FROM SITTING TO LIVING: EXAMINING THE ROLE OF MEDITATION IN UNDERSTANDING THE EMOTION REGULATORY MECHANISMS OF MINDFULNESS

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ABSTRACT

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Mindfulness has received widespread interest for its purported benefits to emotional well-being. Despite a rapidly growing literature base supporting the salutary relationship between mindfulness and emotion regulation, little is known about how mindfulness confers its emotion regulatory benefits. A pertinent, yet underexplored, approach to addressing this question is to examine neural mechanisms involved in the effects of mindfulness training via meditative practice to “off-the-cushion” changes in emotion regulation. The primary aim of the present study was therefore to determine the extent to which change in neural oscillatory activity (i.e., alpha and theta power) during mindfulness meditation related to subjective (i.e., self-reported negative affect) and neural (i.e., late positive potential [LPP]) measures of emotional reactivity elicited during a subsequent affective picture viewing task. Toward this end, a multimodal experimental paradigm was employed to test three predictions: 1) participants randomized to engage in brief guided mindfulness meditation, relative to those randomized to a control condition, would exhibit increased alpha and theta power during meditation relative to rest; 2) participants in the meditation group, but not those in the control group, would exhibit attenuated LPP responses and report lower negative affect during the picture viewing task; 3) the predicted increases in alpha and theta power during meditation would correlate with the predicted reductions in the LPP and self-reported negative affect during picture viewing. Contrary to

expectations, the guided meditation did not produce demonstrable effects on alpha and theta power, the LPP, or self-reported negative affect relative to the control condition. Change in theta, but not alpha, power during meditation was, however, positively correlated with the early time window of the LPP, suggesting that change in neural activity during meditation may relate to subsequent emotion processing. Overall, the study demonstrated the utility of investigating the relationship between what occurs during mindfulness meditation and its purported effects on emotion regulation. Moreover, reflections on the unexpected nature of the null findings dovetail with the prevailing consensus that theoretical and methodological factors unique to the construct of mindfulness are integral in shaping the direction, design, and interpretability of mindfulness research.

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KEY TO ABBREVIATIONS

fMRI	Functional Magnetic Resonance Imaging
ERP	Event-Related Potential
LPP	Late Positive Potential
EEG	Electroencephalogram
IAPS	International Affective Picture System

INTRODUCTION

Originating from a 2500-year old Buddhist contemplative tradition, mindfulness has received increased interest from people around the world. Although definitions of mindfulness vary across time and context (Gethin, 2011), one of the most cited contemporary definitions of mindfulness refers to the adoption of a nonelaborative, nonjudgmental awareness to present-moment experience (Bishop et al., 2004; Kabat-Zinn, 1994). Perhaps driving its rising popularity, a rapidly growing body of research has shown that adoption and training of mindfulness (e.g., meditation), and possessing higher dispositional levels of mindfulness, are all related to a wide array of salutary effects (Baer, 2003; Brown & Ryan, 2003; Keng, Smoski, & Robins, 2011; Shapiro & Carlson, 2009). One well-documented benefit of mindfulness involves its benefits to emotional well-being. Despite lay and scientific consensus that mindfulness promotes healthy emotion regulation, little is known about *how* mindfulness confers its emotion regulatory effects. Research into this question is complicated by three factors. First, emotion regulation is conceptualized as a complex dynamic process that unfolds over time (Gross & Thompson, 2007; Sheppes & Gross, 2011). Consequently, mechanistic investigations on mindfulness-based emotion regulation may strongly benefit from employing methodologies with temporal sensitivity. Second, mindfulness is a multi-faceted construct differentiable as a state, trait, and mental training modality (Vago & Silbersweig, 2012; Van Dam et al., 2018). Moreover, mindfulness as mental training is itself varied, ranging from formal meditative practice to a panoply of experiential mind-body exercises (e.g., mindful raisin eating; Kabat-Zinn, 1990). This construct heterogeneity complicates operationalization and challenges the ability to draw meaningful inferences from experimental designs (e.g., discriminating the effects of state mindfulness from meditation). Third, one of the most perplexing and obvious challenges in mindfulness research involves understanding how mindfulness training, *specifically via meditative practice*, produces subjective changes to emotional well-being. Despite its importance, surprisingly few studies have systematically measured and tested how neural changes occurring during mindfulness meditation relate to "off-the-cushion" emotion regulation. The purpose of the current study was to address these challenges by elucidating a plausible mechanism that links meditative neural activity with emotional reactivity during a picture viewing task.

The Effects of Mindfulness on Emotion Regulation

Driven by its salutary benefits, the concept of mindfulness as a meditative practice has been integrated in a variety of efficacious psychotherapeutic interventions and is widely practiced by millions of Americans (Baer, 2003; Khoury et al., 2013; Clarke, Black, Stussman, Barnes, & Nahin, 2015). Despite accelerating scientific, medical, and public interest, surprisingly little is known about the means through which mindfulness meditation confers its psychological benefits. One explanatory mechanism involves the effects of mindfulness meditation on emotion regulation (Lutz, Slagter, Dunne, & Davidson, 2008; Chambers, Gullone, & Allen, 2009), a core self-regulatory ability involving modulation of the generation, experience, and expression of emotion (Gross, 1998); and is disrupted in many psychological disorders (Kring & Bachorowski, 1999; Repetti, Taylor, & Seeman, 2002; Aldao, Nolen-Hoeksema, & Schweizer, 2010).

Robust meta-analytic results support the emotion regulatory effects of mindfulness meditation in reducing negative emotionality, anxiety, and neuroticism (Sedlmeier et al., 2012; Eberth & Sedlmeier, 2012). Longitudinal mindfulness-based interventions, which combines didactic instruction with mindfulness meditation, have been shown to improve emotional well-being across diverse samples ranging from healthy students to clinical patients (see Keng et al., 2011 for a review). Experimental studies have also demonstrated that both brief and extended mindfulness meditation practice: (1) lowers the intensity and frequency of negative affect in response to negative situations (Broderick, 2005) and aversive stimuli (Arch & Craske, 2006; Erisman & Roemer, 2010); (2) decreases self-perceived difficulty in regulating emotions (Robins, Keng, Ekblad, & Brantley, 2012); and (3) reduces cognitive interference and autonomic reactivity to emotional stimuli (Ortner, Kilner, & Zelazo, 2007). Further, trait mindfulness has been shown to be robustly correlated with measures of emotional well-being (Brown & Ryan, 2003). Despite the emotional benefits associated with mindfulness (both as a meditative practice and dispositional trait), the neural mechanisms underlying its emotion regulatory properties remain poorly understood. Given that emotion regulation is an essential feature of mental health and normative functioning (Gross & Munoz, 1995), delineating the means through which mindfulness confers its salutary benefits is crucial for identifying novel therapeutic targets, streamlining effective interventions, and understanding the mind-brain relationship more broadly.

The Significance of Temporality

Research aimed at discerning the neural mechanisms of mindfulness-based emotion regulation has predominantly involved neuroimaging studies designed to identify pre-post changes in emotion processing brain activation patterns as a function of mindfulness training (commonly operationalized as mindfulness meditation in conjunction with didactic and experiential exercises; see Desbordes et al., 2012 for a sample protocol). Multiple studies have associated mindfulness training with increased prefrontal activation and reduced activation of the amygdala in response to emotional stimuli (Goldin & Gross, 2010; Allen et al., 2012; Desbordes et al., 2012; Lutz et al., 2014). Consequently, a popular working hypothesis is that mindfulness training promotes emotion regulation via strengthening prefrontal cognitive control mechanisms that down-regulate affective processing regions (Holzel et al., 2011; Tang, Holzel, & Posner, 2015). Interestingly, this frontal-limbic activation pattern shares significant overlap with the neural correlates of cognitive reappraisal, an emotion regulatory strategy involving semantic reinterpretation of emotional stimuli (Ochsner et al., 2004; Banks, Eddy, Angstadt,Nathan, & Phan, 2007; Opialla et al., 2014). Such similarities challenge theoretical models that clearly differentiate mindfulness-based emotion regulation (observation and acceptance of emotions without control or action) from cognitive “top-down” regulation strategies (antecedent-focused voluntary manipulation of input to the affect system; Chambers et al., 2009; Grabovac, Lau, & Willet, 2011; Lutz, Dunne, & Davidson, 2008). Adding further complexity, empirical support for the prefrontal control hypothesis has been equivocal. Holzel et al. (2013) found an unexpected shift in the relationship between prefrontal and limbic activation. Rather than the increased prefrontal activity corresponding to deceased limbic activity typically observed during top-down voluntary emotion regulation, Hozel et al. (2013) reported decreased prefrontal *and* limbic activity in participants after mindfulness training. This suggests that mindfulness training may promote monitoring of arousal rather than voluntary down-regulation, and introduces the possible involvement of implicit (i.e., non-voluntary) emotion regulatory processes. Moreover, activation of frontal-limbic regions is not reliably detected and has been reported more often in samples of beginning meditators relative to experienced meditators (Taylor et al., 2011).

These inconsistencies reflect a key limitation in this line of work—that although changes in regional brain activity have been associated with mindfulness training, little can be inferred about how such changes pertain to the actual *process* of emotion regulation. Given that emotion regulation is conceptualized as a dynamic process that involves modulation of arousal over time

(Gross & Thompson, 2007; Sheppes & Gross, 2011), the temporal constraints of fMRI preclude a precise time-sensitive mapping of brain activity during emotional responding. As previously alluded to, a pertinent question that pervades the literature involves the extent to which mindfulness training engenders implicit non-voluntary down-regulation of emotional arousal, or whether training promotes practitioners to voluntarily adopt a state of mindfulness as an active means of emotion regulation in subsequent tasks or situations. Indeed, the inability to discern differences between mindfulness-based emotion regulation and top-down regulation strategies at the neural spatial level has led some researchers to posit that meaningful insights may instead lie in the temporal domain (Opialla et al., 2014). Further, as Tang et al. (2015) contended, few studies of mindful emotion regulation have sought to relate neural activity with actual measures of emotional arousal. In other words, although fMRI studies have revealed promising leads demonstrating changes in emotion processing brain regions, it remains unclear exactly how mindfulness training modulates the intensity and duration of the emotional response.

One way to address this limitation is through using event-related potentials (ERPs), electrophysiological scalp signals that reflect event- or stimulus-locked neural activity with millisecond precision. Specifically, the visually evoked late positive potential (LPP), a centro-parietally maximal positive deflection that reaches peak amplitude 300-800 ms after the onset of emotional stimuli, is a well-studied ERP measure of emotional processing that has been employed in a variety of emotion regulation studies (see Schupp, Flaisch, Stockburger, & Junghofer, 2006; Hajcak, MacNamara, & Olvet, 2010 for reviews). The LPP is thought to index the motivational relevance of visual stimuli such that its amplitude increases with the arousal level of emotional stimuli (Cuthbert, Schupp, Bradley, Birbaumer, & Lang, 2000; Schupp et al., 2000; Keil et al., 2002; Hajcak, Weinberg, MacNamara, Foti, 2012). Early time windows (300-

1000 ms) of the LPP are thought to index bottom-up attention allocation (Olofsson, Nordin, Sequeira, & Polich, 2008), whereas later time windows (>1000 ms) have been shown to index semantic processing and meaning making (Foti & Hajcak, 2008; MacNamara, Foti, & Hajcak, 2009). Importantly, both early and late time windows are sensitive to various emotion regulation strategies (Moser, Hajcak, Bukay, & Simons, 2006; Moser, Krompinger, Dietz, & Simons, 2009; Moser, Hartwig, Moran, Jendrusina, & Kross, 2014; Thiruchselvam, Blechert, Sheppes, Rydstorm, & Gross, 2011), and have been shown to correlate with self-reported changes in emotional arousal (Hajcak & Nieuwenhuis, 2006).

