudes in response to face displays, regardless of whether the facial emotion was angry, happy, or neutral. This P2 modulation in anxious individuals serves as an indicator of attentional commitment to processing facial emotional expressions. Rossignol, Campanella, Bissot, & Philippot (2013) observed that individuals with high social anxiety

[2]Adapted with permission from Gupta, R. S., Kujawa, A., & Vago, D. R. (2021). A preliminary investigation of ERP components of attentional bias in anxious adults using temporospatial principal component analysis. *Journal of Psychophysiology*.

displayed enhanced P2 amplitudes in response to angry-neutral compared to fear-neutral face pairs, suggesting enhanced allocation of attention to angry faces. Additionally, Fox, Derakshan, & Shoker (2008) studied high trait anxiety and low trait anxiety groups and observed that angry expressions elicited an enhanced N2pc, but only in participants reporting high levels of trait anxiety, suggesting that participants with high trait anxiety exhibit rapid exogenous orienting of spatial attention to threatening cues.

Although neural measures, such as ERPs, are thought to be more reliable than behavioral measures, such as RTs, the scoring of ERP components varies considerably across studies. For example, while Helfinstein et al. (2008) examined the P1 mean amplitude averaged across electrodes O1 and O2 95–140 ms after face onset, Mueller et al. (2009) measured the P1 as the most positive peak in the time window of 80–150 ms following face or probe onset at electrodes PO7 and PO8. Similarly, Eldar et al. (2010) quantified the P2 as the mean amplitude over electrodes O1 and O2 195-250 ms after face display onset, while Rossignol et al. (2013) measured the P2 as the mean amplitude 240–400 ms after face pair presentation at electrodes O1 and O2. Further, it appears that prior work has yet to characterize the reliability of early emerging ERPs in dot-probe tasks.

The aforementioned results clearly demonstrate that a variety of cue- and probe-locked ERP components have been examined in dot-probe studies; however, the choice of which components to focus on to capture attentional bias is inconsistent across the literature. Additionally, the scoring and labeling of ERP components in attentional bias studies varies widely. Thus, a special method is required to more systematically select ERP components sensitive to early and later stages of processing in dot-probe tasks. Principal component analysis (PCA) provides an effective way to analyze high-density ERP datasets and to separate components that vary in their sensitivity to spatial, temporal, or functional parameters (Dien & Frishkoff, 2005). PCA has successfully been utilized to differentiate ERPs sensitive to emotion in a variety of studies

using other paradigms besides the dot-probe (Kujawa, Weinberg, Hajcak, & Klein, 2013; Mulligan, Infantolino, Klein, & Hajcak, 2020; Pegg et al., 2019).

The present preliminary study used temporospatial PCA to systematically identify the timing and scalp distributions of ERPs elicited to angry-neutral and happy-neutral face pair cues and bar probes in a dot-probe task adapted from Mueller et al. (2009) in adults with moderate to high levels of anxiety. The present analyses are part of a larger study investigating the neurobiological mechanisms of mindfulness-based cognitive therapy (MBCT) [NCT03571386], including effects on ERP markers of threat-related attentional bias in anxious populations (described in **Chapter 3**). The PCA analyses were performed on the dot-probe task administered to a sample population with moderate to high levels of anxiety prior to an MBCT intervention. The PCA results not only informed which cue- and probe-locked components to examine in analyses associated with the clinical intervention study, but also clarified scoring windows and electrode sites to use for each of these components.

Subsequently, analyses were performed to determine whether the mean value around the PCA-derived peaks were reliably measured in the ERP waveforms using the Spearman-Brown split-half reliability method. A secondary exploratory PCA analysis was conducted to determine the extent to which ERPs derived through PCA were moderated by the position of emotional (angry or happy) faces in the face pair cues. Accounting for the location of the emotional face in this analysis revealed whether the N2pc was elicited to emotional faces, as this ERP arises at posterior scalp sites contralateral to an attended object (Luck, 2014). Behavioral analyses were also conducted to determine the effects of emotion and congruency on reaction times in the dot-probe task. While the present study lacks a healthy comparison group, identification of components in the anxious sample using temporospatial PCA will yield promising and reliable ERP measures of attentional bias that can be extended to designs comparing anxious and healthy comparison groups.

2.2 Methods

2.2.1 Participants

In order to participate in the larger treatment study, participants had to (1) be between the ages of 18 and 55 years, (2) have moderate to high levels of anxiety, indexed by a score of 40 or above on the State-Trait Anxiety Inventory, Trait Scale (Spielberger, Gorsuch, Lushene, Vagg, & Jacobs, 1983), and (3) be considered stable on maintenance medications for anxiety or depression at least one month prior to enrollment. Participants were excluded if they had (1) endorsed 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 minutes 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 during the treatment study.

In the present study, 25 anxious adults (21 female, 4 male) with a mean age of 32.12 years (*SD* = 10.05) were recruited from the greater Nashville community using ResearchMatch and the Vanderbilt University Medical Center research notification distribution listserv. Participant racial breakdown included 4% Asian, 8% Black or African American, 84% White, and 4% were more than one race. Participants' ethnicity included 12% Hispanic or Latino. Participants provided written informed consent and received monetary compensation for their participation. The study was approved by the Vanderbilt University Institutional Review Board.

2.2.2 Dot-Probe Task

A dot-probe task adapted from Mueller et al. (2009) (see **Figure 1**) with simultaneous EEG recording was used to assess threat-related attentional bias in the anxious participants.

2.2.2.1 Stimuli

Pairs of face stimuli were created using grayscale photographs of males and females portraying angry, happy, and neutral facial expressions from Ekman's Pictures of Facial Affect (Ekman & Friesen, 1976). All of the happy face stimuli 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 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 centimeter (cm) x 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 x 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 x 2 cm with a thickness of 0.1 cm and was presented centrally on the lower part of the screen. All stimuli were set on a black background and presented on a 24-inch monitor with a Dell desktop computer running E-Prime (Psychology Software Tools, Pittsburgh, PA). Participants made responses to the stimuli using a Cedrus RB-844 button box (Cedrus, San Pedro, CA).

2.2.2.2 Procedure

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. 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 field. 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. Accuracy was measured as the number of correct responses ("hits") and the number of incorrect responses ("misses"). Trials with incorrect responses, response times <100 ms, or response times >1500 ms were excluded from behavioral analyses.

2.2.3 Power Analysis

In order to determine whether there was sufficient power to detect emotion and congruency effects, a post-hoc power analysis was performed in G*Power 3.1 (Faul, Erdfelder, Lang, & Buchner, 2007) using a sample size of 25, alpha of .05, and within-subjects emotion and congruency effect sizes from Mueller et al. (2009), as the present experimental design was based closely on the Mueller study. Results indicated that there was sufficient power to detect within-subjects emotion and congruency effects (power estimate > 0.99).

2.2.4 EEG Recording and Data Reduction

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.

Data were processed using Brain Vision Analyzer (Brain Products GmbH, Germany). Data were first filtered between 0.1-30 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 61-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, Coles, & Donchin, 1983). When required, topographic interpolation by spherical splines was performed.

For the cue condition, data were segmented into (1) trials where angry-neutral face pairs were presented, and (2) trials where happy-neutral face pairs were presented. For the probe condition, data were segmented into (1) presentation of angry congruent probes (i.e., probe replaces angry face in angry-neutral face pairs), (2) presentation of angry incongruent probes (i.e., probe replaces neutral face in angry-neutral face pairs), (3) presentation of happy congruent probes (i.e., probe replaces happy face in happy-neutral face pairs), and (4) presentation of happy incongruent probes (i.e., probe replaces 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 where participants responded

correctly were used to calculate each subject's averages, and subsequently, the grand averages. Subject averages and grand averages were computed with individual channel mode enabled. The mean number of trials included in the grand averages at electrode PO4 were as follows: angry cue: 349 trials; happy cue: 351 trials; angry congruent probe: 173 trials; angry incongruent probe: 176 trials; happy congruent probe: 177 trials; and happy incongruent probe: 172 trials.

2.2.5 Temporospatial PCA

The temporospatial PCA technique was used to identify and differentiate ERPs elicited to cues and probes in the dot-probe task. PCA belongs to a class of factor-analytic procedures which use eigenvalue decomposition to extract linear combinations of variables (latent factors) in order to account for patterns of covariance in the data parsimoniously (i.e., with the fewest factors) (Dien & Frishkoff, 2005). In ERP data, PCA extracts linear combinations of data from all time points and recording sites to distinguish patterns of electrocortical activity (e.g., Kujawa et al., 2013; Pegg et al., 2019).

PCA was conducted separately on the cue and probe data using the ERP PCA Toolkit, version 2.86, in MATLAB (Dien, 2010b). Two ERP averages per subject were entered into the data matrix for the cue PCA (i.e., angry cue, happy cue), and four ERP averages per subject were entered into the data matrix for the probe PCA (i.e., angry congruent probe, angry incongruent probe, happy congruent probe, happy incongruent probe). For both the cue and probe data, a temporal PCA was performed first to separate the ERP components in the temporal domain (Dien, 2010a, 2012; Dien & Frishkoff, 2005). A promax rotation was used, as it is most effective for the temporal PCA (Dien, 2010a, 2012), along with a covariance relationship matrix (Kayser & Tenke, 2003), Kaiser weighting (Dien, Beal, & Berg, 2005), and the kappa for the promax set at 3 (Dien, 2010a). For the decomposition procedure, singular value decomposition was used. The temporal PCA utilized the time points as variables and the subjects, conditions, and recording sites as observations (Dien & Frishkoff, 2005). A parallel test (Horn, 1965) was used on the resulting Scree

plot (Cattell, 1966), which compares the Scree of the dataset to that obtained from a fully random dataset. For the cue data, 9 temporal factors accounted for a greater proportion of variance than those generated by the random dataset and accounted for 97.0% of the total variance. For the probe data, 7 temporal factors accounted for a greater proportion of variance than those generated by the random dataset and accounted for 95.6% of the total variance.

These temporal factors were then entered into a spatial PCA (Dien, 2010a, 2012; Dien & Frishkoff, 2005). An infomax rotation was used, as it is most effective for the spatial PCA (Dien, 2010a). The spatial PCA utilized recording sites as variables and the subjects, conditions, and temporal factor scores as observations (Dien & Frishkoff, 2005). The parallel test of this Scree plot extracted 3 spatial factors from each cue temporal factor and 4 spatial factors from each probe temporal factor. Overall, 27 temporospatial factor combinations were generated for the cue dataset and 28 temporospatial factor combinations were generated for the probe dataset.

Temporospatial factors accounting for at least 0.5% of the total variance were subjected to a robust ANOVA (Dien, 2017; Keselman, Wilcox, & Lix, 2003) in the ERP PCA Toolkit to evaluate the effect of emotion (i.e., angry face pairs versus happy face pairs) in the cue condition and the effects of both emotion and congruency (i.e., congruent versus incongruent) in the probe condition. PCA factor scores were converted to microvolt scaling, and 49,999 bootstrapping simulations were run 11 times in order to compute the standard deviation of the resulting p-values; the median p-value was then reported. If twice the standard deviation of the p-values plus the median p-value exceeded the alpha threshold (0.05), the result was treated as a borderline significant result (Dien, 2017). Significant temporospatial factors and their descriptions are reported in **Table 1**.

2.3 Results

2.3.1 Behavioral (RT) Analyses

Behavioral analyses were conducted in jamovi (Lenth, 2020; R Core Team, 2021; Singmann, 2018; the jamovi project, 2021). Participants made an average of 703.76 hits (*SD* = 30.79) and 15.08 misses (*SD* = 30.60) in the dot-probe task. A 2 (emotion: angry versus happy face pair cues) x 2 (congruency: congruent versus incongruent probes) repeated-measures ANOVA was conducted on the RT data. The emotion x congruency interaction was not significant [$F(1,24) = 0.224$, $p = 0.640$, $\eta_p^2 = 0.009$]. The main effect of emotion was also not significant [$F(1,24) = 0.036$, $p = 0.851$, $\eta_p^2 = 0.002$]. However, the main effect of congruency was significant [$F(1,24) = 5.283$, $p = 0.031$, $\eta_p^2 = 0.180$], such that RTs were shorter for congruent (angry-congruent: *M* = 321.56, *SD* = 57.72; happy-congruent: *M* = 321.26, *SD* = 57.85) versus incongruent (angry-incongruent: *M* = 323.12, *SD* = 54.81; happy-incongruent: *M* = 324.12, *SD* = 58.99) probes. These results suggest that anxious participants exhibit hypervigilance and greater visual attentional allocation toward emotional (angry and happy) versus neutral face cues. Reaction times to probes as a function of emotion and congruency are shown in **Figure 2**.

2.3.2 PCA

2.3.2.1 Cue PCA

Of the 23 factor combinations accounting for more than 0.5% of the total variance, 4 factor combinations were significantly sensitive to emotion ($p < .05$). Two factor combinations (TF4/SF2 and TF4/SF3) will not be discussed because they had widespread scalp distributions that did not appear to be consistent with commonly observed cue-locked ERPs. However, there was a significant effect of emotion on Temporal Factor 5/Spatial Factor 3 (TF5/SF3), $T_{WJt}/c(1.0, 22.0) = 6.90$, $p = 0.012$, MSe = 0.02, a factor combination consisting of a very early negativity. This factor combination peaks at 38 ms at channel Oz and resembles an early C1 ERP component; the C1 typically onsets 40–60 ms poststimulus and peaks 80–100 ms poststimulus (Luck, 2014). This

factor combination presented as an increased negativity for happy compared to angry face pair cues, suggesting that at very early, pre-attentive stages of processing, activity in the primary visual cortex (V1) (Clark & Hillyard, 1996; Eldar et al., 2010; Pourtois, Grandjean, Sander, & Vuilleumier, 2004) is enhanced by happy face pair cues. Following TF5/SF3, there was also a significant effect of emotion on Temporal Factor 3/Spatial Factor 1 (TF3/SF1), $T_{WJt}/c(1.0, 22.0) = 4.96$, $p = 0.035$, MSe = 0.08, a factor combination consisting of an early positivity. This factor combination peaks at 86 ms at channel PO4 and resembles an early P1 component; the P1 typically onsets 60–90 ms poststimulus and peaks 100-130 ms poststimulus (Luck, 2014). This factor combination presented as an increased positivity for happy compared to angry face pair cues, suggesting that more attention is allocated to happy face pair cues at this stage of processing.

2.3.2.2 Probe PCA

Of the 23 factor combinations accounting for more than 0.5% of the total variance, 4 factor combinations were significantly sensitive to either emotion, congruency, or an interaction between emotion and congruency ($p < .05$). Three factor combinations (TF1/SF1, TF5/SF1, and TF7/SF2) will not be discussed because they were either noisy or had scalp distributions that did not appear to be consistent with commonly observed probe-locked ERPs. However, there was a significant effect of congruency on TF4/SF3, $T_{WJt}/c(1.0, 22.0) = 5.75$, $p = 0.029$, MSe = 0.06, a factor combination consisting of an early positivity. This factor combination peaks at 220 ms at channel PO4 and resembles a P2 component; the P2 typically peaks around 200 ms poststimulus (Eldar et al., 2010; Helfinstein et al., 2008; Rossignol et al., 2013). This factor combination presented as an increased positivity for incongruent compared to congruent probes, which may reflect more elaborative processing and emotional evaluation of neutral, compared to emotional (angry and happy), faces (i.e., attentional avoidance from the emotional faces). The effect of emotion on TF4/SF3 was nonsignificant, $T_{WJt}/c(1.0, 22.0) = 0.00$, $p = 0.99$, MSe = 0.14, and the interaction

between emotion and congruency was also nonsignificant, $T_{WJt}/c(1.0, 22.0) = 2.34$, $p = 0.16$, MSe = 0.08.