Recent studies involving the LPP have yielded promising insights into the emotion regulatory properties of mindfulness. Mindfulness has been broadly associated with reduced LPP responses to negative emotionally evocative stimuli (Sobolewski, Holt, Kublik, & Wrobel, 2011; Brown, Goodman, & Inzlicht, 2013; Lin, Fisher, Roberts, & Moser, 2016). Sobolewski et al. (2011) employed a cross sectional design comparing experienced meditators to non-meditating controls, finding smaller LPPs elicited by negative stimuli in mediators relative to controls. Complimenting these findings, Brown et al. (2013) found that higher dispositional mindfulness corresponded to smaller LPP responses to both negative and positive high arousing stimuli, suggesting that trait mindfulness attenuates broadband emotion processing of motivationally salient stimuli. In an experimental study comparing brief mindfulness meditation with an active control, Lin et al. (2016) found that meditation prior to an affective picture viewing task produced a linear reduction in the difference between negative and neutral LPPs across time. Importantly, such temporal modulation of the LPP difference reflects two core characteristics of emotional reactivity, defined as the extent to which emotional arousal varies in intensity over time (Rothbart, & Derryberry, 1981): (1) *recovery time*, or the duration needed to return from maximum response to baseline; and (2) *duration of response,* or the time that responding stays above some reference threshold (Davidson, 1998, 2000). Critically, the ability to modulate emotional reactivity constitutes a core component of the multidimensional construct of emotion regulation (Gratz & Roemer, 2004; Shapero, Abramson, & Alloy, 2016). Further exemplifying the interrelated nature of emotional reactivity and emotion regulation, recent neuroscientific work has demonstrated that the hierarchical interplay between dissociable neural networks of emotional reactivity and regulation underlie changes in subjective emotional experience (Jacob, Gilam, Lin, Raz, & Hendler, 2018). Consequently, Lin and colleague's (2016) findings suggested that brief mindfulness meditation may promote emotion regulation via "online" attenuation of emotional reactivity to aversive negative events—as operationalized by temporal reductions in the difference in LPP amplitude between negative and neutral stimuli. Further, the observed attenuation of the LPP in meditating participants mirrored that of control participants with high dispositional mindfulness, suggesting that the emotion regulatory effects associated with trait mindfulness can be acquired through meditative practice. Critically, these findings converge to support the notion that both prolonged (Sobolewski et al., 2011) and brief (Lin et al., 2016) mindfulness meditation can engender trait-like attenuations in emotional reactivity (Slagter et al., 2011; Desbordes et al., 2012; Brown et al., 2013).

Operationalizing the Multiple Facets of Mindfulness

Collectively, these studies underscore the importance of approaching mindfulness as a multi-faceted construct (Vago & Silbersweig, 2012; Lin et al., 2016), showing that long-term meditative experience, brief meditation practice, and high trait mindfulness are all associated with reduced emotional reactivity. In particular, the distinction between mindfulness as a meditative practice and as an inducible state of mind is often unaccounted for in mindfulness-based emotion regulation studies—obfuscating the extent to which detected effects are attributable to meditation training or on-task engagement of state mindfulness. Exemplifying the utility of experimental ERP designs to answer prevailing questions about mindful emotion regulation, Lin et al. (2016) differentially operationalized mindfulness meditation and state mindfulness, finding that voluntary engagement in state mindfulness (i.e., instructing participants to view the emotional stimuli mindfully) did not produce demonstrable changes in emotional reactivity, nor did it moderate the effects of brief meditation. Instead, as previously mentioned, it was the practice of mindfulness meditation itself, that lead to subsequent decreases in emotional reactivity. In conjunction with Desbordes' et al. (2012) observation that participants assuming an ordinary non-mindful state after meditative training exhibited reduced amygdala activity to emotionally aversive stimuli, these findings show that meditation, but not necessarily voluntary engagement of state mindfulness, attenuates emotional reactivity. Indeed, mindfulness meditation in novice non-meditators appears to confer implicit emotion regulatory effects and does not appear to promote explicit emotion regulation involving voluntary antecedent- or response-focused strategies (see Gyurak, Gross, & Etkin, 2011 for a theoretical review on explicit vs. implicit emotion regulation). A critical implication of these findings is to shift investigative attention toward the role of meditative practice—specifically to the link between the neural processes that occur during mediation and the observed changes in emotion processing. In other words, it may be fruitful to extend the aforementioned line of electrophysiological research by examining the extent to which meditative neural changes relate to the emotion regulatory effects (i.e., reduced emotional reactivity) observed after meditation.

The Unique but Understudied Role of Meditative Practice

Multiple conceptual process models have theorized that the development of internally-directed nonreactive awareness during mindfulness meditation engenders its well-documented benefits to emotional well-being (Vago & Silbersweig, 2012; Holzel et al., 2011; Lutz et al., 2015). However, rigorous testing of these models is limited by the extent that psychological states can be measured during meditation. One potential solution involves measuring EEG neural oscillations—electrical scalp activity that occur at varying rhythmic frequencies. Synchronous oscillatory activity within specific ranges of frequency (i.e., frequency bands) have been shown to reliably correspond to a variety of psychological states and processes (Ward, 2003). Importantly, a substantive line of research aimed at exploring neural oscillatory activity during mindfulness meditation have detected increased activity (i.e., synchronization) in the alpha (8-13 Hz) and theta (4-8 Hz) frequency range. Critically, alpha and theta synchronization (also referred to as increased alpha and theta power) during meditation have been collectively thought to index internally-directed focused attention (see Cahn & Polich, 2006; Lomas, Ivtzan, & Fu, 2015 for reviews).

Although the functional significance of alpha oscillations has been subject to debate, one leading hypothesis implicates alpha synchronization in the engagement of internally-directed attention (Cooper, Croft, Dominey, Burgess, & Gruzelier, 2003; Ray & Cole, 1985; Shaw, 1996). Supporting this view, alpha synchronization has been detected in non-meditative tasks requiring memory, imagination, mental imagery, and inhibition of external stimulation (Jensen, Gelfand, Kounios, & Lisman, 2002; Cooper et al., 2003, Cooper, Burgess, Croft, & Gruzelier, 2006; Larson-Prior et al., 2011). Theta synchronization is widely thought to reflect a marker of executive attention, as increases in theta power have been detected during cognitive tasks involving sustained attention (Ishii et al., 1999), attention switching and orientation (Dietl, Dirlich, Vogl, Lechner, & Strian, 1999), memory encoding (Klimesch, 1997), and performance monitoring (Cavanagh, Cohen, & Allen, 2009).

Interestingly, the concurrent presence of alpha and theta synchronization during mindfulness meditation parallels the Theravada Buddhist perspective that development of concentrated internally-directed attention is vital to acquiring the cognitive and emotional benefits of meditation (Gunaratana, 2002). However, surprisingly few studies have sought to relate meditative neural activity (e.g., alpha and theta power) to dependent measures of emotion processing (e.g., self-reported emotional intensity, LPP etc.)—creating a "black box" on what might be a *fundamental* level of analysis toward understanding the emotion regulatory properties of mindfulness meditation.

Consequently, the purpose of the current study was to elucidate a plausible mechanism that links neural oscillatory activity during mindfulness meditation with "off-the-cushion" changes in emotion regulation. Adapting the experimental procedures described in Lin et al. (2016), novice non-meditators were randomly assigned to complete a guided audio mindfulness meditation or listen to a control audio (collectively referred to as audio induction) prior to completing an affective picture viewing task. Continuous EEG was recorded to measure alpha and theta power during the audio induction, and the LPP during the subsequent picture viewing task. Heeding the repeated calls to adopt a multimodal neuroscientific approach (Holzel et al., 2011; Vago & Silbersweig, 2012; Lutz et al., 2015; Tang et al., 2015), questionnaire measures of trait mindfulness, attention, and state affect were collected to link neurophysiological data with subjective self-report. Together, these measures were used to test the central hypothesis that changes in alpha and theta power during meditation relative to rest (henceforth referred to as meditative alpha and theta, respectively), reflecting engagement of internally-directed focused attention, relates to reduced online emotional reactivity to negative stimuli. It was predicted that: 1) meditation-naïve participants randomized to mindfulness meditation would exhibit increased alpha and theta power relative to control condition participants; 2) participants assigned to the meditation condition would exhibit less emotional reactivity indexed by reduced LPPs and self-reported negative affect; 3) the predicted increases in meditative alpha and theta were expected to correlate with the reductions in the LPP and self-reported negative affect. Confirming these predictions would provide compelling evidence that meditative-induced changes in alpha and theta contribute to reduced emotional reactivity across multiple levels of analysis.

METHOD

Participants

Two hundred twelve female students were recruited from Michigan State University's Human Participation in Research subject pool for course credit (see power analyses described in the 'Predictions and Analyses' section). An all-female sample was recruited to minimize experimental confounds related to gender, and to replicate the screening criteria of Lin et al. (2016). Importantly, previous studies have demonstrated that relative to men, women exhibit higher arousal and a greater LPP response to negative stimuli (Bradley, Codispoti, Sabatinelli, & Lang, 2001; Syrjanen & Wiens, 2013), employ different emotion regulatory strategies (McRae, Ochsner, Mauss, Gabrieli, & Gross 2008), exhibit larger effects of emotion regulation (Augustine & Hemenover, 2009; Webb, Miles, & Sheeran, 2012) and possibly respond differently to mindfulness meditation (de Vibe et al., 2013; Luders, Thompson, & Kurth, 2015). Furthermore, because women are more susceptible to mood and anxiety disorders (Seedat et al., 2009; McLean, Asnaani, Litz, & Hofmann, 2011) and are more likely to adopt a meditation practice (Barnes, Bloom, & Nahin, 2008), recruiting an all-female sample confers unique clinical and practical value.

Prospective participants were screened for history of neurological illness and meditation experience. All participants identified as novices, endorsing no prior meditative experience. Consented participants were randomized to either a meditation (n = 106) or control group (n = 106) involving different audio inductions. All participants were naïve to group assignments throughout the entire duration of the experiment. One participant was excluded from all analyses due to having a hairstyle that restricted EEG data collection. The remaining two hundred eleven participants (control: n = 106, meditation: n = 105) had useable data for at least one task of interest, comprising a final sample that ranged in age from 18 to 28 years old (*M* = 19.20, *SD* = 1.34). The majority of the sample identified as Caucasian/White (79.7%), the remaining participants identified as African American/Black (6.9%), Asian (2%), Latino/Hispanic (3.8%), Bi-Racial/Multi-Racial (2.8%), or Other (1.5%).

To maximize data retention, degrees of freedom varied across analyses based on excluded participants. One participant did not complete the questionnaire battery due to experimenter negligence. Six participants were removed from analyses involving the resting task: five to excessive artifacts (i.e., more than 50% of total segments) and one from loss of the data file. Three participants were removed from analyses involving the audio induction due to excessive artifacts. Nine participants were excluded from analyses involving picture viewing due to excessive artifacts that rendered fewer than 12 trials per valence condition (the minimum number of trials needed to maintain adequate reliability; see Moran, Jendrusina, Moser, 2013). Importantly, analyses involved a minimum of 94 participants per group and a maximum of 104 participants per group, exceeding the minimum sample size needed for adequate power (see 'Predictions & Analyses' section below).

Procedural Overview

Immediately after consenting, participants completed a brief self-report questionnaire on negative state affect (described in the 'Measures' section below). Upon completing the questionnaire, participants were fitted with an electrode cap for EEG recording. Continuous EEG was recorded during completion of three sequential tasks: (1) to measure baseline resting EEG as a means to account for individual differences in non-meditative alpha and theta activity, all participants were instructed to close their eyes and sit quietly for 5 minutes; (2) participants were then randomly assigned to complete a guided audio meditation exercise or listen to a control audio clip. To control for differences in EEG activity between eyes-closed and eyes-open conditions (Barry et al., 2007), participants were instructed to keep their eyes closed during the audio induction; (3) immediately following the induction, participants completed an affective picture viewing task. Upon finishing the EEG tasks, the equipment was removed and participants again completed the questionnaire on negative state affect, before completing a battery of self-report questionnaires, and a manipulation check measure (described in the 'Measures' section below). See Figure 2 for a visual flow diagram of the task procedures.

Tasks and Materials

Rest Condition. Participants were encouraged to sit relaxed with arms and legs in a comfortable position. Participants were then instructed to close their eyes and sit quietly after they heard a tone. After 5 minutes, participants heard the tone again to indicate the end of the task.

Audio Induction. The meditation induction was comprised of a 20-minute guided open monitoring (OM) meditation exercise led by Steve Hickman from the University of San Diego Center for Mindfulness (Hickman). An OM meditation, as opposed to focused attention (FA) meditation, was selected because of its unique emphasis on fostering nonreactive awareness of arising internal experience—an ability that has been theorized to engender emotion regulatory effects (Lutz et al., 2008; 2014; Perlman et al., 2010; Fox et al., 2016). The recording instructed participants to direct their attention inward, taking notice of present-moment feelings, thoughts, and physical sensations in an open, nonjudgmental manner. Listeners were directed to orient back to their breath when attention wavered.

The control condition involved an 18-minute audio recording of a TED talk by the linguist Chris Lonsdale (Lonsdale, 2013). The recording instructed participants how to quickly acquire second language fluency. Importantly, the clip was selected to match the duration, didactic style, gender, and speech of the guided meditation.

Picture Viewing Task. Stimuli included 60 pictures taken from the International Affective Picture System (IAPS; Lang et al., 2008). The images were selected and organized into two equal groups on valence and arousal ratings: 30 negative, high arousing pictures and 30 neutral, low arousing pictures. To maximize cross-study generalizability and replication, the images were identical to the ones presented in Lin et al. (2016). The stimuli were presented on a Pentium R Dual Core computer using E-Prime software (Psychology Software Tools, Inc., Sharpsburg, PA, USA) to control the timing and duration of the images. Each image was displayed in color on a 19'' flat-screen LCD monitor approximately 41'' from the participant.

On each trial, a white fixation cross (+) was presented at the center of the screen for 500 ms. A randomly selected image was displayed on the entire screen for 5000 ms. The inter-trial interval between image offset and fixation onset varied randomly between 2000-4000 ms. Presentation of the 60 non-repeating images were divided into three blocks of 20 trials, with each block containing 10 negative and 10 neutral images.

Self-Report Measures

Mindfulness. The 39-item Five-Factor Mindfulness Questionnaire (FFMQ; Baer et al., 2006), a psychometrically validated scale ($\alpha = .87$)[1] that differentiates dispositional mindfulness into five facets, was used to check for baseline differences in trait mindfulness between the experimental groups. Accounting for possible group differences in trait mindfulness is particularly important because high levels of trait mindfulness have been associated with reduced

[1] All reliability estimates were computed from the current sample.

emotional reactivity (Brown et al., 2013; Lin et al., 2016). The five factors include: (a) observing (α = .77), defined as noticing internal and external experiences; (b) describing (α = .81), defined as verbalization of internal experiences; (c) acting with awareness (α = .84), defined as attending to the present moment experience; (d) nonjudging (α = .88), defined as adopting a non-evaluative perspective toward thoughts and feelings; and (e) nonreactivity (α = .72), defined as allowing internal experiences to pass without attachment or elaboration. Participants responded to each item using a 5-point Likert scale ranging from 1 (*never* or *rarely true*) to 5 (*very often* or *always true*).

Negative State Affect. The negative affect subscale (NAS) of the Positive and Negative Affect Schedule (PANAS; Watson, Clark, & Tellegan, 1988) was used to measure state negative affect. Participants responded to each of the 10 items using a 5-point Likert scale (α = .83) ranging from 1 (v*ery slightly or not at all*) to 5 (*very much*), with higher scores indicating more distress and experience of a particular negative emotion. The NAS exhibits strong psychometric properties and correlates with other measures of psychological distress (Crawford & Henry, 2004). Participants were instructed to complete the NAS based on how they felt in the present moment. The NAS was completed twice: once at the start of the experiment (pre-NAS) and once immediately following picture viewing (post-NAS).

Attentional Control Scale. The Attentional Control Scale (ACS; Derryberry & Reed 2002) is a 20-question self-report measure of attention (α = .84) that separates attentional control into attentional focusing (α = .76) and attentional shifting (α = .77). Specifically, attentional focus refers to the ability to sustain attention while ignoring distractions; whereas, attentional shifting is the ability to redirect attention when attention wavers. Together, these abilities represent core aspects of attention, and are central to not only the practice of mindfulness meditation (Holzel et al., 2011), but also engagement and completion of the experimental procedures more generally. Therefore, accounting for attentional control is a necessary precaution against the possibility that groups may differ in attentional capacity to engage in the audio induction and subsequent study tasks.

Mini-International Personality Item Pool. The Mini-International Personality Item Pool (Mini-IPIP; Donnellan, Oswald, Baird, & Lucas, 2006) is a 20-item short form of the 50-item International Personality Item Pool—Five-Factor Model (Goldberg, 1999) designed to measure the Big Five personality traits: extraversion ($\alpha = .86$), neuroticism ($\alpha = .60$), agreeableness ($\alpha = .68$), conscientiousness ($\alpha = .72$), and openness ($\alpha = .77$). A recent meta-analysis demonstrated that although all five personality traits display appreciable relationships to mindfulness, the strongest relationship was found with neuroticism (Giluk, 2009). Indeed, neuroticism may be particularly important to account for given that it has also been associated with increased LPP amplitudes (Brown al., 2013) and differential use of emotion regulation strategies (Gross & John, 2003).

Manipulation Check. Directly replicating Lin et al. (2016), a post-session manipulation check questionnaire was used to assess for potential differences in participant engagement and reception to the experimental manipulation and picture viewing task. Participants rated the extent to which they found the audio induction engaging, interesting, and arousing (1 = *not at all*, 7 = *very*). Participants were also asked to indicate their level of comprehension (1 = *did not understand*, 7 = *completely understand*), emotional reaction (1 = *very negative*, 4 = *neutral*, 7 = *very positive*) and whether they learned anything (1 = *very little*, 7 = *very much*). For the picture viewing task, participants rated their overall engagement, interest, arousal (1 = *not at all*, 7=

very), and emotional reaction (1 = *very negative,* 4 = *neutral*, 7 = *very positive*). Specific degree of arousal (1 = *not at all*, 7 = *very*) to neutral and negative pictures was also assessed.

Sleepiness. Because of the well-established relationship between sleepiness and alpha synchronization, in addition to previous research showing that novice meditators are particularly susceptible to sleepiness and drowsiness during meditation (Britton, Lindahl, Cahn, Davis, & Goldman, 2014), participants were required to report their sleepiness (1 = *feeling active, vital, alert, or wide awake*, 8 = *I fell asleep*) across the 5-minute resting task, audio induction, and picture viewing task using the single-item Stanford Sleepiness Scale (Hoddes, Dement, & Zarcone, 1972).

Electrophysiological Recording and Data Reduction

Continuous EEG was recorded using active Ag/AgCl electrodes (BioSemi ActiveTwo) placed at the left and right mastoids and 64 scalp sites per the modified 10-20 system. Electrodes placed on the left and right mastoids served as a reference—the average activity of the mastoids was subtracted from each scalp site to isolate electrical scalp activity. To remove ocular artifacts from the EEG data, the electrooculogram (EOG) activity generated from eye movement and blinks was recorded from electrodes placed at the outer cathi of each eye, and above (at site FP1) and below the left eye. The common-mode sense active electrode and the driven right-leg passive electrode formed the ground during data acquisition. All signals were digitized at 1024 Hz.

Offline analyses were performed using Brain Vision Analyzer 2 (BrainProducts, Gilching, Germany). The EEG signals were re-referenced to the average of the left and right mastoids. Ocular artifacts were corrected using the algorithm developed by Gratton et al. (1983). All signals were low-pass filtered at 20 Hz and high-pass filtered at 0.01 Hz. An artifact rejection algorithm was applied to automatically reject trials and segments containing excessive movement, facial muscle activity, sweat, and other physiological artifacts based on the following criteria: a voltage step of more than 50 uV between sample points, a voltage difference of more than 400 uV within 200 ms intervals, voltage exceeding ±200 uV, and a maximum voltage difference of less than 0.50 uV within 1000 ms intervals.

Power Spectral Analysis

The EEG recorded during rest and the audio induction was partitioned into 2-second epochs. A fast Fourier transform (FFT), used to convert the data from the temporal to frequency domain, was then applied to all artifact-free epochs after the data was weighted with a hamming window that tapers the distal 10% of each epoch. Application of the hamming window smoothens signal discontinuity at the beginning and end of each epoch that arises as a function of segmentation. The data was then averaged across epochs and integrated spectral power was computed for the alpha (8-13 Hz) and theta (4-8 Hz) frequency bands. Following the regional division outlined in Lagopoulos et al. (2009), spectral power at each electrode site was averaged across 3 regions of interest (ROIs) across the scalp– frontal (F8, F6, F4, F2, Fz, F1, F3, F5, F7, AF8, AF4, AFz, AF3, AF7, Fp2, Fpz, Fp1, FT8, FC6, FC4, FC2, FCz, FC1, FC3, FC5, FT7), temporal-central (T8, C6, C4, C2, Cz, C1, C3, C5, T7, TP8, CP6, CP4, CP2, CPz, CP1, CP3, CP5, TP7), and posterior (P10, P8, P6, P4, P2, Pz, P1, P3, P5, P7, P9, PO8, PO4, POz, PO3, PO7, O2, Oz, O1, Iz). All values were log transformed to normalize their distribution. Difference values between the audio induction and rest were computed to capture within-subject changes in alpha and theta power.

Picture Viewing Analysis

For the picture viewing task, EEG epochs of 5200 ms (200 ms baseline) were extracted from the continuous data file for analysis. Consistent with prior work (Moser et al., 2014; Lin et al., 2016), the LPP was partitioned based on early and late time windows in order to examine the effects of the experimental manipulation on early automatic attention and later semantic processing, respectively. Adapting the parameters specified in Lin et al. (2016), the electrophysiological activity during the early window was termed the *early maximal LPP* and quantified as the average voltage across the 500-900 ms time window (±200 ms from which the LPP was maximally positive [700 ms]). The late window response was termed the *late sustained LPP* and quantified as the average voltage across successive 1000 ms time windows ranging from 1000 to 5000 ms post-stimulus onset. The LPP was calculated at the electrode site Pz, where its amplitude was maximal.

Predictions

1. **There would be no baseline group differences in measures of trait mindfulness, attentional control, negative state affect, Big Five personality traits, and sleepiness across the tasks; participant responses to the manipulation check will replicate Lin et al. (2016)**. FFMQ, ACS scores, pre-NAS, Mini-IPIP, and sleepiness ratings were submitted to independent-samples t-tests with Group (meditation, control) as a between-subject variable. No group differences in dispositional mindfulness, attentional control, negative state affect, Big Five personality traits, and sleepiness were expected. Given that the task procedures and manipulation check items were identical to Lin et al. (2016), manipulation check responses were expected to replicate Lin and colleagues' findings. Namely, that participants would rate the control audio to

be more interesting and endorse learning more relative to the guided meditation. Other ratings on the manipulation check were not expected to differ by group.

2. **Alpha and theta power would increase during the audio induction relative to rest for meditation participants but not controls.** Log-transformed alpha and theta values were subjected to two separate 2 Task (audio, rest) X 3 ROI (frontal, temporal-central, posterior) repeated measures ANOVAs (rANOVAs) with Group (meditation, control) as a between-subject factor. Based on prior research (see Lomas et al., 2015 for a review), a significant Task X Group interaction was expected such that both alpha and theta were predicted to uniquely increase during the audio induction from rest in the meditation relative to control group. Because regional differences in meditative alpha and theta vary across studies (Aftanas & Golocheikine, 2001; Ahani et al., 2014; Lagopoulos et al., 2009; Takahashi et al., 2005), no specific predictions regarding interactions involving ROI were made. However, only regions exhibiting significant changes in meditative alpha and theta were included in subsequent analyses. Independent-sample t-tests were also used to directly compare the log-transformed band power between the audio inductions (i.e., alpha and theta power during meditation vs. control). It was expected that meditating participants would exhibit greater alpha and theta power relative to non-meditating controls. A power analysis using an aggregate effect size (d = .93 for alpha, d = 1.21 for theta) from previous studies involving novice meditators (Ahani et al., 2014; Takahashi et al., 2005; Yu et al., 2011; Kubota et al., 2001; Chan et al., 2008) indicated that a minimum sample of 12 participants was needed to detect the within-subject increase in alpha power between meditation and rest with a power of .80. However, because the current study involved an active control group, a power analysis using a conservative effect size estimate of d = .30 indicated that a

minimum sample of 90 total participants was needed to detect the predicted interaction with a power of .80.

3. **There would be reduced LPP responses and lower ratings of negative state affect in the meditation but not control group.** The primary LPP analysis consisted of two rANOVAs. The early maximal LPP was submitted to a 2 Valence (negative, neutral) one-factor rANOVA with Group (meditation, control) as a between-subject factor. The late sustained LPP was submitted to a 2 Valence (negative, neutral) X 4 Time (1000-2000, 2000-3000, 3000-4000, 4000-5000 ms) rANOVA with Group (meditation, control) as a between-subject factor. Main and interactive effects involving Time and Valence were analyzed using within-subject contrasts. Greenhouse-Geisser corrections were applied to *p*-values associated with multiple *df* repeated measures comparisons when appropriate. Based on previous work (Lin et al., 2016), the manipulation was not expected to modulate the early maximal LPP. However, given that the early maximal LPP is negatively correlated with trait mindfulness and meditation experience (Brown et al., 2013; Lin et al., 2016; Sobolewski et al., 2011), it was possible that the increased sample size of the current study could reveal early LPP attenuation in the meditation relative to the control group. Seeking to replicate Lin et al. (2016), it was predicted that there would be a significant Time x Valence x Group interaction, such that the difference in LPP amplitude by valence would decrease linearly over time for the meditation but not control group. Similarly, the difference between post- and pre-NAS was expected to be lower in the meditation group relative to controls. A power analysis using the Lin et al. (2016) effect size (d = .46) indicated that a sample of 48 total participants (24 per group) was needed to detect this effect with a power of .80.

4. **Meditative alpha and theta power would relate to the reductions in LPP and self-reported negative affect.** In the meditation group, the predicted increases in meditative alpha and theta (prediction 2) were expected to relate to smaller differences between the LPP response to negative and neutral stimuli (prediction 3). Increases in meditative alpha and theta were likewise predicted to relate to smaller differences between post- and pre- NAS. Importantly, these relationships should be evidenced in only the meditation but not control group via a Fisher r-to-z test of independent correlations. This would demonstrate that meditative-induced changes in alpha and theta power relate to the attenuation of emotion reactivity. Due to the novelty of this analysis (to my knowledge, no study has examined relationships between meditative neural oscillatory activity with measures of emotional arousal), a power analysis using a medium effect size estimate (q = .37) suggested that a sample of 188 participants (94 per group) was needed to detect the proposed effect with a power of .80. Because this analysis required the most participants, a total of 188 participants were selected as the target sample size. Given that previous studies relating alpha power with measures of emotional arousal (self-report arousal: Balconi et al., 2009; self-report arousal and LPP: Poole & Gable, 2014) yielded an aggregate effect size of r = .47, the effect estimate was a relatively conservative approximation.