The original, grand average cue ERP waveforms at Oz and PO4 and grand average probe ERP waveforms at PO4 are shown in **Figure 3**, and the ERP waveforms and spatial topographies for the three temporospatial factors are shown in **Figure 4**.

2.3.3 Split-Half Reliability

Using the PCA results to inform ERP scoring, analyses were conducted to determine whether the mean value around the PCA-derived C1-Cue, P1-Cue, and P2-Probe peaks were reliably measured in the original ERP waveforms. First, for both the cue and probe datasets, odd and even trials were averaged separately. Temporal peak and peak electrode information from the PCA (see **Table 1**) were used to determine appropriate time windows and locations to search for peaks in the ERP waveforms. A 28-48 ms search window at Oz was used to identify the C1-Cue peak, a 76-96 ms search window at PO4 was used to locate the P1-Cue peak, and a 210-230 ms search window at PO4 was used to identify the P2-Probe peak. The mean value around the peaks (50 ms) for the odd and even average waveforms were then exported from Brain Vision Analyzer. Finally, Spearman-Brown-corrected correlations were computed on the odd and even averages to assess split-half reliability.

Reliability coefficients suggested acceptable to excellent split-half reliability for the C1 to angry cues (Spearman $r = 0.92$, $p < .001$), C1 to happy cues (Spearman $r = 0.87$, $p < .001$), P1 to angry cues (Spearman $r = 0.96$, $p < .001$), P1 to happy cues (Spearman $r = 0.85$, $p < .001$), P2 to angry congruent probes (Spearman $r = 0.81$, $p < .001$), P2 to angry incongruent probes (Spearman $r = 0.82$, $p < .001$), P2 to happy congruent probes (Spearman $r = 0.85$, $p < .001$), and P2 to happy incongruent probes (Spearman $r = 0.70$, $p < .001$). These results provide additional insight into the peaks for the three components and suggest that the mean value around the peaks tends to be reliably measured in the ERP waveforms.

2.3.4 Secondary Exploratory Analysis: The Effect of Emotional Face Position

A secondary exploratory analysis was conducted to determine the extent to which ERPs derived through PCA were moderated by the position of the emotional (angry or happy) face. As before, a PCA was conducted on the cue data; however, four averages per subject were entered into the data matrix for this PCA (i.e., angry-neutral (angry face on the left), neutral-angry (angry face on the right), happy-neutral (happy face on the left), and neutral-happy (happy face on the right)). Temporospatial factors accounting for at least 0.5% of the total variance were subjected to a robust ANOVA to evaluate the effects of both emotion and position (i.e., emotional face on the left versus emotional face on the right).

Of the 29 factor combinations accounting for more than 0.5% of the total variance, no factor combinations were significantly sensitive to the interaction between emotion and position ($p < .05$). However, four factor combinations were significantly sensitive to emotion, and one of these factor combinations (TF3/SF1), $T_{WJt}/c(1.0,22.0) = 4.85$, $p = 0.049$, MSe = 0.24, again resembled an early P1 component, peaking 86 ms poststimulus at channel PO8 and presenting as an increased positivity for happy compared to angry face pair cues. Additionally, one factor combination (TF6/SF3) was significantly sensitive to position, $T_{WJt}/c(1.0,22.0) = 6.05$, $p = 0.024$, MSe = 0.11, peaking 178 ms poststimulus at channel P4. This factor combination showed decreased amplitudes for right-sided (ipsilateral to P4) emotional faces (neutral-angry and neutral-happy) compared to left-sided (contralateral to P4) emotional faces (angry-neutral and happy-neutral). The remaining factor combinations (TF1/SF2, TF4/SF2, TF4/SF3) will not be discussed because they were noisy or had scalp distributions that did not appear to be consistent with commonly observed cue-locked ERPs.

2.4 Discussion

The present analyses are part of a larger study investigating the neurobiological mechanisms of MBCT, including ERP markers of threat-related attentional bias in adults with moderate to high levels of anxiety using a dot-probe task adapted from Mueller et al. (2009) (described in **Chapter 3**). The PCA analyses were performed on the dot-probe task ERP data administered prior to the MBCT intervention. The goal of this preliminary study was to utilize PCA to systematically identify the timing and scalp distributions of ERPs elicited to cues and probes in the aforementioned dot-probe task in an anxious adult population.

Temporospatial PCA identified 2 components sensitive to face pair cues. The first cue-locked component was an early relative negativity for happy versus angry face pair cues peaking around 38 ms poststimulus over central occipital sites. This component appears to be consistent with the C1-Cue observed in previous dot-probe studies with anxious and healthy adults (Eldar et al., 2010; Pourtois et al., 2004). The second cue-locked component was an early relative positivity for happy versus angry face pair cues peaking around 86 ms poststimulus over parieto-occipital sites. This component appears to be consistent with the P1-Cue previously observed in dot-probe studies with anxious adults (Helfinstein et al., 2008; Mueller et al., 2009; Rossignol et al., 2013). Temporospatial PCA also identified one component sensitive to incongruent versus congruent probes. The probe-locked component was an early relative positivity that was enhanced for incongruent (probes replacing neutral faces) compared to congruent (probes replacing emotional faces) probes peaking around 220 ms poststimulus over parieto-occipital sites. This component appears to be consistent with the P2-Probe observed in a previous dot-probe study with healthy adults (Pintzinger, Pfabigan, Pfau, Kryspin-Exner, & Lamm, 2017). The PCA results were subsequently used to determine whether the mean value around the PCA-derived C1-Cue, P1-Cue, and P2-Probe peaks were reliably measured in the original ERP waveforms. Reliability was

acceptable for all three components, suggesting that the mean value around these peaks can be reliably measured in the ERP waveforms with the current task design.

Gupta et al. (2019) conducted a review on the neural chronometry of threat-related attentional bias which showed that early ERP components, including the P1, N170, P2, and N2pc, are modulated by threatening and emotional stimuli in anxious populations, reflecting enhanced allocation of attention to threat and emotion at earlier stages of processing. In the present study, emotion and congruency-related modulations of early components in anxious adults performing the dot-probe task were also observed, but the present findings were somewhat surprising. The C1-Cue component peaked around 38 ms poststimulus and was enhanced for happy versus angry face pair cues, suggesting enhanced, pre-attentive processing of happy faces, or early perceptual-level avoidance of angry faces, at the level of V1. In a previous dot-probe study comparing anxious and nonanxious participants, between-group analyses indicated that anxious participants had a more negative C1 amplitude compared to nonanxious participants in response to angry-neutral face pairs, but the two groups did not differ in their C1 amplitudes in response to happy-neutral face pairs (Eldar et al., 2010). Similarly, in another dot-probe study focusing on healthy adults, within-group analyses indicated that the C1 component was enhanced for fearful, compared to happy, faces (Pourtois et al., 2004). Additionally, in both of the aforementioned studies, the C1 peaked later (~80-90 ms poststimulus) than the C1-Cue identified in the present study. Studies have suggested that C1 modulation by the cue's emotional valence in the dot-probe task could result from interactions between V1 and subcortical limbic structures (e.g., the amygdala) responsible for threat detection (Eldar et al., 2010; Pourtois et al., 2004). Thus, the enhanced C1 to happy face pair cues in this study may reflect a very early form of avoidance from the threatening (angry) face pair cues. Additionally, the present C1-Cue results suggest that anxious adults differentiate emotion conditions at very early stages of information processing,

further supporting the view that ERPs are a promising method to examine the time course of attentional bias at the neural level.

Additionally, the P1-Cue component peaked around 86 ms poststimulus and was enhanced for happy compared to angry face pair cues, suggesting that relatively more attention was allocated to the happy face pair cues. Interestingly, in previous dot-probe studies with anxious adults, the P1 peaked later (~100-150 ms poststimulus) (Helfinstein et al., 2008; Mueller et al., 2009; Rossignol et al., 2013). Additionally, prior work has indicated that the P1 is enhanced to angry-neutral face pairs in adults with social anxiety, but it is unclear whether this finding extends to other types of anxiety. For example, between-group analyses from Helfinstein et al. (2008) demonstrate that high socially anxious individuals displayed higher mean P1 amplitudes to angry-neutral face pairs compared to low socially anxious individuals, suggesting increased sensory processing of faces in individuals with high levels of social anxiety. Within-group analyses conducted by Mueller et al. (2009) similarly showed that individuals with SAD display larger P1 amplitudes to angry-neutral versus happy-neutral face pairs, suggesting an early hypervigilance to angry faces. However, between-group analyses conducted by Rossignol et al. (2013) demonstrated that, compared to low socially anxious individuals, high socially anxious individuals displayed increased P1 amplitudes in response to neutral-emotional face pairs (neutral–angry, neutral–happy, neutral–disgust and neutral–fear), irrespective of the emotional expression included in the pair. These results suggest that a generalized hypervigilance to emotional faces may occur in social anxiety. On the other hand, the present P1-Cue results suggest the possibility that participants high in trait anxiety may tend to avoid the angry face pair cues at early stages of processing (Gupta et al., 2019).

Finally, P2-Probe amplitudes were larger for incongruent versus congruent probes. These results may reflect more elaborative processing and emotional evaluation of neutral, compared to emotional (angry and happy), faces (i.e., attentional avoidance from the emotional faces).

Interestingly, in a previous dot-probe study with healthy adults, within-group analyses showed that women displayed larger P2 amplitudes in congruent compared to incongruent negative conditions, which could indicate sustained attentional engagement with negative, compared to neutral, information (Pintzinger et al., 2017). The vigilance-avoidance model suggests that anxious individuals initially direct attentional resources toward threat during early, automatic stages of processing, but then direct their attention away from threat during later, more strategic stages of processing in an attempt to avoid detailed elaborative processing of threatening material (Mogg et al., 1997, 1987). The present results instead suggest that anxious adults display avoidance from emotional (both angry and happy) face stimuli.

The rapid nature of the dot-probe design used in the present study may explain the earlier C1-Cue and P1-Cue latencies observed in the present results. A 100 ms cue presentation duration was utilized, but many of the studies referenced herein utilized longer durations for cue stimuli, such as 500 ms (Eldar et al., 2010; Helfinstein et al., 2008; Pintzinger et al., 2017; Rossignol et al., 2013). The primary goal was to examine early forms of attentional bias; thus, the brief cue duration was well-suited to the present investigations. The rapid nature of the task may also cause ERP components to overlap. Indeed, both the cue and probe PCAs described herein revealed that there are several distinct components emerging in a very short period of time (300 ms poststimulus), highlighting the complexity of these neural responses. PCA is a powerful tool which allows us to extract components which may have otherwise been masked in the typical ERP results. For example, the P1-Cue and P2-Probe components are not evident in the original ERP cue and probe waveforms at PO4, likely due to the overlap of several components in the waveforms (see **Figure 3**). However, PCA helps disentangle these overlapping components so the P1-Cue and P2-Probe can be clearly observed (see **Figure 4**).

A secondary exploratory analysis was conducted to test the extent to which ERPs derived through PCA were moderated by the position of the emotional (angry or happy) face. No

temporospatial factors were sensitive to the interaction between emotion and position. However, one component was significantly sensitive to position, peaking 178 ms poststimulus at channel P4. This factor combination showed decreased amplitudes for right-sided (ipsilateral to P4) emotional faces (neutral-angry and neutral-happy) compared to left-sided (contralateral to P4) emotional faces (angry-neutral and happy-neutral). The timing and electrode position of this temporospatial factor is somewhat similar to that of an N2pc component, which typically occurs 200-300 ms poststimulus at posterior scalp sites contralateral to an attended object (Luck, 2014). However, the ipsilateral versus contralateral effect was surprising and did not suggest that anxious participants attend more to emotional, versus neutral, faces, as observed in prior studies specifically designed to elicit the N2pc. Prior dot-probe studies have shown that high-trait anxious, socially anxious, and healthy populations display N2pc amplitude or latency modulations to threatening and other emotional faces, reflecting rapid orienting to threatening and emotional cues, in general (Gupta et al., 2019). However, it is important to note that the dot-probe task used in the present study was adapted from Mueller et al. (2009), and this prior study primarily focused on examining the P1 component elicited to face pair cues and probes and was not specifically designed to elicit the N2pc component. In the current version of the task, the fixation cross was presented centrally on the lower part of the screen, and face cues were presented in the upper visual field. However, several dot-probe studies designed to elicit the N2pc component present the fixation cross at the center of the screen with cues presented to the left and right of this central fixation cross (Fox et al., 2008; Holmes, Bradley, Kragh Nielsen, & Mogg, 2009; Kappenman et al., 2014, 2015; Reutter, Hewig, Wieser, & Osinsky, 2017). Future studies aiming to investigate the N2pc will benefit from a design that can better test the differences between spatial orientation of the cues relative to the fixation cross followed by application of temporospatial PCA to isolate the relevant components.

Behavioral analyses indicated that RTs were shorter for congruent versus incongruent probes, suggesting that anxious participants exhibit hypervigilance and greater visual attentional allocation toward emotional (angry and happy) versus neutral face cues. Interestingly, the P2-Probe PCA results appeared to reflect more elaborative processing and emotional evaluation of neutral, compared to emotional (angry and happy), faces (i.e., attentional avoidance from the emotional faces). The enhanced P2 amplitude elicited to probes appearing in the location of neutral, versus emotional, face cues suggests that incongruent probes more immediately capture attention because participants are already attending to the location of the neutral face. However, the RT effects suggest that participants are attending more toward the location of the emotional face at the time of probe onset, and are therefore faster to respond to congruent probes. Therefore, another possibility is that the enhanced P2 amplitude elicited to incongruent probes reflects the greater amount of attentional resources required when shifting attention toward incongruent probes. Additionally, these differing results further reinforce the importance of including neurophysiological measures (i.e., ERPs) along with (often less reliable) behavioral measures to improve the metrics obtained from the dot-probe task.

This preliminary study has a number of limitations which should be acknowledged. First, the present study lacks a healthy comparison group; thus, it is unclear whether the PCA-derived C1-Cue, P1-Cue, and P2-Probe components are specifically anxiety related or whether these components would also be observed in non-anxious samples. However, these three components are particularly promising and reliable ERP measures of attentional bias that can be extended to designs comparing anxious and healthy comparison groups.

Secondly, in order to determine whether the present findings varied as a function of anxiety, exploratory correlations were performed between the STAI-T scores, the temporospatial factor peaks (TF5SF3, TF3SF1, TF4SF3), and the mean amplitudes around the PCA-derived peaks in the ERP waveforms (C1-Cue, P1-Cue, P2-Probe). None of the amplitude values were

significantly correlated with STAI-T scores. While these results were surprising, the lack of correlation between trait anxiety and ERPs may result from the fairly restricted range of STAI-T scores across participants. Specifically, all participants had moderate to high levels of anxiety, indexed by a score of 40 or above on the STAI-T. Although well-powered to detect within-subjects condition effects, the relatively small sample size in this preliminary study may also have limited the ability to detect more modest between-subjects effects of trait anxiety on ERPs.