In response to widely cited issues regarding the inclusion of difference scores in data analysis, computation of difference values (subtraction-based differences between two conditions) in EEG and other neural measures (e.g., fMRI) is a fundamental step in isolating processes of interest (see Luck, 2014 for a full explication). Moreover, correlating difference values with other neural or self-report measures is a standard method of analysis (see Angus et al., 2015; Cheng, Chen, & Decety, 2014; Weinberg et al., 2016; Franken et al., 2008; Dennis & Hajcak et al., 2009; Lin et al., 2016; Liu et al., 2014 for select examples involving ERPs). With regards to reliability concerns, only 12 trials are needed to reach high reliability ($\alpha > .7$) for the LPP difference between negative and neutral responses (Moran, Jendrusina, Moser, 2013). Moreover, although no study has computed the reliability of meditative alpha or theta, as few as 100 2*s* epochs of data are needed to reach very high reliability ($\alpha > .9$) for alpha frontal asymmetry (Towers & Allen, 2009)—a similar spectral power difference measure computed as the difference in alpha power between the right and left hemisphere. Together, the current task design (i.e., 30 trials of picture viewing, ~20 minutes of audio data) far exceeded the minimums stated above, addressing statistical concerns related to reliability and the analysis of difference values more broadly.

Secondary exploratory analyses focused on examining the relationship between meditative neural oscillatory activity and self-reported trait measures of mindfulness and attention. Despite implicit consensus surrounding the functional significance of meditative alpha and theta, surprisingly, few, if any studies have deliberately sought to test their validity. In seeking to address this gap in the literature, it stands to reason that if meditative alpha is an index of attending inward in the present moment, and theta is an index of focused non-elaborative attention, then both measures should positively correlate with the acting with awareness subscale of the FFMQ (FFMQ-AA, defined as the propensity to attend to the present) and the attentional focus subscale of the ACS (ACS-F, defined as the capacity to intentionally sustain concentration on desired targets or processes), respectively. That is, individuals with high self-reported trait mindful awareness and attentional focus were expected to exhibit larger increases in alpha and theta power during meditation relative to rest. However, it is also possible that high trait mindful awareness and attentional focus correspond to greater resting alpha and theta, thus limiting the magnitude of change between meditation and rest.

RESULTS

Baseline Trait Measures, NAS, Manipulation Check, and Sleepiness

Descriptive statistics of questionnaire measures and manipulation check responses by group are presented in Tables 1 and 2, respectively. With the exception of a marginal difference in Big Five openness[2] (controls: $M = 3.83$, $SD = .70$, meditation: $M = 3.63$, $SD = .79$; $t(1, 208) = 1.91$, $p = .06$), there were no group differences in dispositional mindfulness (five factors, overall), attentional control (focus, shift, overall), the other four Big Five personality traits (extraversion, agreeableness, conscientiousness, neuroticism), or pre-experiment negative affect (ts < |1.59|, ps > .11).

Replicating Lin et al. (2016), independent-samples t-tests comparing participant responses to the audio recording revealed group differences in interest ($t(1, 208) = 4.31$, $p < .01$), and learning ($t(1, 208) = 3.65$, $p < .01$), such that participants who listened to the control audio rated the induction as more interesting (controls: $M = 4.54$, $SD = 1.63$, meditation: $M = 3.56$, $SD = 1.66$), and endorsed learning more (controls: $M = 4.65$, $SD = 1.39$, meditation: $M = 3.52$, $SD = 1.41$). The groups also differed marginally in emotional reaction ($t(1, 208) = 1.99$, $p = .05$), such that participants reacted more positively to the control audio ($M = 4.76$, $SD = 1.00$) than the guided meditation ($M = 4.48$, $SD = 1.01$). Importantly, there were no differences in engagement, arousal, or understanding (ts < |1.59|, ps > .11), suggesting that participants approached the inductions with equal levels of engagement and comprehension. Comparing participant responses to the picture viewing task yielded no group differences. Specifically, there were no differences in engagement, interest, arousal, and overall emotional reaction (ts < |1.05|, ps > .13).

[2] Confirming the lack of a priori reasoning implicating openness as a potential confounding variable, exploratory analyses showed that Mini-IPIP openness did not relate to any of the dependent variables of interest (i.e., meditative alpha and theta, early and late LPP) across the control (rs < |.13|, ps > .21) and meditation (rs < |.12, ps> .25) groups.

Lastly, comparing participant ratings of sleepiness across tasks yielded a group difference during only the audio induction ($t(1, 208) = -2.77$, $p < .01$), such that participants reported higher levels of sleepiness during the guided meditation ($M = 4.35$, $SD = 1.48$) relative to the control audio ($M = 3.79$, $SD = 1.42$). Sleepiness did not differ between groups during the rest or picture viewing task (*t*s < |1.40|, *p*s > .16).

Alpha & Theta Power During Rest and Audio Induction

Descriptive statistics of alpha and theta values are presented in Table 3. To check for baseline differences in resting state alpha and theta power, log-transformed alpha and theta values across ROI (frontal, temporal-central, posterior) were submitted to a one-way ANOVA with Group as a between-subject factor. As expected, no group differences emerged across any region for alpha or theta power (*F*s < 2.40, *p*s > .12).

Alpha. Consistent with the literature comparing alpha power during rest relative to active situations, a main effect of Task emerged ($F(1, 200) = 104.65$, $p < .01$, $\eta^2_p = .34$), such that alpha power, collapsed across sites, was greater during rest ($M = .71$, $SD = .25$) than audio induction ($M = .64$, $SD = .24$, $t(201) = 10.25$, $p < .01$). There was also a main effect of ROI ($F(1.31, 261.46) = 439.12$, $p < .01$, $\eta^2_p = .69$), such that, irrespective of task, alpha power increased linearly from frontal to posterior regions of the scalp ($F(1, 200)_{linXlin} = 471.57$ $p < .01$, $\eta^2_p = .70$, see Table 3 for mean values). These main effects were qualified by a significant Task X ROI interaction ($F(1.49, 298.76) = 140.82$, $p < .01$, $\eta^2_p = .41$), such that the effect of ROI was greater during rest relative to audio induction (i.e., the magnitude of alpha power increase from frontal to posterior regions was larger during rest than audio induction; $F(1, 200)_{linXlin} = 174.92$, $p < .01$, $\eta^2_p = .47$). Critically, there were no significant interactions involving Group (*F*s < .66, *p*s > .42).

Similarly, the independent-samples t-tests comparing alpha power between meditation and control audio without accounting for rest did not yield significant group differences across any region (*t*s < |.86|, *p*s > .39).

Theta. Again consistent with a multitude of past studies showing increased theta during more cognitively demanding tasks relative to rest, an expected main effect of Task emerged ($F(1, 200) = 1740.69$, $p < .01$, $\eta_p^2 = .90$), such that theta power, collapsed across sites, was greater during the audio induction ($M = .70$, $SD = .12$) than rest ($M = .50$, $SD = .08$, $t(201) = 41.71$, $p < .01$). There was also a main effect of ROI ($F(1.29, 258.19) = 13.56$, $p < .01$, $\eta_p^2 = .06$), such that, collapsing across task, theta power was greatest at the frontal ($M = .61$, $SD = .10$) region relative to both temporal-central ($M = .59$, $SD = .10$; $t(201) = 4.62$, $p < .01$) and posterior ($M = .59$, $SD = .10$; $t(201) = 3.72$, $p < .01$) regions; whereas theta power at temporal-central and posterior regions did not differ ($t(201) = 1.23$, $p = .22$). These main effects were qualified by a significant Task X ROI interaction ($F(1.26, 252.41) = 56.52$, $p < .01$, $\eta_p^2 = .22$), such that whereas theta power differed across all regions during the audio induction (*t*s > |2.78|, *p*s < .01; highest at the frontal region [$M = .713$, $SD = .13$], followed by temporal-central [$M = .694$, $SD = .13$], and posterior [$M = .687$, $SD = .13$], respectively), theta power did not differ by region during the rest task (*t*s < |1.26|, *p*s > .21). Again, there were no significant interactions involving Group (*F*s < 1.35, *p*s > .25). Independent samples t-tests comparing theta power between meditation and control audio without accounting for rest did not yield significant group differences across any region (*t*s < |.37|, *p*s > .71).

Effects of Audio Induction on LPP and NAS Ratings

Grand averaged ERP waveforms across all participants are presented in Figure 3. ERP waveforms and amplitudes across the two experimental conditions are presented in Figure 4 and Table 4, respectively.

Early Maximal LPP. As expected, a main effect of Valence emerged ($F(1, 199) = 348.76$, $p < .01$, , $\eta^2_p = .64$), such that negative stimuli elicited larger LPP amplitudes ($M = 7.26$, $SD = 6.64$) than neutral stimuli ($M = -.19$, $SD = 5.61$). Consistent with Lin et al. (2016), there was no significant Valence X Group interaction ($F(1, 199) = .87$, $p = .35$, $\eta^2_p < .01$).

Late Sustained LPP. For the late sustained LPP, there were main effects of Valence ($F(1, 199) = 39.93$, $p < .01$, $\eta^2_p = .17$) and Time ($F(1.54, 305.95) = 47.68$, $p < .01$, $\eta^2_p = .19$), such that the LPP was more positive for negative stimuli, but reduced in positivity linearly over time irrespective of stimulus valence ($F(1, 199)_{\text{lin}} = 57.93$, $p < .01$, $\eta^2_p = .23$). These main effects were qualified by a Time X Valence interaction ($F(1.59, 317.22) = 5.55$, $p = < .01$, $\eta^2_p = .03$), such that the difference in LPP amplitude by stimulus valence diminished linearly over time ($F(1, 199)_{\text{linXlin}} = 6.79$, $p = .01$, $\eta^2_p = .03$; see Figure 3). Unexpectedly, there was no Time X Valence X Group interaction ($F(1.59, 317.22) = .90$, $p = .39$, $\eta^2_p = .01$), suggesting that the guided meditation did not differentially modulate the late sustained LPP. Other interactions involving Group were likewise insignificant (Fs < 1.09, ps > .30).

NAS Ratings. Comparing pre- and post-experiment NAS ratings across the entire sample revealed an increase in NAS ratings over time (pre-NAS: $M = 11.93$, $SD = 3.02$, post-NAS: $M = 15.56$, $SD = 5.70$, $t(209) = 11.35$, $p < .01$). However, neither the post-NAS ratings ($t(208) =

|1.41|, *p* = .25), nor post-pre difference score (*t*(208) = |1.50|, *p* = .14) differed by group. See Table 1 for descriptive statistics.

Relationships among Alpha & Theta Power and Self-Report Measures

Alpha. Meditative alpha, across all regions, was not related to either the early (*r*s < .16, *p*s > .11) or late sustained LPP (*r*s < .08, *p*s > .43) As expected, no significant correlations emerged in the control condition (early LPP: *r*s < |.14|, *p*s >.18; late sustained LPP: *r*s < |.05|, *p*s > .65).

NAS difference ratings were significantly correlated with meditative alpha at frontal (*r* = .24, *p* = .02) and posterior (*r* = .23, *p* = .02), but not the temporal-central (*r* = .17, *p* = .10) sites. Visual inspection of the scatter plots (see Figure 5), however, suggested the presence of outliers. Removing two participants with extreme NAS values (-11, 27) rendered all correlations non-significant (frontal: *r* = .14, *p* = .16, temporal-central: *r* = .09, *p* = .38, posterior: *r* = .13, *p* = .21).

Unexpectedly, NAS difference ratings were significantly correlated with control audio alpha at temporal-central (*r* = .26, *p* < .01) and posterior (*r* = .33, *p* < .01), but not frontal (*r* = .17, *p* = .10) sites, suggesting that participants exhibiting higher alpha during the control audio relative to rest reported more negative affect from pre- to post- experiment. Visual inspection of the scatterplots did not suggest the presence of outliers (see Figure 5). As a precaution, removing the participant with the extreme NAS value (-11) reduced the magnitude of all correlations but did not alter their statistical significance (frontal: *r* = .08, *p* = .42, temporal-central: *r* = .20, *p* = .05, posterior: *r* = .26, *p* = .01). Comparing the correlations (both with and without removal of outliers) between groups using Fisher r-to-z transformations did not yield significant differences across any of the three regions (zs < |1.21| *p*s > .23).

FFMQ-AA, and ACS-F did not relate to meditative or control audio alpha across any region (*r*s < |.15|, *p*s > .13). See Table 5 for full correlation tables.

Theta. Unexpectedly, meditative theta exhibited significant *positive* correlations with the early LPP across all three regions (frontal: $r = .28$, $p < .01$; temporal-central: $r = .27$, $p < .01$; posterior: $r = .27$, $p < .01$), such that higher meditative theta was associated with a larger negative-neutral difference in the early LPP response. Meditative theta was also marginally correlated with the late sustained LPP across frontal ($r = .19$, $p = .06$), temporal-central ($r = .19$, $r = .06$), and posterior sites ($r = .20$, $p = .05$); higher meditative theta was associated with a larger negative-neutral difference in the late sustained LPP. In contrast, no significant correlations emerged in the control condition (early LPP: *r*s < .07, *p*s > .50; late sustained LPP: *r*s < .11, *p*s > .30). See Figures 6 and 7 for scatterplots. Comparing correlations between groups using Fisher r-to-z transformations yielded trending but non-significant differences for the early LPP (frontal: $z = |1.67|$, $p = .09$, temporal-central: $z = |1.48|$, $p = .14$, posterior: $z = |1.41|$, $p = .16$), and no difference for the late sustained LPP (frontal: $z = |.84|$, $p = .40$, temporal-central: $z = |.62|$, $p = .53$, posterior: $z = |.64|$, $p = .52$) across the three regions.

NAS difference ratings did not relate to meditative or control audio theta across any region (*r*s < .16, *p*s > .11). Likewise, FFMQ-AA, and ACS-F did not relate to meditative or control audio theta across any region (*r*s < |.08|, *p*s > .44). See Table 5 for full correlation tables.

DISCUSSION

The present study sought to advance understanding of the emotion regulatory effects of mindfulness meditation. Specifically, it aimed to discern whether brain changes occurring during meditation reflect mechanisms through which mindfulness meditation confers its "off-the-cushion" benefits to emotion regulation in daily life. Toward this end, the study leveraged a multimodal experimental approach adapted from Lin et al. (2016) to test three predictions: 1) participants who engaged in guided mindfulness meditation would uniquely exhibit increases in neural activity (alpha and theta power) during meditation relative to rest; 2) meditation would produce less emotional reactivity (LPP) and self-reported negative affect (NAS ratings); 3) the predicted changes in meditative neural activity would correlate with the predicted reductions in the emotion measures.

Main Analyses and Predicted Outcomes

Regarding the first prediction, the guided meditation did not produce demonstrable differences in alpha or theta power relative to the control audio. This null finding is inconsistent with Lomas and colleagues' (2015) conclusion—namely, that mindfulness meditation uniquely produces increased alpha and theta power relative to rest. The absence of this effect in the current study could be explained by three prescriptive factors of consideration noted in critical reviews of contemplative science (Vago & Silbersweig, 2012; Van Dam et al., 2018): meditation experience, training duration, and meditative technique. Indeed, the ability to detect change in meditative neural oscillatory activity may depend on the meditation experience of the sample, and or the frequency and duration of meditative training. From Lomas and colleagues' (2015) meta-analysis, only three of twelve studies reporting increased meditative alpha (Milz, Faber, Lehmann, & Pascual-Marqui, 2014; Takahashi et al., 2005; Yu et al., 2011) and three of fourteen studies reporting increased meditative theta (Kubota et al., 2001; Takahashi et al., 2005; Tanaka et al., 2014) were comprised of novices completing a single session of meditation; the rest involved advanced practitioners or repeated weeks-long training intervals. Although this pattern of findings does not conclusively demonstrate the *absence* of a relationship between mindfulness meditation and enhanced alpha and theta power, the possibility that the design parameters of the current study (i.e., one session of meditation with novice participants) may have been insufficient to modulate meditative alpha and theta is nonetheless a parsimonious consideration.

A related methodological implication is that very few studies to date have compared within-subject changes in meditative oscillatory activity to an active control group (none of the novice studies cited above employed controls; but see Baijal & Srinivasan, 2010 for a controlled study involving experienced meditators), challenging the extent to which reported changes reflect unique properties of meditation or, as the current findings suggest, reflect non-meditative components of the task (e.g., listening to and following instruction with eyes closed). In light of this, terminologies that are intended to characterize change during meditation relative to baseline or control conditions (including the terms 'meditative alpha' and 'meditative theta' used herein) may be misnomers given the potentiality for the implicit and misleading connotation that what is being described (e.g., change alpha and theta power from rest to induction) is *unique* to meditation. In line with the repeated calls to improve precision and clarity surrounding terms and concepts related to mindfulness, it may be prudent to exercise caution when creating terms for measures, changes, or groups (e.g., referring to novice non-meditators randomized to meditation as 'meditators') that are designated to distinguish meditation from other conditions.

Moreover, nuanced but potentially meaningful differences in meditation technique may influence meditative alpha and theta power. Strikingly, all but *one* of the aforementioned studies reporting increased meditative alpha and theta in novice practitioners involved a variant of breath focused meditation (Milz et al., 2014; Kubota et al., 2001; Takahashi et al., 2005; Yu et al., 2011). Explicit instructions to monitor the breath via counting or biofeedback manipulation, as opposed to open attendance to arising experience (as instructed in the current OM meditation), may preferentially recruit performance monitoring of attention—a process that is reliably known to elicit alpha and theta synchronization (Clayton, Yeung, & Kadosh, 2015; Cooper et al., 2003). Because breath monitoring is conceptualized as a form of FA meditation (Lutz et al., 2008; Lee, Kulubya, Goldin, Goodarzi, & Girgis, 2018; Lippelt, Hommel, & Colzato, 2014), our null finding appears consistent with the growing consensus that although FA and OM meditation are often subsumed under the term mindfulness meditation, each involve unique neural and functional properties (Lippelt et al., 2014).

Lastly, to my knowledge, no studies have systematically examined the test-retest properties of meditative alpha and theta, raising the additional possibility that poor reliability may have contributed to the null finding. Investigation into the psychometric properties of meditative EEG measures appears much needed as scientific interest continues to grow (Lee et al., 2018). Taken together, future studies are encouraged to clarify the considerations expounded here by examining the extent to which meditation experience, training duration, and technical variation modulates alpha and theta activity relative to matched control conditions. Given that experienced practitioners of OM style meditation (e.g., Vipassana) have shown increased trait levels of resting alpha and theta power relative to novices (Kakumanu et al., 2018), one particularly intriguing question involves whether repeated OM meditation training would produce increased resting alpha and theta synchronization over time.

Concerning the second prediction, neither the early nor late sustained LPP differed by experimental condition. The absence of early LPP modulation replicated Lin et al. (2016) and is consistent with another brief mindfulness intervention study (Eddy, Brunye, Tower-Richard, Mahoney, & Taylor, 2015). The current finding, derived from the largest sample size to date, strongly supports the prevailing notion that a single-session mindfulness intervention is insufficient to modulate bottom-up attentional mechanisms during early emotion processing (Eddy et al., 2015; Lin et al., 2016; Olofsson et al., 2008; Hajcak et al., 2012). The question remains, however, whether prolonged OM meditation training can modulate the early LPP. Although cross-sectional studies involving experienced meditators report smaller early LPP responses relative to novices (Reva, Pavlov, Loktev, Korenyok, & Aftanas, 2014; Sobolewski et al., 2011), longitudinal studies are needed to corroborate the assumption that extensive mindfulness training attenuates the early LPP.

In contrast to the prediction that the guided meditation, but not control audio, would attenuate the late sustained LPP (as in Lin et al., 2016), the current study found late LPP attenuation across the whole sample (i.e., collapsed across both groups). Given that numerous studies have reported late LPP attenuation almost exclusively in experimental conditions involving some form of emotion regulation (see Hajcak et al., 2010 for a review), the finding of a "main effect" without a qualifying group interaction is particularly puzzling. Moreover, modulation of the late LPP is unlikely to occur by chance. In fact, sustained difference in the LPP response between negative and neutral stimuli have been shown to persist over time, even after repeated exposure (Codispoti et al., 2006; Ferrari et al., 2011). With the exception of comparing mindfulness to other emotion regulation strategies (e.g., cognitive reappraisal), no other electrophysiological studies on mindfulness and emotion processing has failed to differentiate LPP attenuation between active and control condition (Brown et al., 2013; Eddy et al., 2015, Lin et al., 2016; Reva et al., 2014; Uusberg, Uusberg, Talpsep, & Paavar, 2016). One explanation involves the addition of the rest task prior to completing the audio induction. It may be that the resting task in conjunction with the audio inductions engendered boredom or restlessness that altered motivated attention during the LPP task. This suggestion, while in line with Lang and Bradley's (2010) theoretical postulation linking LPP amplitude with attention and motivational significance, is highly speculative. Another related but more data-driven possibility involves the group difference in audio induction sleepiness. The increased sleepiness engendered by the guided meditation may have impeded participants from engaging in the meditation, and in turn confounded the effect and associated statistical power to detect group differences. This possibility receives further consideration below (see 'Baseline & Manipulation Check Findings').

Regarding the third prediction, meditative theta, but not alpha, exhibited moderate and marginal positive correlations to the early and late sustained LPP, respectively. Specifically, participants with higher meditative theta, across all three scalp regions, exhibited larger LPP responses. Comparing the correlations across group revealed trending differences for the early LPP but not the late sustained LPP. Despite the lack of statistical significance, the fact that the analyses were preplanned, coupled with the observation that the magnitude of the correlations were remarkably stable across all scalp regions, suggests that the relationship between meditative theta and the early LPP is, at least, worth further elaboration.

Curiously, the directionality of the relationship is surprising and seemingly inconsistent with the extant literature. Given that mindfulness meditation has been associated with increased theta power and reduced emotional reactivity, it stood to reason that enhanced meditative theta would relate to a reduced, *not* enhanced LPP response. Upon further consideration, however, this expectation may be premature. As previously discussed, studies involving novice practitioners reporting enhanced meditative theta have primarily utilized breath-oriented FA meditations. The reported theta synchronization during FA meditation may reflect the recruitment of sustained attention and cognitive control during counting or active breath monitoring (Clayton, Yeung, & Kadosh, 2015; Nigbur, Ivanova, & Sturmer, 2011). In this light, enhancement of theta power during FA meditation appears to functionally reflect the cultivation of concentration, rather than the fostering of nonreactive awareness typically associated with OM meditation (Lutz et al., 2008). Consequently, because the current study utilized an OM meditation and did not observe a unique increase in meditative theta (over and above that of the control condition), the functional significance of meditative theta as an individual difference measure is unclear. With that said, the subsequent interpretations of the meditative theta-early LPP relationship is exploratory, not intended to provide explanatory inferences, but to stimulate future research.

On one hand, if enhanced meditative theta broadly indexes focused attention (Cahn & Polich, 2006; Lomas et al., 2015), then participants with relatively lower meditative theta may be characterized as more distractible or drowsy. Therefore, the attenuated LPP observed in participants with low meditative theta could reflect a broadband reduction in vigilance, which in turn reduced motivated attention to the stimuli (Ferrari, Codispoti, Cardinale, & Bradley, 2008; Hajcak, Dunning, & Foti, 2009; Lang & Bradley, 2010). In support of this possibility, several studies have demonstrated that states of distraction or fatigue reduce early LPP amplitudes and other related ERPs of attention (Kato, Endo, & Kizuka, 2009; Paul, Simon, Kniesche, Kathmann, & Endrass, 2013; Thiruchselvam et al., 2011).

On the other hand, relatively greater levels of meditative theta could reflect increased mind wandering, a near ubiquitous experience of first-time meditators (Brandmeyer, & Delorme, 2018; Britton et al., 2014). Indeed, enhanced theta power has been observed during both self-detected states and objective markers of mind wandering (Braboszcz, Delorme, 2010; Qin, Perdoni, & He, 2011). Of particular relevance, a recent study found that novice meditators did not show dissociable levels of theta power between meditation and mind wandering, whereas advanced practitioners exhibited enhanced theta power during meditation relative to mind wandering (Brandmeyer, Delorme, 2018). From this perspective, the positive correlation between meditative theta and the LPP could reflect the extent to which proclivity to mind wander corresponded to larger LPPs. Supporting this view, mind wandering is distinct from distraction (Unsworth & McMillan, 2014), and has been shown to elicit negative affect and enhanced physiological arousal (Killingsworth & Gilbert, 2010; Ruby, Smallwood, Engen, & Singer, 2013; Smallwood et al., 2007)—effects that are known to amplify the LPP response (Yuan et al., 2014). Relatedly, if greater meditative theta reflects mind wandering, then lower meditative theta (in first-time OM meditators) may reflect the opposite, a state of nonelaborative awareness. Although far from parsimonious, this speculation is in line with extant theoretical models of mindful emotion regulation postulating that engagement in nonelaborative experiential awareness (a distinguishing feature of OM meditation) ameliorates emotional reactivity to aversive stimuli (see Chambers et al., 2009 for a review).