The third limitation arises from a lack of correction for multiple comparisons. In order to account for potential Type I errors resulting from multiple comparisons, a false discovery rate (FDR) correction, such as the Benjamini-Hochberg method (Benjamini & Hochberg, 1995), is often applied to the robust ANOVAs. However, the purpose of this study was to use PCA to identify cue- and probe-locked components, their scoring windows, and their electrode sites in the present dot-probe task in order to inform hypotheses for the larger, ongoing study. Thus, the goal was to minimize Type II errors which would have likely arisen from a stringent FDR correction. Therefore, in the present study, if the robust ANOVA indicated that there was a significant ($p < .05$) effect of emotion in the cue condition or emotion and/or congruency in the probe condition, the temporospatial factor was retained for further evaluation. Fortunately, there are several strengths associated with using robust ANOVAs. The robust statistics function generates inferential statistical tests comparable to ANOVAs that are designed to be more robust against violations of statistical assumptions. This robust statistic features trimmed means and winsorized variances/covariances to minimize effects of outliers, a bootstrapping routine to estimate the sample mean distribution rather than making the assumption that the data is normally distributed, and a Welch-James approximate degrees of freedom statistic (resulting sometimes in decimal degrees of freedom) that avoids the assumption of homogeneous error variances/covariances. The latter also makes it unnecessary to use Greenhouse-Geisser or Huynh-Feldt epsilon corrections since sphericity is not assumed (Dien, 2017; Keselman et al.,

2003). Overall, however, replication of this study is still required due to the lack of correction for multiple comparisons.

A final limitation pertains to the face cue stimuli used in the present study. In accordance with Mueller et al. (2009), the present study utilized faces from Ekman's Pictures of Facial Affect (Ekman & Friesen, 1976). All of the happy faces used in the present study exhibited smiles with exposed teeth, while half of the angry faces used featured exposed teeth and the other half featured compressed lips. Although faces were matched as closely as possible, it is possible that differences in the mouth regions of the angry faces differentially affected the ERPs. It has been shown that larger P1, N170, vertex positive potential (VPP), and slow positive wave (SPW) ERPs occur to mouth expressions with teeth, and that high luminance/contrast in the mouth-teeth border may drive these ERP effects (DaSilva et al., 2016). Indeed, early visual components are also sensitive to low-level stimulus features such as luminance and contrast (Johannes, Münte, Heinze, & Mangun, 1995). Fortunately, there is some evidence that luminance levels of the Ekman faces may not differ significantly. Pourtois et al. (2004) conducted a dot-probe experiment similar to the one used in the present study using Ekman faces. After face stimuli were trimmed to exclude hair and non-facial contours, there were no significant differences in low-level properties (e.g., luminance, spatial frequency) for the different emotional face conditions. In order to further investigate the effects of exposed and non-exposed teeth on ERP components, future studies may implement a brief passive viewing task featuring emotional faces with and without exposed teeth prior to selecting facial stimuli for implementation in attentional bias tasks. While the aforementioned limitation makes it difficult to interpret the emotion-related effects of the PCA-derived components, the results still highlight that the C1-Cue, P1-Cue, and P2-Probe are promising and reliable markers to investigate in future attentional bias studies.

2.5 Conclusion

The present study used temporospatial PCA to systematically identify ERP components sensitive to emotionally-valenced face pair cues and spatially-relevant probes in a dot-probe task in adults with moderate to high levels of anxiety. Results highlight three reliably elicited components that are of interest for future research. One factor combination resembled a C1-Cue, consisting of an early negativity at 38 ms poststimulus over central occipital sites. The component was enhanced for happy versus angry face pair cues, suggesting that enhanced, pre-attentive processing of happy faces and avoidance of angry faces occurs at the level of V1. The subsequent factor combination resembled a P1-Cue, consisting of an early positivity at 86 ms over parieto-occipital sites. The component was also enhanced for happy versus angry face pair cues, indicating enhanced allocation of attention to the happy faces and avoidance from the angry faces. The final factor combination resembled a P2-Probe, consisting of an early positivity at 220 ms poststimulus over parieto-occipital sites. The component was enhanced for incongruent compared to congruent probes, which may reflect more elaborative processing and emotional evaluation of neutral, compared to emotional (angry and happy), faces (i.e., attentional avoidance from the emotional faces). These results highlight the C1-Cue, P1-Cue, and P2-Probe as promising and reliable neurophysiological markers for attentional bias research and suggest that anxious adults display avoidance from angry face stimuli. It is recommended that future ERP attentional bias studies utilize PCA to systematically identify the timing and scalp distribution of ERPs elicited to task-related stimuli.

CHAPTER 3: Study 2 - The Effect of Mindfulness-Based Cognitive Therapy on ERP Markers of Attentional Bias in Anxiety

3.1 Introduction

Mindfulness-Based Cognitive Therapy (MBCT) is a manualized 8-week skills-training group program (Segal et al., 2013) based on components of cognitive behavioral therapy (CBT) (Beck, Rush, Shaw, & Emery, 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).

It has been shown that MBCT can reduce anxiety and depressive symptoms in adults with anxiety disorders (Craigie et al., 2008; Evans et al., 2008; Kim et al., 2009). For example, using an uncontrolled pre-post design, Craigie, Rees, Marsh, & Nathan (2008) investigated symptom change and recovery in pathological worry after MBCT in adults with a primary diagnosis of GAD. Intent-to-treat analysis revealed significant improvements in pathological worry, stress, quality of life, and a number of other symptoms at post-treatment, which were maintained at follow-up. Evans et al. (2008) conducted a small, non-randomized, cross-sectional trial of MBCT for GAD and demonstrated that subjects in the study, as a group, experienced a significant decrease in their anxiety, tension, worry and depressive symptoms following the course.

While the studies conducted by Craigie et al. (2008) and Evans et al. (2008) lack control groups, other studies have included some type of comparison group. For example, Kim et al. (2009) examined the effectiveness of MBCT and an anxiety disorder education program in the treatment of patients with panic disorder or GAD and observed significantly greater decreases in anxiety and depression scores for patients in the MBCT group than for patients in the anxiety disorder education group. Piet, Hougaard, Hecksher, & Rosenberg (2010) randomly assigned

participants with SAD to group MBCT and group CBT in a crossover design with participants receiving treatments in reversed order. MBCT achieved moderate-high pre-post effect sizes (*d* = 0.78 on a composite SAD measure) not significantly different from those of CBT (*d* = 1.15). The authors concluded that MBCT appears to be a useful, low-cost treatment for SAD, although potentially less efficacious than CBT. CBT may be more effective for some individuals and MBCT for others depending on specific etiological and maintaining factors. If researchers can better understand the mechanisms driving symptom change in CBT, MBCT, and other interventions, individuals can be better matched to treatments that are most likely to be effective (i.e., precision medicine) (Fernandes et al., 2017; Lenze et al., 2021).

MBCT may reduce anxiety and depression by changing a range of emotional and evaluative dimensions that underlie general aspects of wellbeing (Hofmann et al., 2010). MBCT-induced changes in threat-related attentional bias may be a key mechanism driving the intervention's effects on anxiety and mood symptoms in anxious populations. Consistent with this possibility, studies with chronic pain patients and adults with alcohol dependence have demonstrated that mindfulness training can mitigate and modulate attentional bias (Garland, Boettiger, Gaylord, Chanon, & Howard, 2012; Garland, Gaylord, Boettiger, & Howard, 2010; Garland & Howard, 2013; Vago & Nakamura, 2011), albeit as assessed with behavioral measures such as reaction time and self-report measures. Behavioral measures may not be sensitive enough to reveal the mechanisms by which MBCT acts on threat-related attentional biases in anxious populations. Fortunately, ERPs, with their exquisite temporal resolution, are well-suited for illuminating the potential physiological mechanism through which MBCT may target early and late stages of threat-related attentional bias and reduce symptoms of anxiety.

The current study sought to determine whether an 8-week MBCT intervention can modify ERP markers of threat-related attentional bias in anxious populations, potentially reflecting reductions in threat-related attentional biases due to the intervention. Participants with moderate

to high levels of anxiety, evidenced by scores of 40 or above (Addolorato et al., 1999; Julian, 2011; Weinstein, 1995) on the State-Trait Anxiety Inventory, Trait Scale (STAI-T) (Spielberger et al., 1983), were recruited. Prior to MBCT intervention, participants completed a dot-probe task adapted from Mueller et al. (2009) with simultaneous EEG recording. Primary ERP analyses focused on the 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). Additionally, a temporospatial factor combination resembling a P1-Cue, consisting of an early positivity at 86 ms over parieto-occipital sites, was previously observed (see **Chapter 2** and Gupta, Kujawa, & Vago (2021)). Furthermore, examining both the P1-Cue and P1-Probe allows for examination of attentional allocation to threatening stimuli at early and later stages of processing, respectively. Following completion of the task, participants completed the 8-week MBCT intervention adapted from Segal, Williams, & Teasdale (2013). After MBCT intervention, participants again completed the dot-probe task with simultaneous EEG recording. P1-Cue and P1-Probe amplitudes were assessed again to determine whether any MBCT-induced changes occurred.

In line with findings from Mueller et al. (2009), it was hypothesized that, prior to MBCT intervention, anxious participants would display enhanced P1 amplitudes to angry-neutral versus happy-neutral face pair cues in the dot-probe task, reflecting hypervigilance to threat at early stages of information processing, and decreased P1 amplitudes to probes replacing angry versus neutral faces, reflecting avoidance from threat at later stages of information processing. MBCT may facilitate early detection of negative thinking patterns, feelings, and body sensations (Teasdale et al., 2000) driving the formation and preservation of threat-related attentional biases and allow individuals to disengage from these habitual, automatic, and dysfunctional cognitive routines (Chiesa & Serretti, 2011), thus mitigating threat-related attentional biases. Thus, following MBCT intervention, it was hypothesized that patients would display decreased P1

amplitudes to angry-neutral versus happy-neutral face pair cues, reflecting reduced hypervigilance to threat at early stages of information processing, and increased P1 amplitudes to probes replacing angry versus neutral faces, reflecting reduced avoidance from threat at later stages of information processing.

The present study also sought to investigate the relationship between P1 threat-related attentional bias markers and symptom change with treatment. MBCT appears to be an effective treatment for reducing anxiety and mood symptoms (Craigie, Rees, Marsh, & Nathan, 2008; Evans et al., 2008; Kim et al., 2009); however, a question that remains unanswered is whether MBCT-induced modifications of neural attentional bias markers like P1 are associated with improved anxiety symptoms. Additionally, it is likely that anxious participants have varying levels of depression, as anxiety and depression are highly comorbid (Zhou et al., 2017). It has been shown that there are notable differences in the pattern of attentional bias in GAD compared to clinical depression, such that hypervigilance to threat may be less evident in those with elevated symptoms of depression due to motivational deficits (Mogg & Bradley, 2005). Therefore, the present study also explored how severity of participants' depression affects MBCT-induced modification of P1 threat-related attentional bias markers. Specifically, participants' scores on the Depression Anxiety Stress Scale (DASS) Anxiety and Depression subscales (Lovibond & Lovibond, 1995) were analyzed to explore differential relationships between symptoms and physiological outcomes. It was hypothesized that (1) MBCT would reduce anxiety and depression symptoms, (2) P1-Angry Cue amplitude changes (indexing changes in early hypervigilance to threat) would be associated with DASS-A (anxiety symptom) changes, and (3) P1-Angry Congruent Probe amplitude changes (indexing changes in later avoidance of threat) would be associated with both DASS-A (anxiety symptom) and DASS-D (depression symptom) changes. The reasoning behind these predictions was that hypervigilance to threat is common in anxiety

disorders (Richards, Benson, Donnelly, & Hadwin, 2014), whereas avoidance is common in both anxiety and depressive disorders (Trew, 2011).

Lastly, exploratory analyses were performed on (1) P1-Cue and P1-Probe latencies to determine whether MBCT modified the timing of these threat-related attentional bias markers, (2) amplitudes and latencies for the C1 elicited by the face-pair cues (C1-Cue), as a temporospatial factor combination resembling a C1-Cue consisting of an early negativity at 38 ms poststimulus over central occipital sites was previously observed (see **Chapter 2** and Gupta, Kujawa, & Vago (2021)), and (3) behavioral data to determine the effects of emotion and congruency on reaction times in the dot-probe task.

In sum, the present study illuminates a potential physiological mechanism through which MBCT may target early and late stages of threat-related attentional bias and reduce symptoms of anxiety. The effect of depression on MBCT-induced P1 marker modification was also explored.

3.2 Methods

3.2.1 Participants

In order to participate in the study, participants had to (1) be between the ages of 18 and 55 years, (2) have moderate to high levels of anxiety, indexed by a score of 40 or above on the STAI-T, and (3) be considered stable on maintenance medications for anxiety or depression at least one month prior to enrollment. Participants were excluded if they had (1) endorsed 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 minutes 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 during the study.

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 in the present study. Sixty-five participants completed the pre-MBCT EEG assessment, and 50 of these participants completed the MBCT course and post-MBCT EEG. These 50 adults (39 females, 11 males) had a mean age of 31.92 years (*SD* = 8.75). In terms of race, participants were 8.00% Asian, 8.00% Black or African American, 82.00% White, and 2.00% were more than one race. Participants' ethnicity included 4.00% Hispanic or Latino.

It is important to note that 13 of the 50 participants completed in-person MBCT prior to the COVID-19 pandemic and the remaining 37 participants completed virtual MBCT during the COVID-19 pandemic. As shown in **Table 2**, 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.

3.2.2 MBCT Intervention

The in-person and virtual 8-week MBCT courses, adapted from Segal, Williams, & Teasdale (2013), were led by instructors with over 12 years of mindfulness teaching experience and qualifications to teach MBCT. The courses were held in a group format and consisted of up to approximately 12 participants in each in-person group and 20 participants in each virtual group. The Zoom platform was used for the virtual courses.

The MBCT courses consisted of (1) a pre-program orientation, (2) a brief individual interview with the MBCT instructor (virtual MBCT only), (3) eight weekly group classes 2-2.5 hours in duration, (3) an all-day retreat during the sixth week of the program, (4) learning "formal" meditation practices, including body scan meditation, gentle yoga, sitting meditation, and walking meditation, (5) learning "informal" meditation practices and skills for daily life, including noting pleasant and unpleasant events and becoming aware of breathing and routine activities like eating, driving, walking, conversations, (6) daily homework assignments involving formal and informal practices, and (7) individual and group dialogue discussing home assignments and any problems. Participants were expected to attend at least 5 of the 8 classes and the all-day retreat in order to qualify for study completion.

3.2.3 Dot-Probe Task

A dot-probe task adapted from Mueller et al. (2009) (see **Figure 1**) with simultaneous EEG recording was used to assess threat-related attentional bias in the anxious participants prior to and following MBCT.

3.2.3.1 Face Stimuli

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 of the happy face stimuli 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 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 centimeter (cm) x 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 x 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 x 2 cm with a thickness of 0.1 cm and was presented centrally on the lower part of the screen. All stimuli were set on a black background and presented on a 24-inch monitor with a Dell desktop computer running E-Prime (Psychology Software Tools, Pittsburgh, PA). Participants made responses to the stimuli using a Cedrus RB-844 button box (Cedrus, San Pedro, CA).

3.2.3.2 Task Procedure

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. 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 field. 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. Accuracy was measured as the number of correct responses (“hits”) and the number of incorrect responses (“misses”). Trials with incorrect responses, response times <100 ms, or response times >1500 ms were excluded from behavioral analyses.

3.2.4 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 COVID-19 pandemic, a few 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-COVID 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 0.1-30 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 (1) trials where angry-neutral face pairs were presented, and (2) trials where happy-neutral face pairs were presented. For the probe condition, data were segmented into (1) presentation of angry congruent probes (i.e., probe replaces angry face in angry-neutral face pairs), (2) presentation of angry incongruent probes (i.e., probe replaces neutral face in angry-neutral face pairs), (3) presentation of happy congruent probes (i.e., probe replaces happy face in happy-neutral face pairs), and (4) presentation of happy

incongruent probes (i.e., probe replaces 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 where participants responded correctly were used to calculate each subject's averages, and subsequently, the grand averages. Subject averages and grand averages were computed with individual channel mode enabled. In the full sample (*N* = 50), pre-MBCT, the mean number of trials included in the grand averages at electrode P8 were as follows: angry cue: 341.48 trials; happy cue: 342.12 trials; angry congruent probe: 170.34 trials; angry incongruent probe: 170.68 trials; happy congruent probe: 172.36 trials; and happy incongruent probe: 169 trials. Post-MBCT, the mean number of trials included in the grand averages at electrode P8 were as follows: angry cue: 348.52 trials; happy cue: 349.16 trials; angry congruent probe: 172.86 trials; angry incongruent probe: 174.94 trials; happy congruent probe: 172.72 trials; and happy incongruent probe: 174.34 trials.

Primary analyses focused on the P1-Cue and P1-Probe amplitudes. 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) were 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 for P1-face and P1-probe peak detection, and (2) results from the temporospatial PCA analysis discussed in **Chapter 2** and Gupta, Kujawa, & Vago (2021), where a temporospatial factor combination resembling a P1-Cue consisting of an early positivity at 86 ms over parieto-occipital

sites was observed. We previously demonstrated that neurophysiological markers of attentional bias are reliably measured in the ERP waveforms (Spearman *r* range: 0.70-0.96; see **Chapter 2** and Gupta, Kujawa, & Vago (2021)). Exploratory analyses were also performed on the P1-Cue and P1-Probe latencies, which were exported along with the peak information.

Exploratory analyses were performed on the C1-Cue amplitudes and latencies. A 30-80 ms search window at electrode Oz was used to identify the C1-Cue peak, and the mean value around the peaks (50 ms) were exported from Brain Vision Analyzer. Time window and electrode site selections were based on (1) Mueller et al. (2009), who used a 50-80 ms time window for C1-Cue peak detection, and (2) results from the temporospatial PCA analysis discussed in **Chapter 2** and Gupta, Kujawa, & Vago (2021)).

3.2.5 Symptom Measures

The State-Trait Anxiety Inventory (STAI) (Spielberger et al., 1983) uses two subscales to measure the presence and severity of current symptoms of anxiety and a generalized propensity to be anxious (Julian, 2011). The STAI-State subscale evaluates the current state of anxiety, asking how respondents feel "right now," using items that measure subjective feelings of apprehension, tension, nervousness, worry, and activation/arousal of the autonomic nervous system. The STAI-Trait subscale evaluates relatively stable aspects of "anxiety proneness," including general states of calmness, confidence, and security (Julian, 2011). As mentioned above, the STAI-Trait was used to recruit participants with moderate to high levels of anxiety for the present study.

The Depression Anxiety Stress Scale – 21 Items (DASS-21) (Lovibond & Lovibond, 1995) was administered prior to and following MBCT intervention to track anxiety and depression symptom changes. DASS-21 items can be reliably grouped into three scales: (a) depression (DASS-D), which assesses dysphoria, hopelessness, devaluation of life, self-deprecation, lack of interest/involvement, anhedonia, and inertia, (b) anxiety (DASS-A), which assesses autonomic

arousal, skeletal muscle effects, situational anxiety, and subjective experience of anxious affect, and (c) stress (DASS-S), which is sensitive to levels of chronic non-specific arousal and assesses difficulty relaxing, nervous arousal, and being easily upset/agitated, irritable/over-reactive and impatient (Antony, Bieling, Cox, Enns, & Swinson, 1998; Brown, Chorpita, Korotitscw, & Barlow, 1997; Lovibond & Lovibond, 1995). Thus, the DASS-21 may hold more promise for distinguishing between anxiety and depression, as well as between symptoms of physical arousal and symptoms of generalized anxiety (e.g., tension or agitation) (Antony et al., 1998). The DASS-A was used as the primary outcome measure of anxiety, and exploratory analyses examined the DASS-D.

In the full sample (N = 50), the DASS-A was found to have acceptable to good internal consistency both pre-MBCT (7 items; α = 0.73) and post-MBCT (7 items; α = 0.80), and the DASS-D also had acceptable to good internal consistency both pre-MBCT (7 items; α = 0.79) and post-MBCT (7 items; α = 0.87). In the virtual sample only (N = 37), the DASS-A had acceptable internal consistency both pre-MBCT (7 items; α = 0.70) and post-MBCT (7 items; α = 0.78), and the DASS-D had acceptable to good internal consistency both pre-MBCT (7 items; α = 0.79) and post-MBCT (7 items; α = 0.89).

3.2.6 Power Analysis

No prior studies have explored P1 activity in anxious populations before and after an MBCT intervention, so no direct estimation of effect size was available. However, Schoenberg et al. (2014) conducted a study in which attention-deficit/hyperactivity disorder-related ERP markers were monitored before and after an MBCT intervention. Therefore, mean amplitude differences and standard deviations from the study were used for this power analysis.

Using G*Power 3.1 (Faul et al., 2007), a power analysis was computed based only upon the two primary outcomes: changes in P1-Cue and P1-Probe amplitudes to face cues and probes, respectively. The study was powered to evaluate these two primary hypotheses using alpha = .05

with .80 power, which permitted us to detect a near-medium effect size of *f* = .248. Power estimates indicated that a sample of 34 subjects would allow us to assess whether MBCT decreases P1 amplitudes to angry-neutral versus happy-neutral face pair cues and increases P1 amplitudes to probes replacing angry versus neutral faces. Accounting for an 18% attrition rate, the goal was to recruit 42 subjects. With no attrition, and using alpha = .05 and power = .80, there would be power to detect effects as small as *f* = .222.

3.2.7 Statistical Analyses

First, independent-samples t-tests were performed in jamovi (R Core Team, 2021; the jamovi project, 2021) to determine whether the in-person and virtual MBCT groups differed in terms of their anxiety and depression symptoms pre- and post-MBCT. Within these groups, paired t-tests were also performed on the pre- and post-MBCT DASS-A and DASS-D scores in Matlab 2021a to determine whether there were significant changes in anxiety and depression symptoms, respectively.

In order to test the study hypotheses, linear mixed-effects (LME) models rather than repeated-measures analysis of variance were used because LME models are better equipped for handling dependencies in repeated-measures data (Gueorguieva & Krystal, 2004; Judd, Westfall, & Kenny, 2012). LME models were implemented in Matlab R2021a using the default settings. The following LME model with a random intercept for subject was used to examine the effects of time and emotion on the P1-Cue amplitudes and latencies: $P1Cue = \beta_0 + \beta_1 time + \beta_2 emotion + \beta_3 time * emotion + \varepsilon, (H_0: \beta_3 = 0)$, where $time$ (pre-MBCT versus post-MBCT) and $emotion$ (angry versus happy) are binary predictor variables and $time * emotion$ represents the interaction between time and emotion. A similar model was applied to the C1-Cue amplitudes and latencies.

An LME model with a random intercept for subject was used to examine the effects of time, emotion, and congruency on the P1-Probe amplitudes and latencies: $P1Probe = \beta_0 + \beta_1 time + \beta_2 emotion + \beta_3 congruency + \beta_4 time * emotion * congruency + \varepsilon, \quad (H_0: \beta_4 = 0)$,

where $congruency$ (congruent versus incongruent) is a binary predictor and $time * emotion * congruency$ is the interaction between time, emotion, and congruency.

The following LME model with a random intercept for subject was used to examine the effects of time and P1-Angry Cue amplitude scores on DASS-A scores: $DASSa = \beta_0 + \beta_1 time + \beta_2 P1AC + \beta_3 time * P1AC + \varepsilon,\ (H_0: \beta_3 = 0)$, where $time$ (pre-MBCT versus post-MBCT) is a binary predictor, $P1AC$ refers to the P1-Angry Cue amplitudes, and $time * P1AC$ is the interaction between time and the P1-Angry Cue amplitudes. A similar model was applied to DASS-D scores to determine whether findings were specific to anxiety, but not depression, symptoms.

In addition, the following LME model with a random intercept for subject was used to examine the effect of time and P1-Angry Congruent Probe amplitude scores on DASS-A scores: $DASSa = \beta_0 + \beta_1 time + \beta_2 P1ACP + \beta_3 time * P1ACP + \varepsilon,\ (H_0: \beta_3 = 0)$, where $time$ (pre-MBCT versus post-MBCT) is a binary predictor, $P1ACP$ refers to the P1-Angry Congruent Probe amplitudes, and $time * P1ACP$ is the interaction between time and the P1-Angry Congruent Probe amplitudes. A similar model was used to examine the effect of time and P1-Angry Congruent Probe amplitudes on DASS-D scores.

The following LME model with a random intercept for subject was used to explore the effects of time, emotion, and congruency on RTs: $RTs = \beta_0 + \beta_1 time + \beta_2 emotion + \beta_3 congruency + \beta_4 time * emotion * congruency + \varepsilon,\ (H_0: \beta_4 = 0)$, where $congruency$ (congruent versus incongruent) is a binary predictor and $time * emotion * congruency$ is the interaction between time, emotion, and congruency.

LME models were first tested with group (in-person versus virtual MBCT) as a covariate to examine where there were any effects of group. With the exception of the DASS-A models (described in more detail below), no main effects of group were observed and there were no substantive changes in other effects resulting from the addition of the group covariate. Therefore, the group covariate was removed from the final models, and the models were applied to the full

sample (in-person MBCT + virtual MBCT, *N* = 50). All models were also applied to the virtual MBCT sample (*N* = 37) only, as this group was more homogenous in nature (i.e., all virtual MBCT participants were taught by the same instructor and all data was collected during the COVID-19 pandemic) and fully powered on its own.

3.3 Results

3.3.1 Anxiety and Depression Symptoms

3.3.1.1 Group Differences in Anxiety and Depression Symptoms

Independent-samples t-tests were performed to determine whether the in-person and virtual MBCT groups differed in terms of their anxiety and depression symptoms pre- and post-MBCT. Results are shown in **Table 2**. In terms of depression symptoms, pre-MBCT, in-person MBCT group DASS-D scores did not significantly differ from virtual MBCT group DASS-D scores, $t(48) = 1.46$, $p = .15$, $d = .47$, *mean difference* = 4.05, *SE difference* = 2.77. Similarly, post-MBCT, in-person MBCT group DASS-D scores did not significantly differ from virtual MBCT group DASS-D scores, $t(48) = -.28$, $p = .78$, $d = -.09$, *mean difference* = -.79, *SE difference* = 2.84.

In terms of anxiety symptoms, pre-MBCT, in-person MBCT group DASS-A scores did not significantly differ from virtual MBCT group DASS-A scores, $t(48) = -1.21$, $p = .23$, $d = -.39$, *mean difference* = -3.36*, SE difference* = 2.78. However, post-MBCT, in-person MBCT group DASS-A scores were significantly lower than virtual MBCT group DASS-A scores, $t(48) = -2.47$, $p = .02$, $d = -.80$, *mean difference* = -5.87, *SE difference* = 2.38.

Subsequently, paired t-tests were performed on the pre- and post-MBCT DASS-A and DASS-D scores from the full and virtual only samples to determine whether there were any significant changes in anxiety and depression symptoms, respectively, within these groups.

3.3.1.2 Full Sample (N = 50): Changes in Anxiety and Depression Symptoms

In the full sample, paired t-tests revealed that post-MBCT DASS-A scores (M = 8.96, SD = 7.75) were significantly decreased compared to pre-MBCT DASS-A scores (M = 12.64, SD = 8.66), $t(49) = 2.88$, $p < .01$. Similarly, post-MBCT DASS-D scores (M = 10.12, SD = 8.74) were significantly decreased compared to pre-MBCT DASS-D scores (M = 18.08, SD = 8.68), $t(49) = 5.66$, $p < .001$.

3.3.1.3 Virtual Sample (N = 37): Changes in Anxiety and Depression Symptoms

In the virtual sample, paired t-tests revealed that post-MBCT DASS-A scores (M = 10.49, SD = 8.03) were decreased compared to pre-MBCT DASS-A scores (M = 13.51, SD = 8.72) with marginal significance, $t(36) = 1.91$, $p = .06$. However, post-MBCT DASS-D scores (M = 10.32, SD = 9.49) were significantly decreased compared to pre-MBCT DASS-D scores (M = 17.03, SD = 8.78), $t(36) = 4.34$, $p < .001$.

3.3.2 MBCT Effects on P1-Cue ERP

3.3.2.1 Full Sample (N = 50)

Pre- and post-MBCT grand average ERP waveforms time-locked to the presentation of angry and happy face pair cues at electrode P8 and mean P1 amplitudes time-locked to angry and happy face pairs for the full sample are shown in **Figure 5**. 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 (B = .07, SE = .32, $t(196) = .22$, $p = .83$). In the main effects model, there was no significant effect of time (B = .06, SE = .16, $t(197) = .36$, $p = .72$) or emotion (B = .02, SE = .16, $t(197) = .14$, $p = .89$) on P1-Cue amplitudes.

The P1-Cue LME model was also used to explore the effects of time and emotion on P1-Cue latencies. The interaction between time and emotion was nonsignificant (B = 2.44, SE = 3.03, $t(196) = .81$, $p = .42$). In the main effects model, there was no significant effect of time (B = .14,

SE = 1.52, *t*(197) = .09, *p* = .93) or emotion (*B* = 1.02, *SE* = 1.52, *t*(197) = .67, *p* = .50) on P1-Cue latencies.

3.3.2.2 Virtual Sample (N = 37)

Pre- and post-MBCT grand average ERP waveforms time-locked to the presentation of angry and happy face pair cues at electrode P8 and mean P1 amplitudes time-locked to angry and happy face pairs for the virtual sample are shown in **Figure 6**. The P1-Cue LME model was again 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 was nonsignificant (*B* = .16, *SE* = .39, *t*(144) = .41, *p* = .68). In the main effects model, there was no significant effect of time (*B* = .19, *SE* = .19, *t*(145) = .99, *p* = .32) or emotion (*B* = -.04, *SE* = .19, *t*(145) = -.18, *p* = .86) on P1-Cue amplitudes.

The P1-Cue LME model was also used to explore the effects of time and emotion on P1-Cue latencies. The interaction between time and emotion was nonsignificant (*B* = 2.65, *SE* = 2.96, *t*(144) = .90, *p* = .37). In the main effects model, there was no significant effect of time (*B* = 1.81, *SE* = 1.48, *t*(145) = 1.22, *p* = .22) or emotion (*B* = -.19, *SE* = 1.48, *t*(145) = -.13, *p* = .90) on P1-Cue latencies.