Exploratory Analyses and Ancillary Findings

Further complicating these considerations, meditative theta (and alpha) did not relate to trait attentional focus or mindful awareness. Because enhanced meditative theta and alpha is most often and consistently observed in advanced meditators rather than novices (Cahn & Polich, 2006; Lomas et al.,2015), their respective relationship to theoretically relevant trait constructs may, too, vary as a function of meditative experience. Multiple prescriptive critiques have cautioned that similar or even identical measures may reflect different latent constructs and or underlying neural processes depending on the meditation expertise of the sample (Davidson & Dahl, 2018; Grossman, 2011; Holzel et al., 2011; Vago & Silbersweig, 2012; Van Dam et al., 2018). Speaking directly to the design of the current study, there may be little reason to expect that meditative theta and alpha recorded in first-time meditators should relate to attentional focus or mindful awareness. It appears more plausible that the relationships between meditative oscillatory activity (i.e., what is occurring during meditation) and trait abilities cultivated through meditation itself (i.e., what is being trained during meditation) would develop only after extended meditation training. This possibility is consistent with Cahn & Polichs' (2006) conclusion that state changes in meditative oscillatory activity is likely to manifest as trait level changes with continued practice.

Toward this end, one fruitful area of future research involves elucidating the role of meditative experience in modulating the functional significance of meditative neural oscillatory activity. Such research will help clarify the nature of potential relationships between meditative oscillatory activity and dependent measures of interest (e.g., the aforementioned relationship between meditative theta and the early LPP). A valuable first step may be to determine whether relationships between meditative neural oscillatory activity (e.g., theta) and measures of theoretically relevant constructs (e.g., attentional focus) are dissociable between advanced practitioners and novices. Later studies could utilize longitudinal approaches to delineate the extent to which such relationships change along the continuum of training experience. Such research may yield critical insights for discerning the neural mechanisms of mindfulness meditation—elucidating how essential factors such as meditation experience, style, and training influence the functional significance of meditative oscillatory activity and its impact on psychological functioning more broadly.

Lastly, NAS ratings increased from pre- to post-experiment across the whole sample. Contrary to predictions, there were no group differences in post NAS ratings or the pre-post difference. The global increase in NAS ratings may reflect the design of the study, such that participants were instructed to rate their affect after exposure to a series of highly negative arousing images that are known to induce transient negative affect (Wiswede, Munte, Goschke, Russeler, 2009). Contrary to expectations, the guided meditation did not decrease self-reported negative affect. The most parsimonious explanation is that the guided meditation did not affect emotion processing in ways that altered subjective appraisal of affect. This interpretation is consistent with the null finding regarding the LPP. To the extent that the LPP corresponds to subjective emotional arousal (Hajcak & Nieuwenhuis, 2006), the NAS ratings mirror the absence of a meditation effect on the LPP response. Another possibility is that the NAS lacked the sensitivity to detect group differences. A confounding variable related to the study procedures (e.g., physical discomfort, boredom) may have masked or superseded the effect of the experimental manipulation. Put more simply, it is unknown whether the global increase in NAS ratings is a direct function of picture viewing or a reflection of "ancillary" distress associated with the demands and length of the session more broadly. To circumvent this potential issue, future studies may consider employing arousal measures after the presentation of each image (e.g., Hajcak & Nieuwenhuis, 2006).

NAS difference ratings did not correlate with meditative alpha or theta. Given that meditative alpha also did not correlate with the LPP, it may be reasonable to conclude that under the parameters of the current study, meditative alpha is unrelated to emotion processing. As discussed above, however, it is unknown whether the relationship between meditative alpha and emotion processing would differ as a function of meditation expertise or extended mindfulness training. That meditative theta did not relate to NAS ratings, despite correlating with both the early and late LPP, warranted additional consideration.

As prefaced above, although the LPP and NAS can be broadly construed as measures of emotion, there is little reason to assume equivalency. There are marked differences in the specific utilization and associated properties of each measure. For example, the NAS was administered before and after the completion of multiple tasks (i.e., rest, audio induction, picture viewing), whereas the LPP is an aggregated measure of the response after every trial of the picture viewing task. Consequently, differences in sampling frequency and durational proximity to the guided meditation may have contributed to the differential relationship to meditative theta.

Second, the NAS and LPP constitute different levels of analysis, the former categorized as a subjective self-report measure, whereas the latter, a neurophysiological ERP measure. It is perhaps less surprising that meditative theta related to the LPP—both EEG measures—but not the NAS because of their respective shared and unshared assessment modality. Indeed, multimodal measures of a particular construct do not necessarily relate to each other and often exhibit differential relationships to other measures (Brenner, Beauchaine, & Sylvers, 2005). In psychophysiology, inconsistency between self-report and neurophysiological measures are relatively common, and among many interpretations, could reflect meaningful differences between implicit automatic processes and subjective appraisal (Amodio, Harmon-Jones, & Devine, 2003; Gavazzeni, Wiens, & Fischer, 2008).

Unexpectedly, control audio alpha at temporal-central and posterior regions were positively correlated with NAS ratings, such that participants with higher control audio alpha reported more increase in negative affect. However, because the correlations did not statistically differ from the meditation group, discussion of this interesting but unpredicted relationship is purely speculative. Temporal-central and posterior alpha activity have broadly been implicated in attention processing. Specifically, alpha synchronization has been linked to attention inhibition and reduced cortical excitability, whereas alpha desynchronization has been shown to facilitate selective attention and increased cortical excitability (Klimesch, 2012; Mathewson et al., 2014). Given that the instructions for the audio induction explicitly demanded attentional engagement, it is reasonable to expect (and find) alpha suppression during the audio relative to rest (i.e., lower control audio alpha). Therefore, *larger* control audio alpha values may broadly capture states of inattention, disinterest, or low arousal. Taken together, the alpha-NAS correlation may reflect the extent of contrast in arousal before and after picture viewing, such that the experience of viewing high arousing negative pictures from a state of low arousal or vigilance may have engendered more distress. Interestingly, the degree of experiential contrast has been implicated in emotion disturbance and theorized as a maintenance factor for generalized anxiety disorder (Newman & Llera, 2011). Despite support from the literature, this interpretation is wholly speculative and is not based on any *a priori* line of reasoning. Again, the correlations were unpredicted and modest in magnitude. Replication is needed before any additional considerations can be made.

Baseline and Manipulation Check Findings

In addition to addressing the main and exploratory aims of the study, baseline and manipulation check measures were analyzed to ensure experimental validity and identify potential confounds. As expected, comparison of trait and state measures showed no group differences in dispositional mindfulness, attentional control, Big Five personality traits, and pre-experiment negative affect—minimizing the possibility that baseline differences confounded the experiment. Analysis of the manipulation check confirmed a near exact replication of Lin et al. (2016): Participants rated the control audio as more interesting, and endorsed learning more than the guided meditation, but reported no differences in engagement, arousal, or understanding. The only item that differed from Lin et al. (2016) was that participants reacted slightly more positively to the control audio relative to the meditation. This effect was small and perhaps unsurprising given the larger sample size and that participants also rated the control audio to be more interesting and educational.

There was, however, an unexpected difference in sleepiness during the audio induction (not measured in Lin et al. 2016), such that participants reported more sleepiness during the guided meditation than the control audio. Interestingly, sleepiness differed only during the audio induction but not during rest and the picture viewing task. This suggests that the guided meditation may have *induced* sleepiness and counters the possibility of a baseline group difference in overall sleepiness.

Importantly, sleepiness has been shown to modulate both alpha and theta activity (Strijkstra, Beersma, Drayer, Halbesma, & Daan, 2003). Therefore, increased sleepiness during the guided meditation could have confounded meditative alpha and theta, and potentially obfuscated the testing of the hypothesized neural mechanism. Moreover, difference in sleepiness between the experimental conditions may provide a compelling alternative explanation to the findings of Lin et al. (2016), such that increased sleepiness induced during the guided meditation, rather than the actual practice of meditation, attenuated the LPP. To adequately address these possibilities, future investigations are strongly encouraged to consider incorporating sleepiness as a control and or predictor variable into the data analytic strategy. Elucidating the significance of the observed difference in audio induction sleepiness may be paramount toward uncovering yet another prescriptive factor of consideration in contemplative science—that novice susceptibility to sleepiness or fatigue in response to meditation may systematically influence outcome variables. Given the complexity of the analysis (i.e., modeling the main and interactive effects of sleepiness and neural oscillatory measures on the LPP [comprised of multiple within-subject data points over time]), future studies may need to adopt a multilevel modeling (MLM) approach. Specifically, MLM growth curve modeling uniquely accounts for idiographic variance in repeated measures (e.g., change in each subject's LPP over successive time windows) while affording flexibility to accommodate a variety of predictor variables (Kristjansson, Kircher, & Webb, 2007). Indeed, implementing MLM in place of traditional ANOVA-based methods may offer unique solutions to circumvent analytic limitations and garner new insights (Aarts, Verhage, Veenvilet, Dolan & Van Der Sluis, 2014; Kristjansson et al., 2007).

Conclusion

In summary, the predictions were generally unsupported by the data: (1) the guided meditation did not produce demonstrable differences in alpha and theta power relative to controls; (2) unexpectedly, participants across the entire sample exhibited late LPP attenuation and did not differ by group in self-reported negative affect; 3) meditative theta, but not meditative alpha, was positively correlated with the early LPP, which trended towards statistical significance when compared to the correlation (i.e., lack thereof) between control audio theta and the early LPP in the control group. Taken together, the findings challenge previous suggestions that brief mindfulness meditation can modulate emotion processing (Eddy et al., 2015, Lin et al., 2016), and call into question whether extant functional interpretations of meditative oscillatory activity are applicable to novice practitioners (Lomas et al., 2015). The failure to replicate Lin et al. (2016) demonstrates not only the value of large sample replication, but also highlights the need for incremental research to support existing claims. The current study also exemplifies the unique challenge of conducting contemplative science research—namely, that meditation specific factors (e.g., meditation experience, meditative style, training duration, etc.) interact with broader issues concerning measurement and construct validity to complicate the design of methodologically rigorous studies with sound predictions and generalizable conclusions.

Echoing Van Dam and colleagues' (2018) sentiments, it would appear that the public media is not the only avenue through which the benefits of mindfulness meditation are susceptible to exaggeration. Conceptual and methodological challenges render scientific investigations equally susceptible to the drawing of premature and likewise exaggerated conclusions. The validity of the neural correlates and putative neural mechanisms of mindfulness meditation appears contingent on a host of conceptual, methodological, and sample dependent factors. Given the constellation of null findings from the current study, it must be acknowledged that, contrary to past suggestions, a single brief mindfulness meditation may simply confer no emotion regulatory benefits to novice practitioners at all—*irrespective* of sample characteristics, experimental parameters, and analytic methodology. In this light, efforts and conclusions aimed at developing a singular holistic framework to explain how mindfulness meditation works appear premature. Perhaps a more tractable and practical endeavor involves identifying and understanding the contextual factors that undergird the extent to which mindfulness meditation is conceptualized or has been previously shown to "work".

Amidst the humbling complexity and mounting skepticism, the findings (or lack thereof) also inspire new directions toward understanding the effects of brief mindfulness meditation in novice practitioners. Specifically, the observation that the guided meditation produced more sleepiness than the control audio introduces another factor to the growing list of prescriptive considerations, shedding light on alternative ways to understand past research and inform the development of future studies. Given that sleepiness is known to modulate attention and emotion processing (Franzen, Siegle, & Buysse, 2008; Thomas et al., 2000), past studies, particularly those involving meditation novices and brief interventions, may benefit from replication efforts that include measures of sleepiness. Furthermore, the discovery that meditative theta related to the early LPP sparks novel and potentially fruitful lines of inquiry. If replicated, the unique directionality of the relationship may lead to valuable insights about the functional significance of meditative theta in novice practitioners. Moreover, given that the LPP is a well-established ERP measure of emotion processing, elucidating the nature of its relationship to meditative theta could be valuable for future studies of mindful emotion regulation. Examining whether meditative theta is sensitive to change as a function of prolonged OM meditation training may be a foundational step in establishing a measure that is sensitive to changes that occur during *and* over the course of meditation practice.

Although the current study yielded more questions and complications than answers or clarity, it did not diminish the intrigue and promise in unveiling the “black box” of meditation research. If anything, the results of this study provide perspective on the difficulties and challenges inherent in linking what occurs during meditation with its “off-the-cushion” effects. Given the vast history, rich intricacy, and prevailing mystery of contemplative practice, there is perhaps no reason to expect anything less.