3.3.3 MBCT Effects on P1-Probe ERP

3.3.3.1 Full sample (N = 50)

Pre- and post-MBCT grand average ERP waveforms time-locked to angry congruent, angry incongruent, happy congruent, and happy incongruent probes and mean P1-probe amplitudes as a function of emotion and congruency in the full sample are shown in **Figure 7**. 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* = -.28, *SE* = .41, *t*(392) = -.68, *p* = .50). In the main effects model, there was no significant effect

of emotion (*B* = -.05, *SE* = .10, *t*(396) = -.51, *p* = .61) or congruency (*B* = -.08, *SE* = .10, *t*(396) = -.77, *p* = .44); however, there was a significant main effect of time (*B* = .48, *SE* = .10, *t*(396) = 4.65, *p* < .001) such that P1-Probe amplitudes were reduced across conditions post-MBCT compared to pre-MBCT.

The P1-Probe LME model was also used to explore the effects of time, emotion, and congruency on P1-Probe latencies. The interaction between time, emotion, and congruency was nonsignificant (*B* = 4.36, *SE* = 6.67, *t*(392) = .65, *p* = .51). In the main effects model, there was no significant effect of time (*B* = 2.07, *SE* = 1.68, *t*(396) = 1.24, *p* = .22), emotion (*B* = -2.23, *SE* = 1.68, *t*(396) = -1.33, *p* = .18), or congruency (*B* = -1.65, *SE* = 1.68, *t*(396) = -.99, *p* = .33) on P1-Probe latencies.

3.3.3.2 Virtual sample (N = 37)

Pre- and post-MBCT grand average ERP waveforms time-locked to the onset of probes replacing angry congruent, angry incongruent, happy congruent, and happy incongruent probes and mean P1-probe amplitudes as a function of emotion and congruency in the virtual sample are shown in **Figure 8**. The P1-Probe LME model was again 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* = -.55, *SE* = .46, *t*(288) = -1.20, *p* = .23). In the main effects model, there was no significant effect of emotion (*B* = .03, *SE* = .12, *t*(292) = .28, *p* = .78) or congruency (*B* = -.14, *SE* = .12, *t*(292) = -1.24, *p* = .22); however, there was again a significant effect of time (*B* = .44, *SE* = .12, *t*(292) = 3.86, *p* < .001) such that P1-Probe amplitudes were reduced post-MBCT compared to pre-MBCT.

The P1-Probe LME model was also used to explore the effects of time, emotion, and congruency on P1-Probe latencies. The interaction between time, emotion, and congruency was nonsignificant (*B* = 1.51, *SE* = 8.18, *t*(288) = .18, *p* = .85). In the main effects model, there was

no significant effect of time (*B* = 2.00, *SE* = 2.05, *t*(292) = .98, *p* = .33), emotion (*B* = -1.95, *SE* = 2.05, *t*(292) = -.95, *p* = .34), or congruency (*B* = -1.73, *SE* = 2.05, *t*(292) = -.84, *p* = .40) on P1-Probe latencies.

3.3.4 P1-Angry Cue and Anxiety and Depression Score Analyses

3.3.4.1 Full Sample (N = 50)

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* = .30, *SE* = .46, *t*(96) = .65, *p* = .52). However, in the main effects model, there was a significant effect of time (*B* = 3.67, *SE* = 1.24, *t*(97) = 2.95, *p* < .01) on DASS-A scores such that DASS-A scores were reduced post-MBCT compared to pre-MBCT. There was also a significant effect of P1-Angry Cue amplitudes (*B* = .65, *SE* = .32, *t*(97) = 2.05, *p* = .04) 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.

In order 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* = -.47, *SE* = .51, *t*(96) = -.94, *p* = .35). In the main effects model, there was no significant effect of P1-Angry Cue amplitudes (*B* = .57, *SE* = .34, *t*(97) = 1.68, *p* = .10) on DASS-D scores; however, there was a significant effect of time (*B* = 7.95, *SE* = 1.37, *t*(97) = 5.81, *p* < .001) on DASS-D scores such that DASS-D scores were reduced post-MBCT compared to pre-MBCT.

3.3.4.2 Group Effects

When group was added as a covariate to the P1-Angry Cue and DASS-A main effects LME model, there was a significant effect of group (*B* = 4.96, *SE* = 2.03, *t*(96) = 2.44, *p* = .02) on DASS-A scores such that in-person MBCT DASS-A scores were lower than virtual MBCT

DASS-A scores. However, there were no substantive changes in other effects when comparing these results to the those from the main effects model without the group variable (described above).

3.3.4.3 Virtual Sample (N = 37)

The P1-Angry Cue and DASS-A LME model was also used to investigate the effects of time (pre-MBCT versus post-MBCT) and P1-Angry Cue amplitudes on DASS-A scores in the virtual sample. The interaction between time and P1-Angry Cue amplitudes was nonsignificant (B = .49, SE = .52, $t(70)$ = .94, p = .35). In the main effects model, there was a marginally significant effect of time (B = 2.92, SE = 1.51, $t(71)$ = 1.93, p = .06) on DASS-A scores such that DASS-A scores were reduced post-MBCT compared to pre-MBCT. There was also a significant effect of P1-Angry Cue amplitudes (B = .92, SE = .34, $t(71)$ = 2.70, p < .01) 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.

In order to determine whether these results were restricted to the DASS-A, the model was also applied the DASS-D data. The interaction between time and P1-Angry Cue amplitudes was nonsignificant (B = -.49, SE = .50, $t(70)$ = -.97, p = .34). In the main effects model, there was a significant effect of time (B = 6.61, SE = 1.46, $t(71)$ = 4.54, p < .001) on DASS-D scores such that DASS-D scores were decreased post-MBCT compared to pre-MBCT. There was also a significant effect of P1-Angry Cue amplitudes (B = .85, SE = .39, $t(71)$ = 2.18, p = .03) on DASS-D scores such that higher P1-Angry Cue amplitudes overall were associated with higher DASS-D scores across both pre- and post-MBCT time points.

3.3.5 P1-Angry Congruent Probe and Anxiety and Depression Score Analyses

3.3.5.1 Full Sample (N = 50)

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 = .49, SE = .61, t(96) = .80, p = .43). In the main effects model, there was no significant effect of P1-Angry Congruent Probes amplitudes (B = .62, SE = .40, t(97) = 1.53, p = .13) on DASS-A scores; however, there was a significant effect of time (B = 3.48, SE = 1.26, t(97) = 2.77, p < .01) 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 = .05, SE = .69, t(96) = .07, p = .94). In the main effects model, there was no significant effect of P1-Angry Congruent Probe amplitudes (B = .31, SE = .43, t(97) = .73, p = .47) on DASS-D scores; however, there was a significant effect of time (B = 7.86, SE = 1.40, t(97) = 5.61, p < .001) such that DASS-D scores were reduced post-MBCT compared to pre-MBCT.

3.3.5.2 Group Effects

As mentioned above, when group was added as a covariate to the P1-Angry Congruent Probe and DASS-A main effects LME model, there was a significant effect of group (B = 4.52, SE = 2.07, t(96) = 2.18, p = .03) on DASS-A scores such that the in-person group DASS-A scores were lower than the virtual group DASS-A scores. However, there were no substantive changes in other effects when comparing these results to the those from the main effects model without the group variable (described above).

3.3.5.3 Virtual Sample (N = 37)

The P1-Angry Congruent Probe and DASS-A LME model was again used to investigate the effects of time (pre-MBCT versus post-MBCT) and P1-Angry Congruent Probe amplitudes on DASS-A scores in the virtual sample. The interaction between time and P1-Angry Congruent Probe amplitudes was nonsignificant (B = 1.12, SE = .76, t(70) = 1.48, p = .14). In the main effects

model, there was no significant effect of P1-Angry Congruent Probe amplitudes (*B* = .87, *SE* = .50, *t*(71) = 1.74, *p* = .09) on DASS-A scores; however, there was a marginally significant effect of time (*B* = 2.93, *SE* = 1.52, *t*(71) = 1.92, *p* = .06) 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* = .80, *SE* = .79, *t*(70) = 1.02, *p* = .31). In the main effects model, there was no significant effect of P1-Angry Congruent Probe amplitudes (*B* = .63, *SE* = .55, *t*(71) = 1.15, *p* = .25) on DASS-D scores; however, there was a significant effect of time (*B* = 6.64, *SE* = 1.53, *t*(71) = 4.35, *p* < .001) such that DASS-D scores were reduced post-MBCT compared to pre-MBCT.

3.3.6 MBCT Effects on C1-Cue ERP

3.3.6.1 Full sample (N = 50)

Pre- and post-MBCT grand average ERP waveforms time-locked to the presentation of angry and happy face pair cues at electrode Oz and mean C1 amplitudes time-locked to angry and happy face pair cues for the full sample are shown in **Figure 9**. The C1-Cue LME model was used to determine the effects of time (pre-MBCT versus post-MBCT) and emotion (angry versus happy) on C1-Cue amplitudes in the full sample. The interaction between time and emotion was nonsignificant (*B* = .04, *SE* = .24, *t*(196) = .15, *p* = .88). In the main effects model, there was no significant effect of time (*B* = -.19, *SE* = .12, *t*(197) = -1.52, *p* = .13) or emotion (*B* = .12, *SE* = .12, *t*(197) = .96, *p* = .34) on C1-Cue amplitudes.

The C1-Cue LME model was also used to explore the effects of time and emotion on C1-Cue latencies. The interaction between time and emotion was nonsignificant (*B* = 2.44, *SE* = 2.61, *t*(196) = .94, *p* = .35). In the main effects model, there was no significant effect of emotion (*B* = .10, *SE* = 1.31, *t*(197) = .08, *p* = .94) on the C1-Cue latencies; however, there was a marginally

significant effect of time (*B* = -2.46, *SE* = 1.31, *t*(197) = -1.88, *p* = .06) such that C1-Cue latencies were increased post-MBCT compared to pre-MBCT.

3.3.6.2 Virtual Sample (N = 37)

Pre- and post-MBCT grand average ERP waveforms time-locked to the presentation of angry and happy face pair cues at electrode Oz and mean C1 amplitudes time-locked to angry and happy face pair cues for the virtual sample are shown in **Figure 10**. The C1-Cue LME model was again used to determine the effects of time (pre-MBCT versus post-MBCT) and emotion (angry versus happy) on C1-Cue amplitudes in the virtual sample. The interaction between time and emotion was nonsignificant (*B* = .02, *SE* = .29, *t*(144) = .06, *p* = 0.95). In the main effects model, there was no significant effect of time (*B* = -.09, *SE* = .15, *t*(145) = -.59, *p* = .56) or emotion (*B* = .09, *SE* = .15, *t*(145) = .60, *p* = .55) on C1-Cue amplitudes.

The C1-Cue LME model was also used to explore the effects of time and emotion on C1-Cue latencies. The interaction between time and emotion was nonsignificant (*B* = 4.49, *SE* = 3.20, *t*(144) = 1.40, *p* = .16). In the main effects model, there was no significant effect of time (*B* = -2.84, *SE* = 1.61, *t*(145) = -1.76, *p* = .08) or emotion (*B* = .08, *SE* = 1.61, *t*(145) = .05, *p* = .96) on C1-Cue latencies.

3.3.7 MBCT Effects on Behavioral (RT) Data

3.3.7.1 Full Sample (N = 50)

Mean RTs to probes as a function of emotion and congruency in the full sample are shown in **Figure 11**. 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 in the full sample. The interaction between time, emotion, and congruency was nonsignificant (*B* = 2.03, *SE* = 7.29, *t*(392) = .28, *p* = .78). In the main effects model, there was no significant effect of emotion (*B* = -.77, *SE* = 1.82, *t*(396) = -.42, *p* = .67) or congruency (*B* = 3.16, *SE* = 1.82, *t*(396)

= 1.73, *p* = .08) on RTs; however, there was a significant effect of time (*B* = 3.68, *SE* = 1.82, *t*(396) = 2.02, *p* = .04) such that RTs were faster overall post-MBCT compared to pre-MBCT.

3.3.7.2 Virtual Sample (N = 37)

Mean RTs to the probe as a function of emotion and congruency in the virtual sample are shown in **Figure 12**. The RT LME model was again used to explore the effects of time (pre-MBCT versus post-MBCT), emotion (angry versus happy), and congruency (congruent versus incongruent) on RTs in the virtual sample. In the behavioral LME model, the interaction between time, emotion, and congruency was nonsignificant (*B* = 1.46, *SE* = 8.86, *t*(288) = .16, *p* = .87). In the main effects model, there was no significant effect of time (*B* = -.61, *SE* = 2.22, *t*(292) = -.28, *p* = .78), emotion (*B* = -.48, *SE* = 2.22, *t*(292) = -.22, *p* = .83), or congruency (*B* = 3.35, *SE* = 2.22, *t*(292) = 1.51, *p* = .13) on RTs.

3.4 Discussion

The goal of the present study was to investigate (1) whether an 8-week MBCT intervention can modify P1 threat-related attentional bias markers in anxious populations, potentially reflecting reductions in threat-related attentional biases due to the intervention, and (2) the relationship between P1 threat-related attentional bias markers and treatment response. Exploratory analyses were performed on (1) P1-Cue and P1-Probe latencies to determine whether MBCT modified the timing of these threat-related attentional bias markers, (2) amplitudes and latencies for the C1 elicited by the face-pair cues (C1-Cue), and (3) behavioral data to determine the effects of emotion and congruency on reaction times in the dot-probe task. Primary findings indicate an overall reduction of P1-Probe amplitudes, anxiety and depression, and reaction times following MBCT. 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-Cue were observed following MBCT.

The in-person and virtual groups did not differ on primary measures aside from anxiety. Post-MBCT, anxiety scores for the in-person versus virtual MBCT 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, Green, Compas, Dickey, & Pegg, 2020). Indeed, the pandemic has been associated with high rates of anxiety and depression (Hyland et al., 2020; Odriozola-González, Planchuelo-Gómez, Irurtia, & de Luis-García, 2020; Rajkumar, 2020). All analyses were conducted on the full and virtual samples, and results were generally consistent between these samples.

3.4.1 MBCT and P1 Threat-Related Attentional Bias Markers

In the first aim, it was hypothesized that, prior to MBCT intervention, anxious participants would display enhanced P1 amplitudes to angry-neutral versus happy-neutral face pair cues in the dot-probe task, reflecting hypervigilance to threat at early stages of information processing, and decreased P1 amplitudes to probes replacing angry versus neutral faces, reflecting avoidance from threat at later stages of information processing. Following MBCT intervention, it was hypothesized that patients would display decreased P1 amplitudes to angry-neutral versus happy-neutral face pair cues, reflecting reduced hypervigilance to threat at early stages of information processing, and increased P1 amplitudes to probes replacing angry versus neutral faces, reflecting reduced avoidance from threat at later stages of information processing. Contrary to these hypotheses, in both the full and virtual samples, anxious participants did not appear to display hypervigilance to threat cues pre-MBCT or a reduction in hypervigilance post-MBCT. Participants in both samples also did not appear to display avoidance from threat pre-MBCT or reduced avoidance from threat 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, it is important to note that Mueller and colleagues specifically focused on participants with SAD; in the present study, participants with moderate to high levels of anxiety were recruited using the STAI-T, widely used as a measure of general anxiety (Julian, 2011). 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 it has been shown that biases occur in all anxiety disorders, including 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 towards specific attentional bias for social-threat words primarily (Maidenberg, Chen, Craske, Bohn, & Bystritsky, 1996).

The present findings also did not match findings from (1) the ERP model of the neural chronometry of attentional bias in Gupta et al. (2019), which posits that anxious populations display modulations of early ERP components, including the P1, in response to threatening and emotional stimuli reflecting enhanced allocation of attention to threat and emotion at earlier stages of processing, and (2) the finding of a temporospatial factor combination, resembling a P1-Cue, that was enhanced for happy versus angry face pair cues, indicating enhanced allocation of attention to the happy faces and avoidance from the angry faces (described in **Chapter 2** and Gupta et al., 2021). However, even within high trait anxiety populations, biases can present in an inconsistent fashion. Zvielli, Bernstein, & Koster (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 (five

categories of threat stimuli, namely, angry faces, attacking dogs, attacking snakes, pointed weapons, violent scenes were used). This may explain why no clear biases to the cues and probes were apparent in the present study.

However, in both samples, P1-Probe amplitudes were reduced across conditions post-MBCT compared to pre-MBCT, suggesting that participants allocated less attention to all probe types 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 led to more efficient processing of the probes. However, practice effects could also explain these results. Practice effects refer to the phenomenon that individuals perform better at cognitive function tests with repeated testing (Wesnes & Pincock, 2002). Thus, it is possible that participants required fewer attentional resources to perform the dot-probe due to familiarity with the task post-MBCT. One method of clarifying whether MBCT or practice-related effects were at the heart of this finding would be to include a control group, which the present study lacked.

3.4.2 P1 Threat-Related Attentional Bias Markers and Treatment Response

In the second aim, it was hypothesized that (1) MBCT would reduce anxiety and depression symptoms, (2) changes in early hypervigilance to threat, indexed by P1-Angry Cue amplitude changes, would be associated with changes in anxiety symptoms, and (3) changes in later avoidance of threat, indexed by P1-Angry Congruent Probe amplitude changes, would be associated with changes in both anxiety and depression symptoms. The reasoning behind these predictions was that hypervigilance to threat is common in anxiety disorders (Richards et al., 2014), whereas avoidance is common in both anxiety and depressive disorders (Trew, 2011).

In agreement with the first hypothesis, anxiety and depression symptoms were significantly reduced in the full sample following MBCT. In the virtual sample, however, only depression levels were significantly reduced post-MBCT; anxiety levels were reduced, but with

marginal significance. These findings are consistent with other studies which have shown that MBCT can reduce anxiety and depressive symptoms in adults with anxiety disorders (Craigie et al., 2008; Evans et al., 2008; Kim et al., 2009).

Contrary to the second and third hypotheses, in the full and virtual samples, P1-Angry Cue amplitude changes (indexing changes in early hypervigilance to threat) were not associated with anxiety symptom changes and P1-Angry Congruent Probe amplitude changes (indexing changes in later avoidance of threat) were not associated with anxiety and depression score changes. However, in both the full and virtual samples, 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 being displayed (Gupta et al., 2019). Williams, Watts, MacLeod, & Mathews (1988) propose 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 the threatening object more readily, ignore the potential threat, thereby reducing autonomic arousal, and decrease threat potential of incoming sensory information.

Interestingly, in the virtual sample only, there was also a significant effect of P1-Angry Cue amplitudes on depression scores such that higher P1-Cue amplitudes were associated with higher depression scores across both pre- and post-MBCT time points. This suggests that participants who displayed larger P1-Angry Cue amplitudes, indexing 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).

3.4.3 Exploratory Analyses

Exploratory analyses were performed on the C1-Cue, as a temporospatial factor combination resembling a C1-Cue consisting of an early negativity at 38 ms poststimulus over central occipital sites was previously observed (see **Chapter 2** and Gupta, Kujawa, & Vago (2021)). This component was enhanced for happy versus angry face pair cues, suggesting that enhanced, pre-attentive processing of happy faces and avoidance of angry faces occurs at the level of V1. However, in the present study, the C1-Cue did not appear to be sensitive to emotional faces in the full and virtual samples, and this pattern did not change post-MBCT. Indeed, C1-Cue dot-probe findings have been mixed (Gupta et al., 2019), and it has been shown that the C1 may not be a consistent measure of either early emotion-related neural activation arising from V1 or selective attention toward emotionally significant stimuli (Santesso et al., 2008). Interestingly, in the full sample only, there was a marginally significant effect of time on C1-Cue latencies such that C1-Cue latencies were increased post-MBCT compared to pre-MBCT.

Exploratory analyses were also performed on behavioral data to determine the effects of emotion and congruency on reaction times in the dot-probe task. In the full sample only, there was a main effect of time such that 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, the faster RTs could also stem from practice effects arising from familiarity with the task at post-testing. Again, inclusion of a control group would help clarify whether MBCT or practice-related effects were at the heart of this finding.

3.4.4 Limitations and Future Directions

This study has a number of limitations which should be acknowledged. First, as mentioned above, the present study lacks a comparison group. A future replication of this study should include a comparison group to clarify whether the reduction in P1-Probe amplitudes, anxiety and

depression scores, and RTs following MBCT specifically resulted from the intervention. However, the present results still suggest that MBCT is a promising intervention to decrease symptoms of anxiety and depression in anxious participants and improve engagement and disengagement capabilities leading to increased probe processing efficiency.

Second, the present study only examined early ERP markers of threat-related attentional bias (i.e., P1-Cue and P1-Probe) in anxious participants with no prior meditation experience. Thus, it is unclear whether MBCT-induced changes in threat-related bias occurred at later stages of processing. A systematic review by Chiesa, Calati, & Serretti (2011) suggests 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, Krompinger, & Baime, 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 alerting (Tang, Hölzel, & Posner, 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 Studies 1 and 2 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).

The lack of significant findings also brings into question whether changes in threat-related attentional bias are a key mechanism driving symptomatic improvements. Hölzel et al. (2011) suggests that mindfulness meditation may exert its effects through a variety of mechanisms, including attention regulation, body awareness, emotion regulation (including reappraisal and exposure, extinction, and reconsolidation), and change in perspective on the self. Several studies have demonstrated mindfulness-induced improvements in emotion regulation (Hölzel et al., 2011; Roemer, Williston, & Rollins, 2015), 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). Interestingly, Chiesa, Serretti, & Jakobsen (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).

Third, it appears that virtual MBCT may be less effective than in-person MBCT for decreasing anxiety symptoms. While anxiety symptoms were significantly reduced in the full sample, this reduction was only marginally significant 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 on Zoom. However, one major confound is that the virtual courses took place during the COVID-19 pandemic. As mentioned above, the pandemic has been associated with high rates of anxiety and depression (Hyland et al., 2020; Odriozola-González 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, as mentioned in the Methods, 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. Participants were also asked not to start individual psychotherapy or a regular meditation or yoga practice during the treatment study. However, due to unforeseen circumstances, some 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. It is unclear whether any of these changes affected the study outcomes.

3.5 Conclusion

The current study sought to determine whether an 8-week MBCT intervention can modify ERP markers of threat-related attentional bias in anxious populations, potentially reflecting reductions in threat-related attentional biases due to the mindfulness intervention, and also sought to investigate the relationship between P1 threat-related attentional bias markers and treatment response. Results suggest that MBCT (1) decreases attentional allocation to probes replacing emotional and neutral face cues by improving engagement and disengagement processes, thus leading to more efficient probe processing, (2) reduces symptoms of anxiety and depression, and (3) speeds up reaction times to probes, again reflecting more efficient responses to probes. Additionally, it was found that (4) participants displaying more attention and hypervigilance to angry face pair cues also had higher levels of anxiety. Overall, results highlight MBCT as a promising intervention to increase processing efficiency and decrease mood and internalizing symptoms in anxious populations.

CHAPTER 4: General Conclusions

Anxiety disorders are associated with threat-related attentional bias, defined as the preferential tendency to allocate attention toward or away from threatening stimuli. Attentional bias may prolong anxiety states by placing inordinate priority on potential threats in the environment, thus intensifying anxious mood states. Event-related potentials (ERPs) have been used to investigate the neural correlates and timing related to the processing of threat-related stimuli in attentional bias studies utilizing the dot-probe task. In the task, two cues (one emotional or threatening and the other neutral) are presented followed by a probe which appears in the location of one of the cues. Modulations of ERPs time-locked to cues and probes may reflect attentional biases occurring at early and later stages of information processing, respectively.

However, ERP components selected for examination and analysis in dot-probe studies vary widely and remain inconsistent. The first study (**Chapter 2**) used temporospatial principal component analysis (PCA) to systematically identify the timing and scalp distributions of ERPs elicited to cues and probes in a dot-probe task in adults with moderate to high levels of anxiety. Results highlighted three reliably elicited components that are of interest for future attentional bias research. One factor combination resembled a C1-Cue, consisting of an early negativity at 38 ms poststimulus over central occipital sites. The component was enhanced for happy versus angry face pair cues, suggesting that enhanced, pre-attentive processing of happy faces and avoidance of angry faces occurs at the level of V1. The subsequent factor combination resembled a P1-Cue, consisting of an early positivity at 86 ms over parieto-occipital sites. The component was also enhanced for happy versus angry face pair cues, indicating enhanced allocation of attention to the happy faces and avoidance from the angry faces. The final factor combination resembled a P2-Probe, consisting of an early positivity at 220 ms poststimulus over parieto-occipital sites. The component was enhanced for incongruent compared to congruent probes, which may reflect more elaborative processing and emotional evaluation of neutral, compared to emotional (angry and

happy), faces (i.e., attentional avoidance from the emotional faces). These results highlight the C1-Cue, P1-Cue, and P2-Probe as promising and reliable neurophysiological markers for attentional bias research and suggest that anxious adults display avoidance from angry face stimuli. It is recommended that future ERP attentional bias studies utilize PCA to systematically identify the timing and scalp distribution of ERPs elicited to task-related stimuli.

MBCT may be an acceptable and potentially effective treatment for reducing threat-related attentional biases and anxiety and mood symptoms, as the intervention teaches individuals to relate to thoughts and feelings as passing events in the mind rather than identifying with them or treating them as accurate readouts of reality. The PCA results from **Chapter 2** helped inform cue- and probe-locked components to examine in the second study (**Chapter 3**), which sought to (1) determine whether an 8-week MBCT intervention can modify ERP markers of threat-related attentional bias in anxious populations, potentially reflecting reductions in threat-related attentional biases due to the mindfulness intervention, and (2) investigate the relationship between ERP threat-related attentional bias markers and treatment response. The goal was to illuminate a potential physiological mechanism through which MBCT may target early and late stages of threat-related attentional bias and reduce symptoms of anxiety. Results suggest that MBCT (1) decreases attentional allocation to probes replacing emotional and neutral face cues by improving engagement and disengagement processes, thus leading to more efficient probe processing, (2) reduces symptoms of anxiety and depression, and (3) speeds up reaction times to probes, again reflecting more efficient responses to probes. Additionally, it was found that (4) participants displaying more attention and hypervigilance to angry face pair cues also had higher levels of anxiety. Overall, results highlight MBCT as a promising intervention to increase processing efficiency and decrease mood and internalizing symptoms in anxious populations.

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Tables

Table 1 (Study 1). Temporospatial factor combinations sensitive to face pair cues and probes.

Factor Combination	Variance (%)	Temporal Peak (ms)	Peak Electrode	Main Effect of Condition T_{WJt}/c (1.0, 22.0) (*p*)	Description
CUES					
TF5/SF3	0.55	38	Oz	Emotion: 6.90 (0.012)	Occipital negativity for happy v. angry face pair cues
TF3/SF1	7.78	86	PO4	Emotion: 4.96 (0.035)	Parieto-occipital positivity for happy v. angry face pair cues
PROBES					
TF4/SF3	1.18	220	PO4	Congruency: 5.75 (0.029)	Parieto-occipital positivity for incongruent v. congruent probes

Table 2 (Study 2). Sample characteristics for the in-person and virtual MBCT groups pre- and post-MBCT. Means and standard deviations (in parentheses) are listed. Asterisks represent p < .05.

	In-Person MBCT Group (*N* = 13)	**Virtual MBCT Group (*N* = 37)**	***t* or χ^2 value**	***p* value**
Demographics				
Age (years)	33.08 (7.74)	31.51 (9.15)	$t(48) = .55$	.59
Gender (% F)	85.00	76.00	$\chi^2(1) = .45$	.50
Race (%)	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)	0.00	5.41	$\chi^2(1) = .73$	.39
Pre-MBCT				
DASS-A	10.15 (8.31)	13.51 (8.72)	$t(48) = -1.21$	.23
DASS-D	21.08 (7.98)	17.03 (8.78)	$t(48) = 1.46$	.15
Post-MBCT				
DASS-A	4.62 (4.93)	10.49 (8.03)	$t(48) = -2.47$	.02*
DASS-D	9.54 (6.39)	10.32 (9.49)	$t(48) = -.28$	.78

Note: 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.

Figures

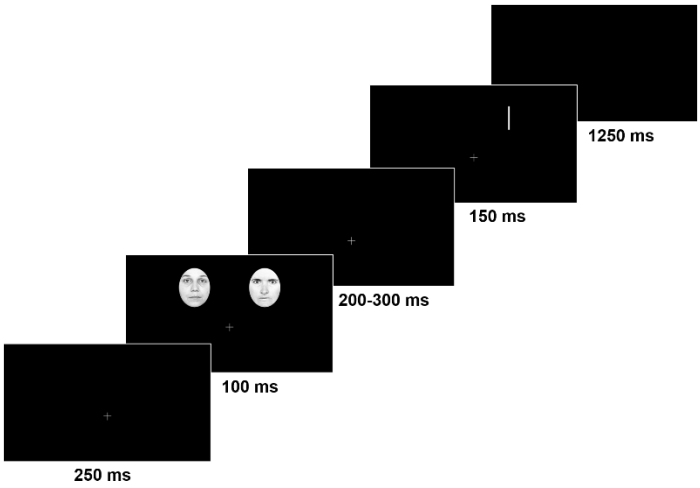
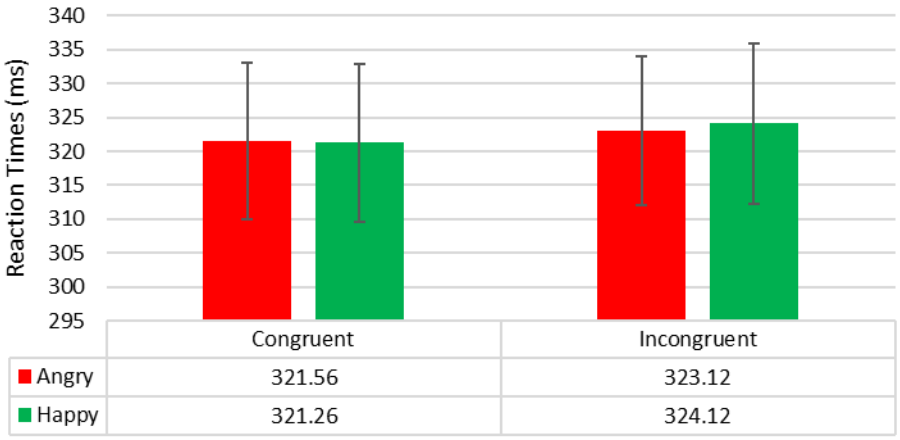


Figure 1 (Studies 1 & 2). Schematic of the dot-probe task.



	Congruent	Incongruent
Angry	321.56	323.12
Happy	321.26	324.12

Figure 2 (Study 1). Mean reaction times to probes as a function of emotion and congruency in the dot-probe task. Means are listed in the table and bars represent standard error of the mean.