APPENDICES

APPENDIX A

TABLES

Table 1. Means, standard deviations, and effect size estimates of self-report battery by group

	Control N=106			Meditation N=104			
Variable	*Range*	*M*	*SD*	*Range*	*M*	*SD*	*d*
FFMQ Overall	2.21-4.49	3.20	.45	2.21-4.23	3.18	.43	.05
FFMQ Observe	11-37	25.47	5.37	17-40	26.48	5.22	.19
FFMQ Describe	9-36	26.25	5.42	12-38	26.08	5.69	.03
FFMQ Acting with Awareness	10-39	27.40	5.94	12-39	26.44	5.72	.16
FFMQ Nonjudgment	9-38	25.71	7.12	10-38	25.44	6.47	.04
FFMQ Nonreactivity	11-34	20.00	4.52	12-30	19.71	3.94	.07
ACS Total	35-73	53.05	7.75	29-73	51.58	8.02	.19
ACS Focus	10-33	23.13	4.23	10-31	22.22	4.07	.22
ACS Shift	20-44	29.92	4.66	18-42	29.36	4.91	.12
NAS Pre-Experiment	10-28	11.96	3.25	10-30	11.89	2.77	.02
NAS Post-Experiment	10-42	15.11	5.42	10-41	16.01	5.96	.16
Sleepiness Rest	1-7	3.66	1.41	1-6	3.52	1.45	.10
Sleepiness Audio	1-6	3.79	1.42	1-7	4.35	1.48	.39
Sleepiness Picture Viewing	1-6	1.90	1.09	1-5	1.70	.92	.20
Mini-IPIP Extraversion	1-5	3.34	.94	1-5	3.35	1.03	.01
Mini-IPIP Agreeableness	1.75-5	4.28	.58	1.75-5	4.27	.62	.02
Mini-IPIP Conscientiousness	2-5	3.77	.76	1.5-5	3.90	.77	.17
Mini-IPIP Neuroticism	1.25-4.75	2.98	.86	1.25-4.75	2.96	.76	.02
Mini-IPIP Openness	1.75-5	3.83	.70	1.5-5	3.63	.79	.27

Note. FFMQ: five factor mindfulness questionnaire (high scores indicate higher levels of dispositional mindfulness, overall score computed as average of all items); ACS: attentional control scale (higher scores indicate greater attention); NAS: negative affect scale (higher scores indicate greater negative state affect); Mini-IPIP: Mini-International Personality Item Pool (higher scores indicate greater endorsement of personality trait).

Table 2. Means, standard deviations, and effect size estimates of manipulation check questionnaire by group

	Control N=106			Meditation N=104			
Variable	*Range*	*M*	*SD*	*Range*	*M*	*SD*	*d*
Audio Engagement	1-7	4.23	1.42	1-7	4.18	1.59	.03
Audio Interest	1-7	4.54	1.63	1-7	3.56	1.66	.60
Audio Emotional Reaction	2-7	4.76	1.00	1-7	4.48	1.06	.27
Audio Arousal	1-6	3.13	1.53	1-6	2.80	1.52	.22
Audio Understanding	1-7	5.37	1.42	1-7	5.44	1.60	.05
Audio Learning	1-7	4.65	1.39	1-6	3.52	1.41	.81
Picture Viewing Engagement	1-7	5.93	1.28	2-7	5.94	1.13	.01
Picture Viewing Interest	1-7	5.07	1.32	1-7	5.16	1.31	.07
Picture Viewing Neutral Arousal	1-7	2.62	1.62	1-7	2.95	1.52	.21
Picture Viewing Negative Arousal	1-7	5.40	1.94	1-7	5.12	1.94	.14
Picture Viewing Overall Arousal	1-7	4.75	1.65	1-7	4.75	1.72	< .01
Picture Viewing Emotional Reaction	1-6	2.90	1.19	1-6	2.78	1.21	.10

Note. Audio Emotional Reaction (lower scores below 4 indicate more negative emotional response, higher scores above 4 indicate more positive emotional response); Picture Viewing Neutral Arousal (higher scores indicate greater arousal to neutral pictures); Picture Viewing Negative Arousal (higher scores indicate greater arousal to negative pictures); Picture Viewing Overall Arousal (higher scores indicate greater arousal to overall task); Picture Viewing Emotional Reaction ((lower scores below 4 indicate more negative emotional response, higher scores above 4 indicate more positive emotional response).

Table 3. Means, standard deviations, and effect size estimates of log-transformed alpha and theta values as function of task, site, and group

	Control Rest: N=102, Induction: N=104			Meditation Rest: N=103, Induction: N=104			
Variable	*Range*	*M*	*SD*	*Range*	*M*	*SD*	*d*
Rest Alpha Frontal	.18-1.06	.57	.21	.17-1.42	.61	.24	.18
Rest Alpha Temporal-Central	.18-1.26	.64	.24	.17-1.41	.68	.25	.16
Rest Alpha Posterior	.24-1.61	.85	.32	.18-1.58	.89	.31	.13
Induction Alpha Frontal	.18-1.14	.55	.21	.15-1.41	.58	.23	.14
Induction Alpha Temporal-Central	.14-1.25	.60	.24	.18-1.39	.62	.24	.08
Induction Alpha Posterior	.17-1.56	.77	.31	.20-1.57	.79	.29	.07
Rest Theta Frontal	.32-.70	.49	.07	.34-.69	.50	.07	.14
Rest Theta Temporal-Central	.27-.70	.49	.08	.29-.70	.50	.08	.13
Rest Theta Posterior	.18-.72	.49	.09	.25-.71	.51	.08	.23
Induction Theta Frontal	.50-1.26	.72	.13	.50-1.30	.71	.13	.08
Induction Theta Temporal-Central	.50-1.20	.70	.13	.51-1.25	.69	.13	.08
Induction Theta Posterior	.49-1.15	.69	.13	.50-1.23	.69	.13	< .01

Note. Values are log-transformed from power spectral density at alpha (8-13 Hz) and theta (4-8 Hz) frequency range.

Table 4. Means, standard deviations, and effect size estimates for the Late Positive Potential (LPP) by group

	Control N=100			Meditation N=101			
Valence by ERP Window	*Range*	*M*	*SD*	*Range*	*M*	*SD*	*d*
Neutral 500-900 ms	-19.65-17.95	-.03	5.51	-12.84-15.73	-.35	5.74	.06
Negative 500-900 ms	-16.40-20.94	7.79	6.15	-20.52-26.34	6.73	7.08	.16
Neutral 1000-2000 ms	-16.21-18.48	.23	5.43	-13.00-16.04	-.33	5.30	.10
Negative 1000-2000 ms	-15.13-15.72	5.27	5.95	-13.22-23.43	3.73	7.02	.24
Neutral 2000-3000 ms	-19.60-20.65	.26	6.59	-14.94-11.78	-.79	6.00	.17
Negative 2000-3000 ms	-23.69-20.37	4.89	7.58	-21.43-20.93	3.06	8.04	.23
Neutral 3000-4000 ms	-23-19-17.74	-.59	7.05	-14.28-15.27	-1.15	6.42	.08
Negative 3000-4000 ms	-23.92-20.32	3.45	8.17	-20.14-21.01	1.56	8.15	.23
Neutral 4000-5000 ms	-25.06-18.04	-1.97	7.81	-26.41-14.74	-1.92	7.28	.01
Negative 4000-5000 ms	-23.75-20.41	2.21	8.35	-19.65-20.22	.27	8.27	.23
Neutral 1000-5000 ms	-20.52-16.63	-.52	6.14	-13.87-12.79	-1.05	5.67	.09
Negative 1000-5000 ms	-21.62-18.33	3.95	7.08	-16.42-18.64	2.16	7.50	.25

Note. Values are in microvolts (μV) extracted from electrode site Pz and time-locked to stimulus onset.

Table 5. Bivariate correlations among attentional focus, trait mindful awareness, and change in neural oscillatory activity by group

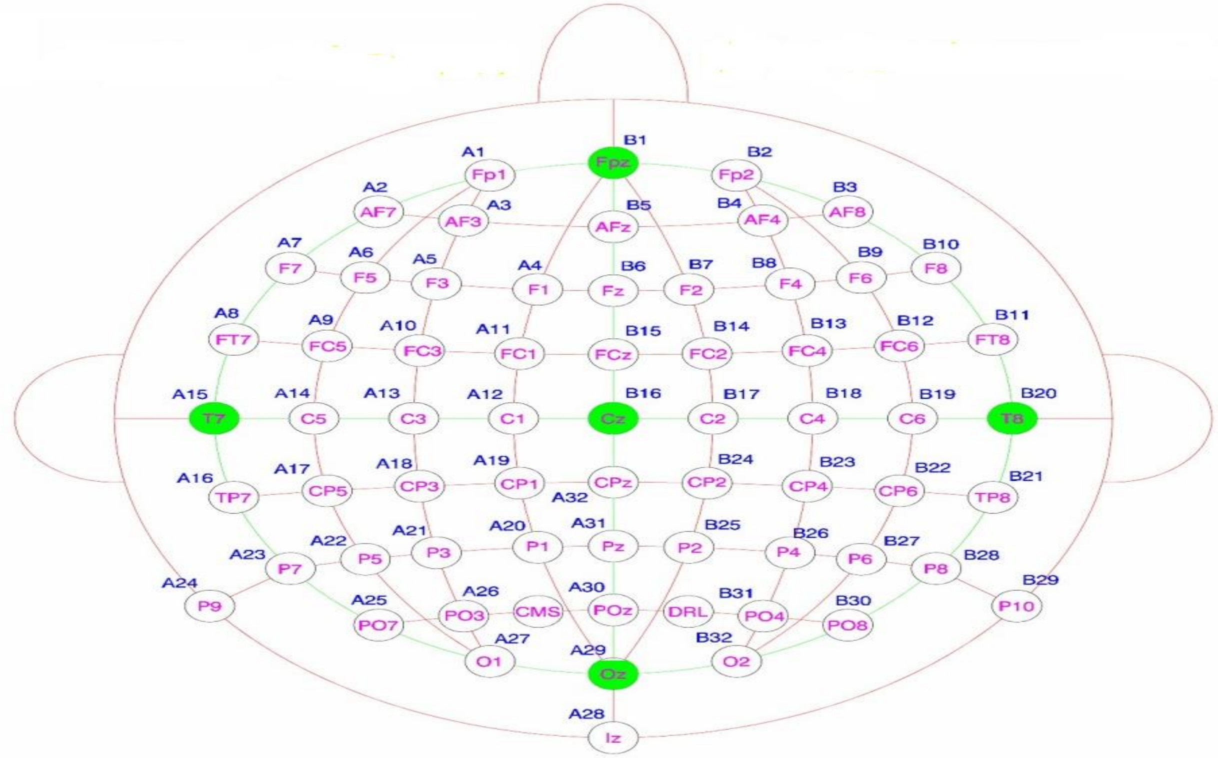
Control	1.	2.	3.	4.	5.	6.	7.	8.
1. ACS Focus	--							
2. FFMQ Acting with Awareness	.56**	--						
3. Alpha Frontal	.15	.08	--					
4. Alpha Temporal-Central	.14	.02	.87**	--				
5. Alpha Posterior	.11	-.10	.68**	.84**	--			
6. Theta Frontal	.07	.08	.35**	.15	-.02	--		
7. Theta Temporal-Central	.06	.02	.21*	.12	-.01	.88**	--	
8. Theta Posterior	.04	-.01	.15	.13	-.09	.73**	.91**	--
Meditation	**1.**	**2.**	**3.**	**4.**	**5.**	**6.**	**7.**	**8.**
1. ACS Focus	--							
2. FFMQ Acting with Awareness	.39**	--						
3. Alpha Frontal	-.05	.04	--					
4. Alpha Temporal-Central	-.12	-.02	.86**	--				
5. Alpha Posterior	-.11	-.07	.74**	.87**	--			
6. Theta Frontal	.02	.05	.46**	.31**	.17	--		
7. Theta Temporal-Central	.02	.01	.34**	.30**	.16	.92**	--	
8. Theta Posterior	-.02	-.01	.30**	.30**	.19	.85**	.96**	--

Note. FFMQ: five factor mindfulness questionnaire (high scores indicate higher levels of dispositional mindfulness, overall score computed as average of all items); ACS: attentional control scale (higher scores indicate greater attention); Alpha and theta values computed as difference in log-transformed power spectral density between audio induction and rest.