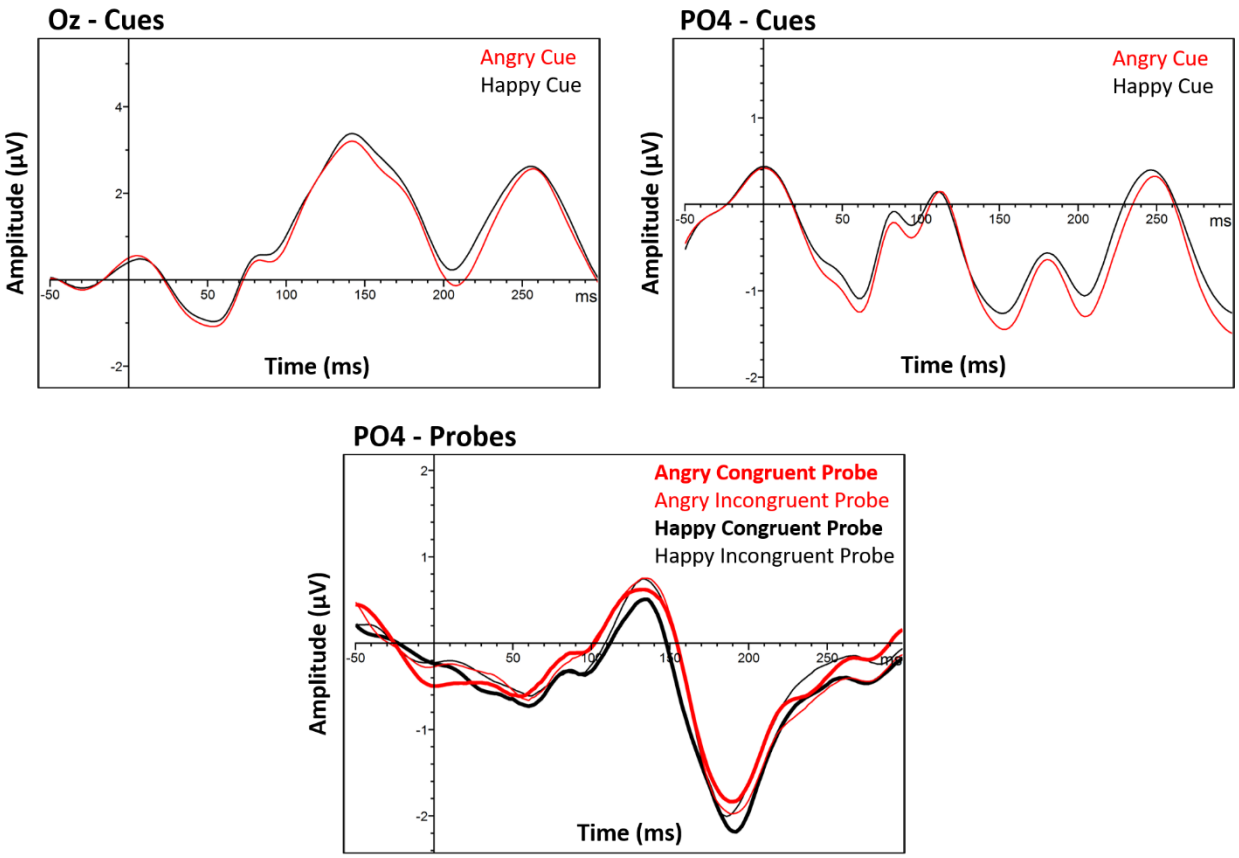


Figure 3 (Study 1). ERPs for angry and happy face pair cues at electrode sites Oz and PO4 and probes at electrode site PO4 prior to PCA.

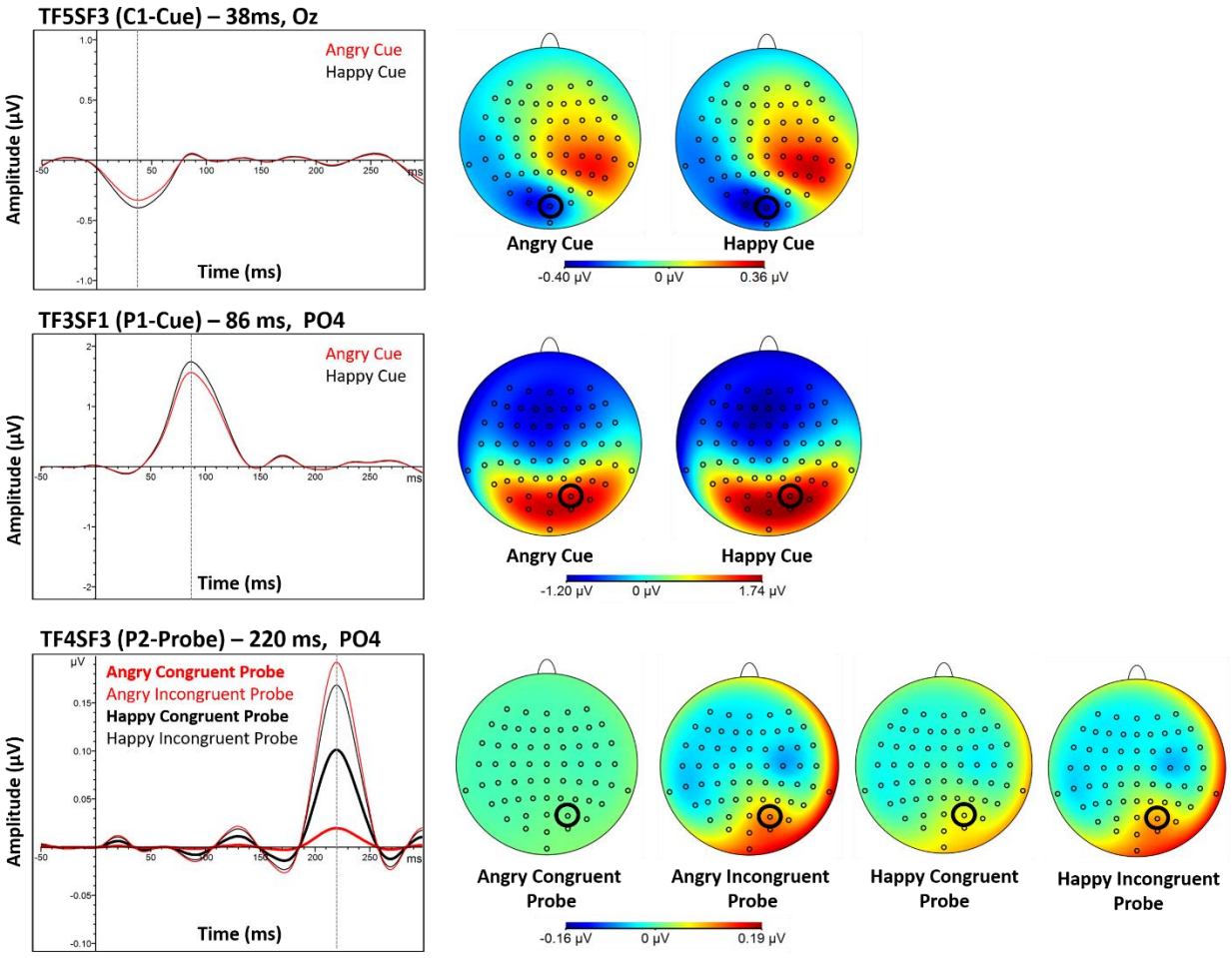


Figure 4 (Study 1). PCA temporospatial factor ERPs and scalp distributions for TF5/SF3 (C1-Cue), TF3/SF1 (P1-Cue), and TF4/SF3 (P2-Probe). Temporal peaks are indicated with dashed lines on the ERP waveform figures and peak electrodes are indicated with black circles on the scalp distribution figures.

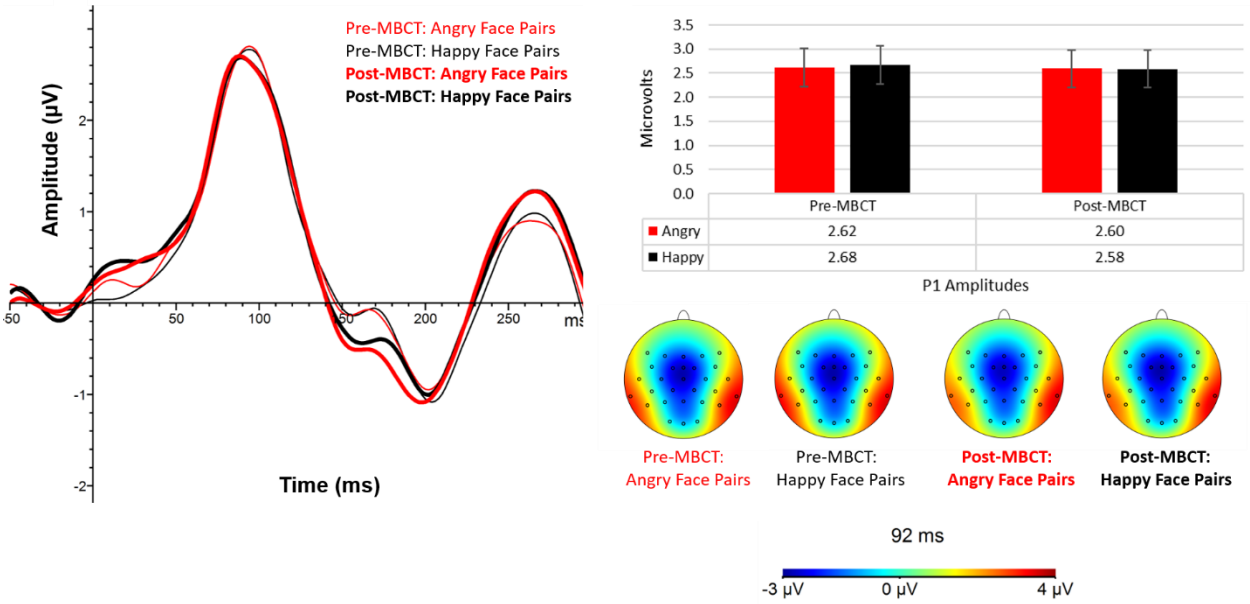


Figure 5 (Study 2). P1-Cue ERPs and scalp distributions for the full sample (*N* = 50). Left: Pre- and post-MBCT grand average ERP waveforms time-locked to the presentation of angry and happy face pair cues at electrode P8. Right: Mean P1 amplitude time-locked to angry and happy face pair cues (means are listed in the table and bars represent standard error of the mean) and scalp distribution figures for each condition at the approximate peak time point (92 ms).

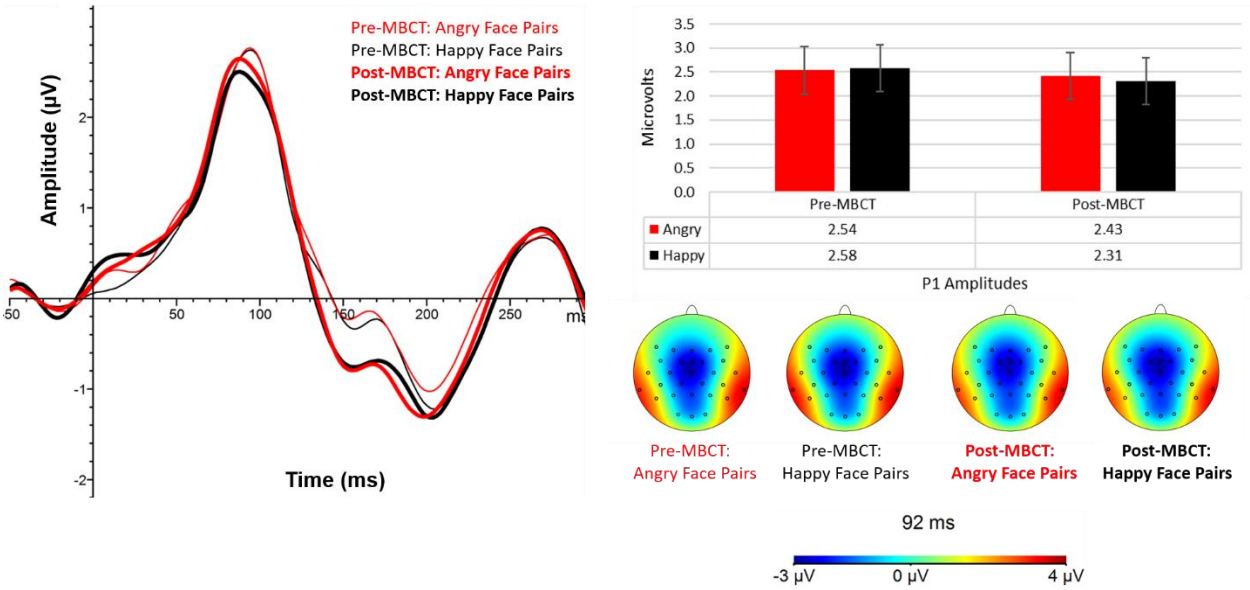


Figure 6 (Study 2). P1-Cue ERPs and scalp distributions for the virtual sample (*N* = 37). Left: Pre- and post-MBCT grand average ERP waveforms time-locked to the presentation of angry and happy face pair cues at electrode P8. Right: Mean P1 amplitude time-locked to angry and happy face pair cues (means are listed in the table and bars represent standard error of the mean) and scalp distribution figures for each condition at the approximate peak time point (92 ms).

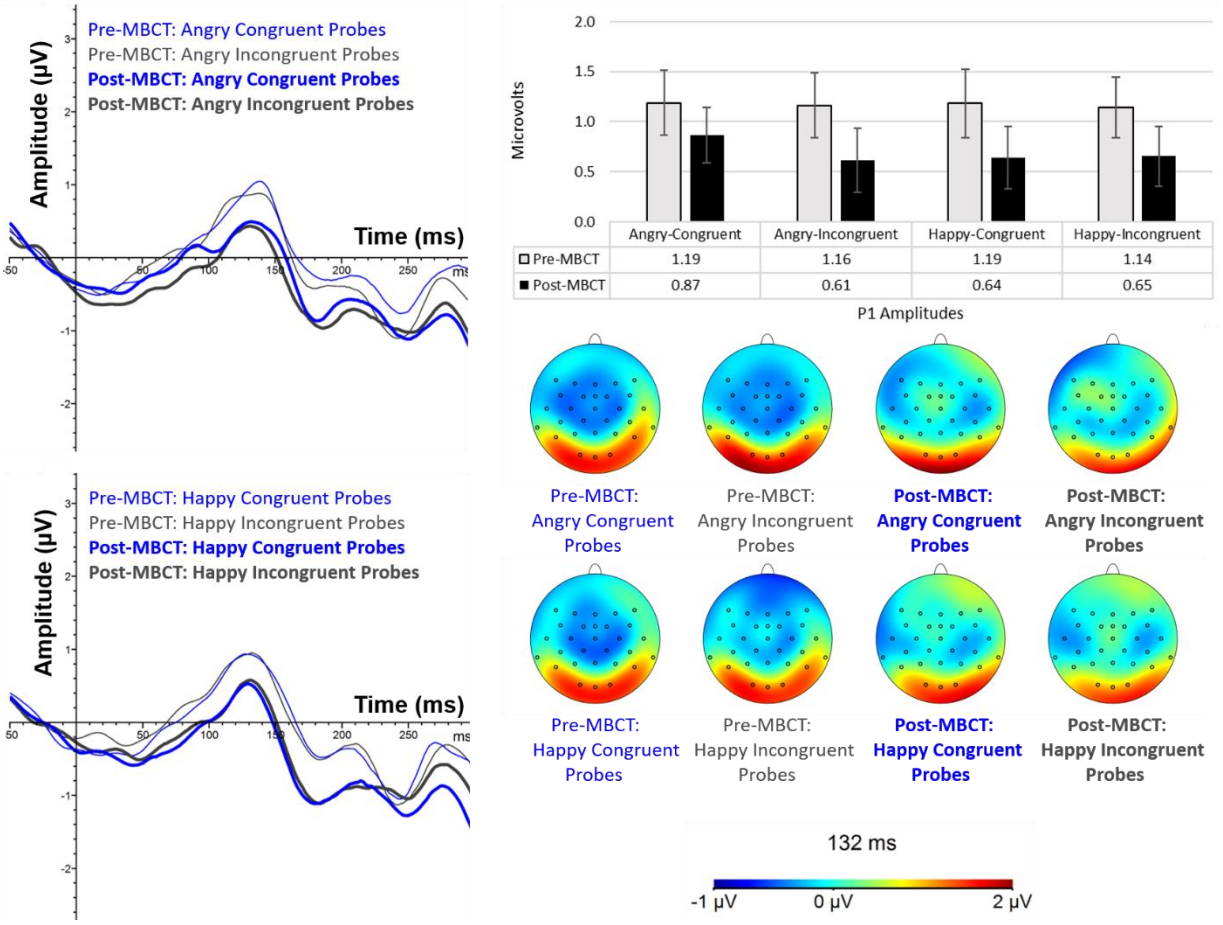


Figure 7 (Study 2). P1-Probe ERPs and scalp distributions for the full sample (*N* = 50). Left: Pre- and post-MBCT grand average ERP waveforms time-locked to the onset of angry congruent and angry incongruent probes (top) and happy congruent and happy incongruent probes (bottom) at electrode P8. Right: Mean P1-Probe amplitudes as a function of emotion (angry versus happy) and congruency (congruent versus incongruent) (means are listed in the table and bars represent standard error of the mean) and scalp distribution figures for each condition at the approximate peak time point (132 ms).

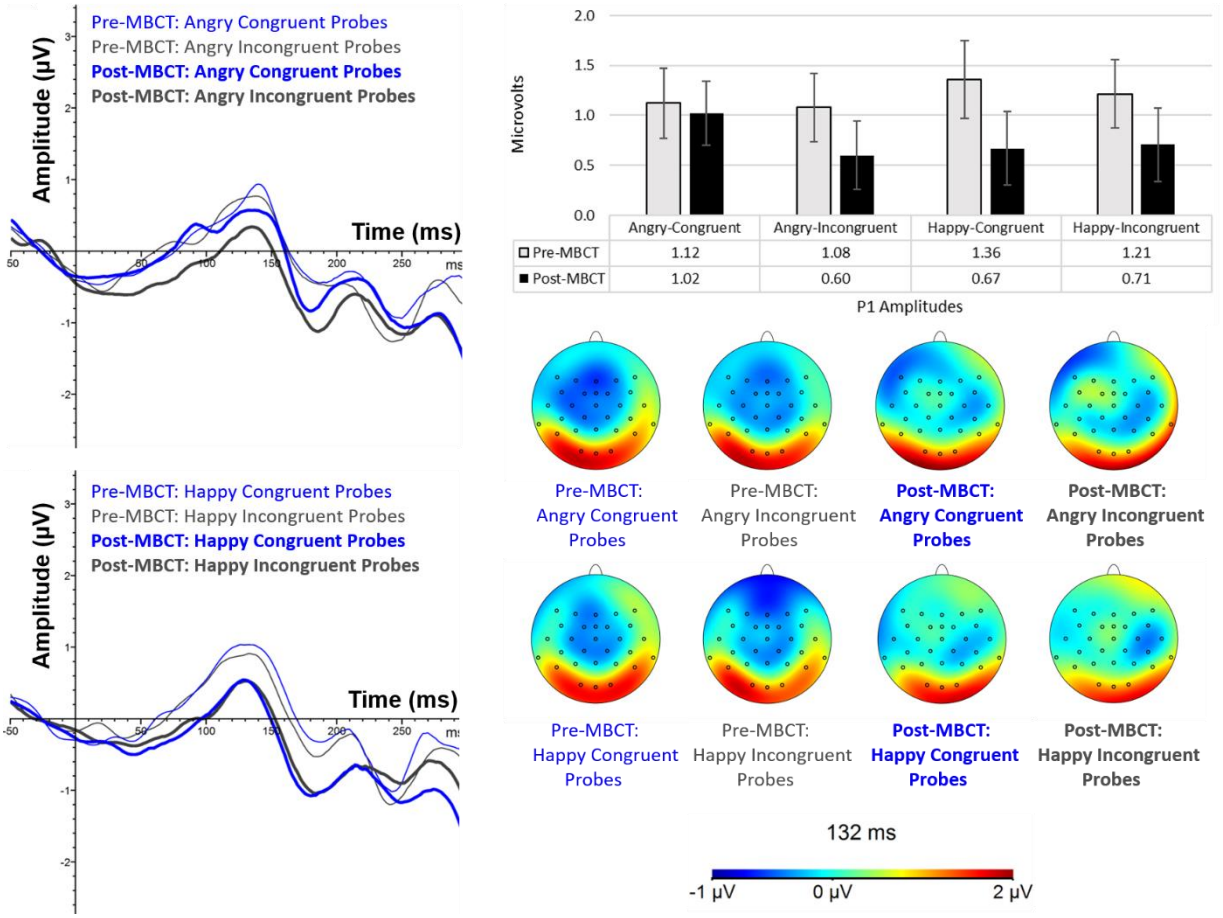


Figure 8 (Study 2). P1-Probe ERPs and scalp distributions for the virtual sample (*N* = 37). Left: Pre- and post-MBCT grand average ERP waveforms time-locked to the onset of angry congruent and angry incongruent probes (top) and happy congruent and happy incongruent probes (bottom) at electrode P8. Right: Mean P1-Probe amplitudes as a function of emotion (angry versus happy) and congruency (congruent versus incongruent) (means are listed in the table and bars represent standard error of the mean) and scalp distribution figures for each condition at the approximate peak time point (132 ms).

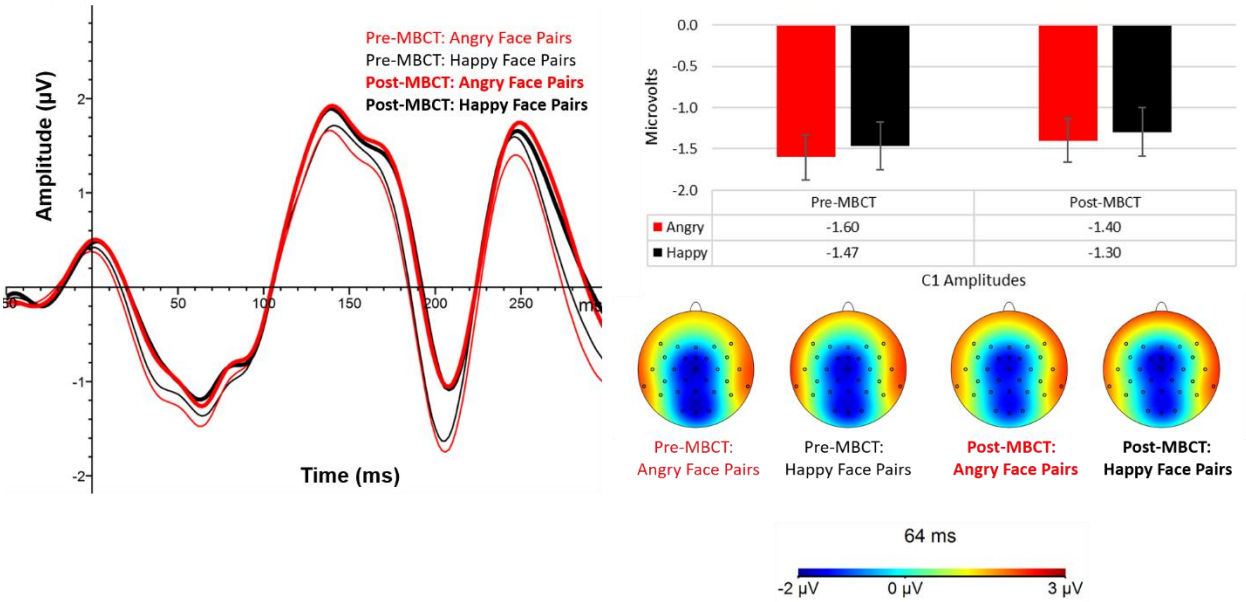


Figure 9 (Study 2). C1-Cue ERPs and scalp distributions for the full sample (*N* = 50). Left: Pre- and post-MBCT grand average ERP waveforms time-locked to the presentation of angry and happy face pair cues at electrode Oz. Right: Mean C1 amplitude time-locked to angry and happy face pair cues (means are listed in the table and bars represent standard error of the mean) and scalp distribution figures for each condition at the approximate peak time point (64 ms).

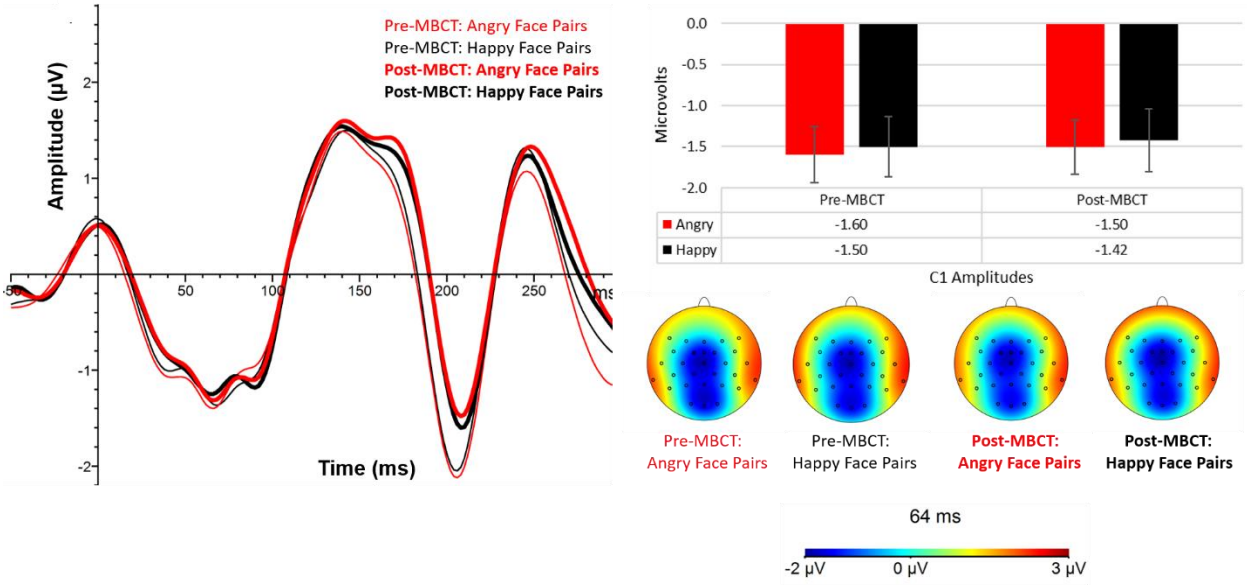
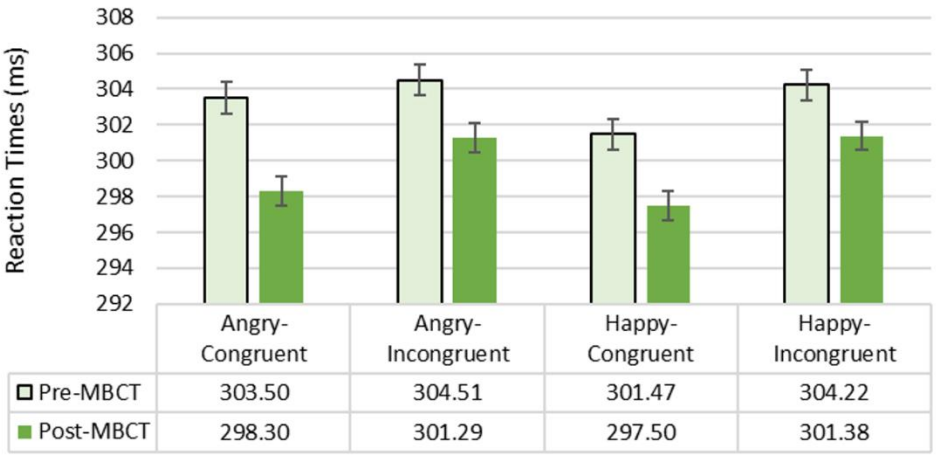
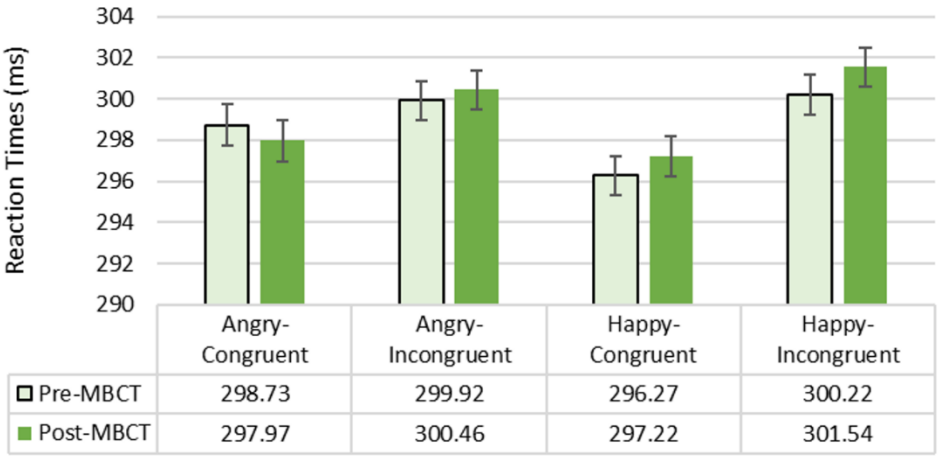


Figure 10 (Study 2). C1-Cue ERPs and scalp distributions for the virtual sample (*N* = 37). Left: Pre- and post-MBCT grand average ERP waveforms time-locked to the presentation of angry and happy face pair cues at electrode Oz. Right: Mean C1 amplitude time-locked to angry and happy face pair cues (means are listed in the table and bars represent standard error of the mean) and scalp distribution figures for each condition at the approximate peak time point (64 ms).



	Angry-Congruent	Angry-Incongruent	Happy-Congruent	Happy-Incongruent
Pre-MBCT	303.50	304.51	301.47	304.22
Post-MBCT	298.30	301.29	297.50	301.38

Figure 11 (Study 2). Mean reaction times to the probe as a function of emotion and congruency in the full sample (*N* = 50). Means are listed in the table and bars represent standard error of the mean.



	Angry-Congruent	Angry-Incongruent	Happy-Congruent	Happy-Incongruent
Pre-MBCT	298.73	299.92	296.27	300.22
Post-MBCT	297.97	300.46	297.22	301.54

Figure 12 (Study 2). Mean reaction times to the probe as a function of emotion and congruency in the virtual sample (*N* = 37). Means are listed in the table and bars represent standard error of the mean.