APPENDIX B

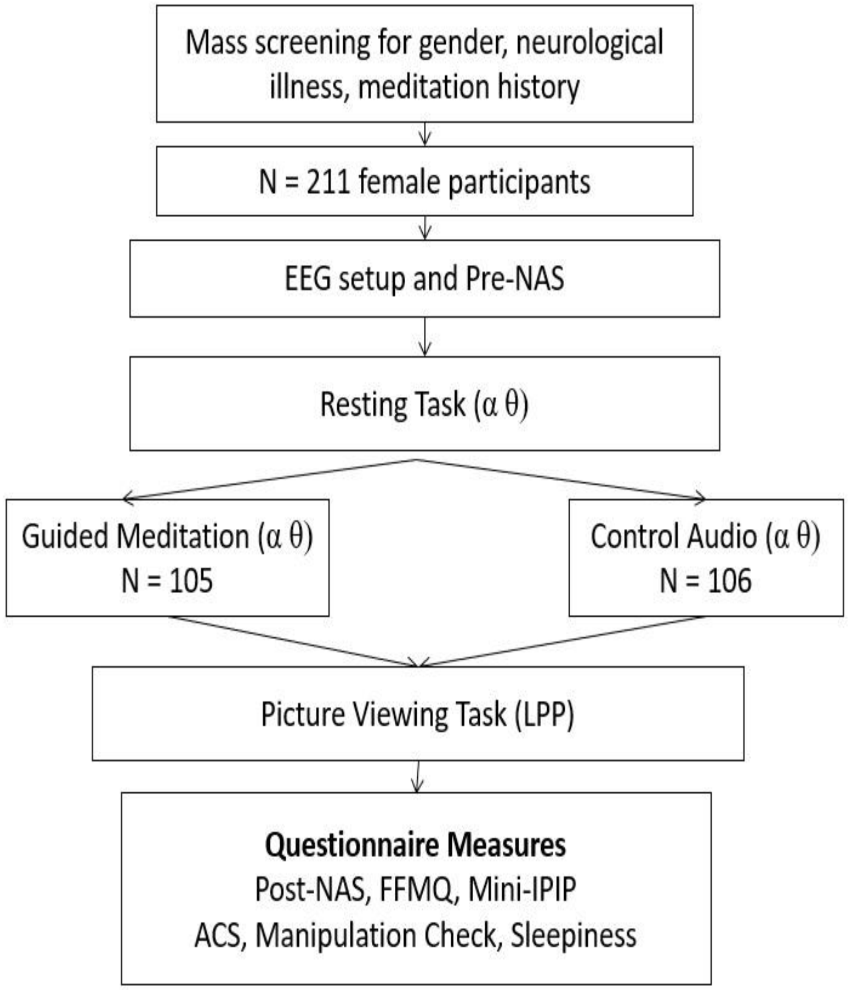
FIGURES

Figure 1. Electrode placement as per the international 10-20 system.



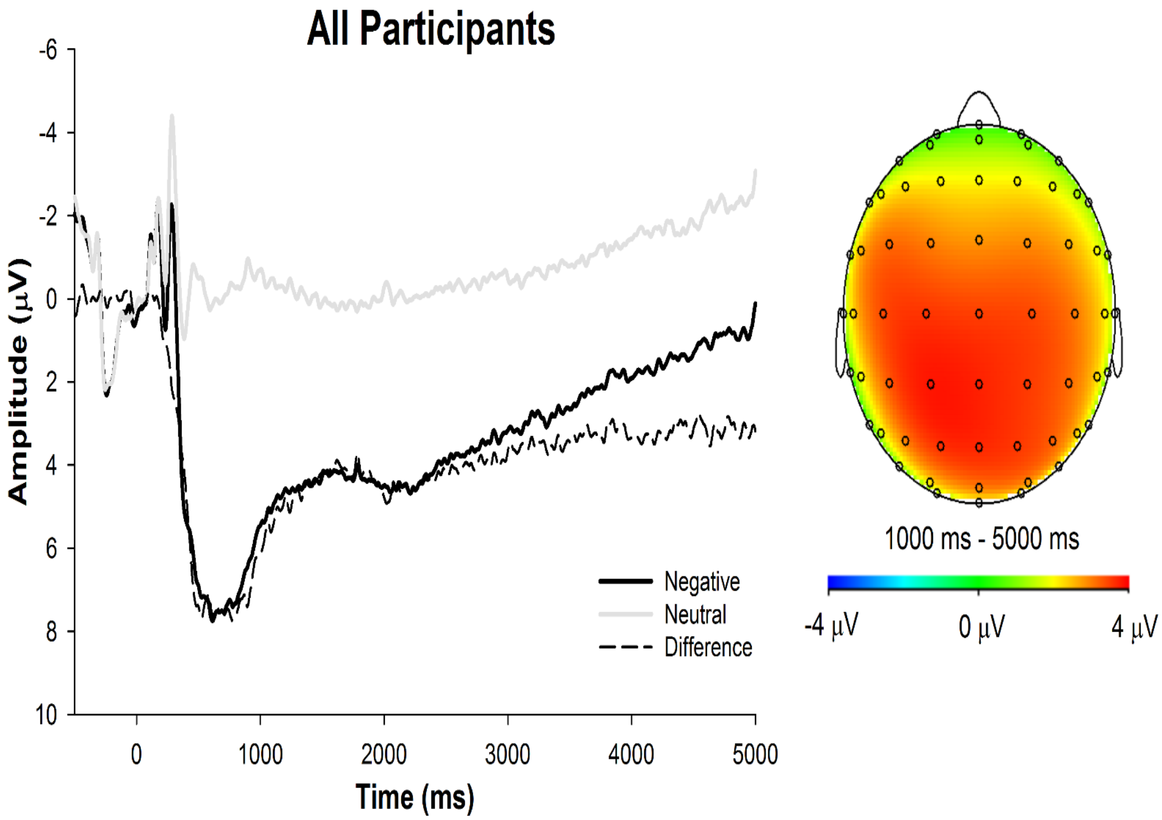
Note. The numbers below above each electrode name indicates the order in which they appear in the data records as a function of left (A) and right (B) hemispheres.

Figure 2. Diagram summarizing participant flow for recruitment, group assignment, and task procedures.



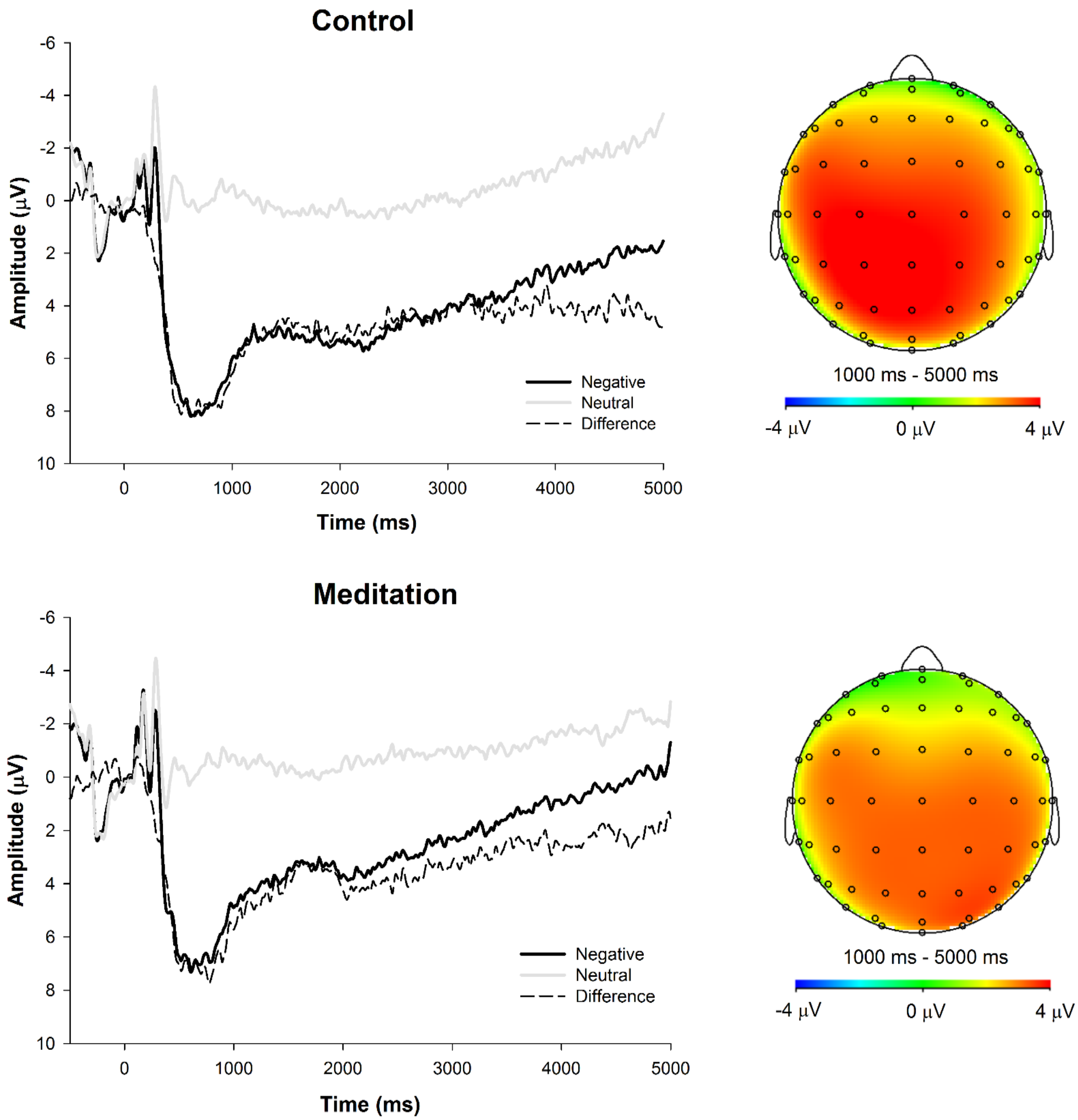
Note. NAS: negative affect scale; LPP: late positive potential; FFMQ: five factor mindfulness questionnaire; ACS: attentional control scale; Mini-IPIP: mini-international personality item pool; Sleepiness: stanford sleepiness scale

Figure 3. LPP waveforms and topographic head map of all participants.



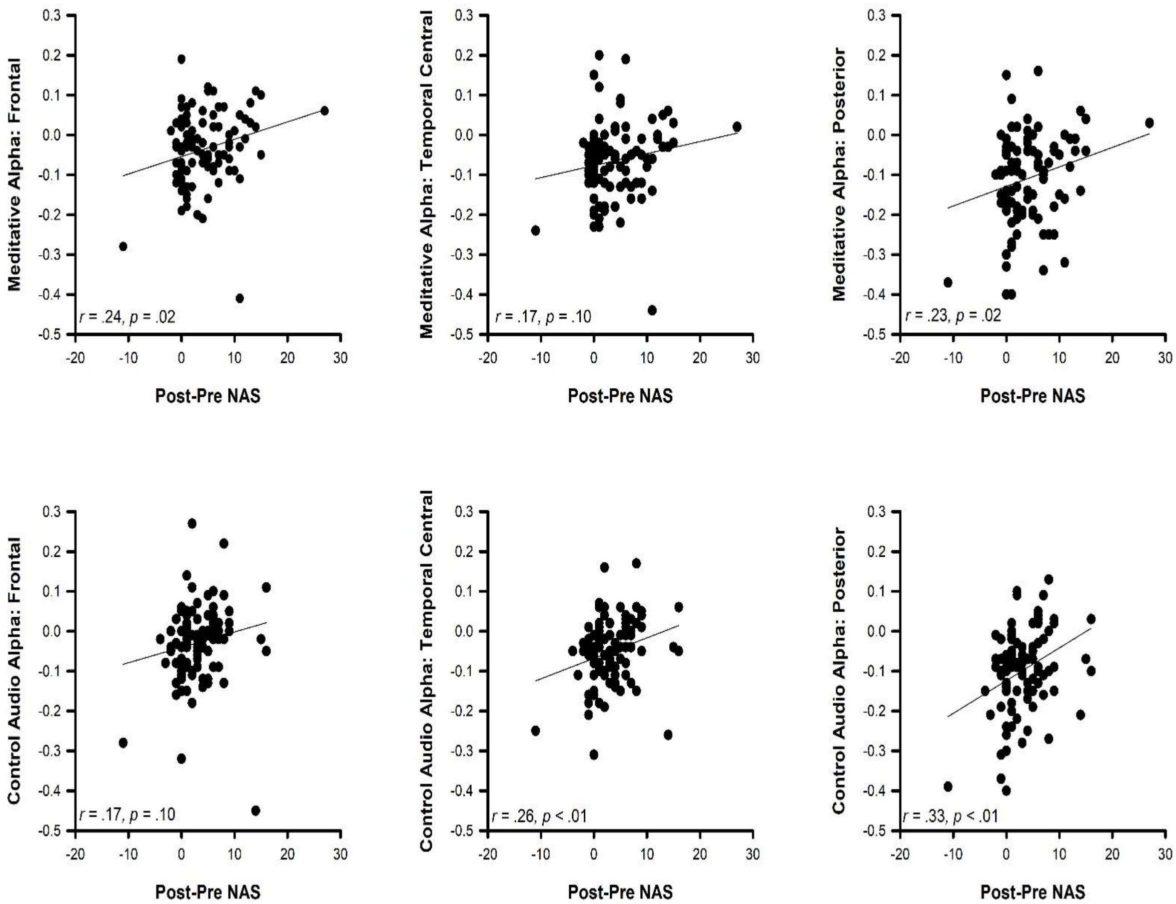
Note. Stimulus-locked grand average waveforms depicting the LPP (left). Grand average waveforms are computed by averaging each participant's waveforms across negative (dark line) and neutral (grey line) trials at electrode site Pz, and then averaging across all participants. Time 0 represents the onset of the stimulus. Head map provides scalp topography of difference in response amplitude between negative and neutral trials across the 1000-5000 time ms window (right).

Figure 4. LPP waveforms and topographic head map by experimental group.



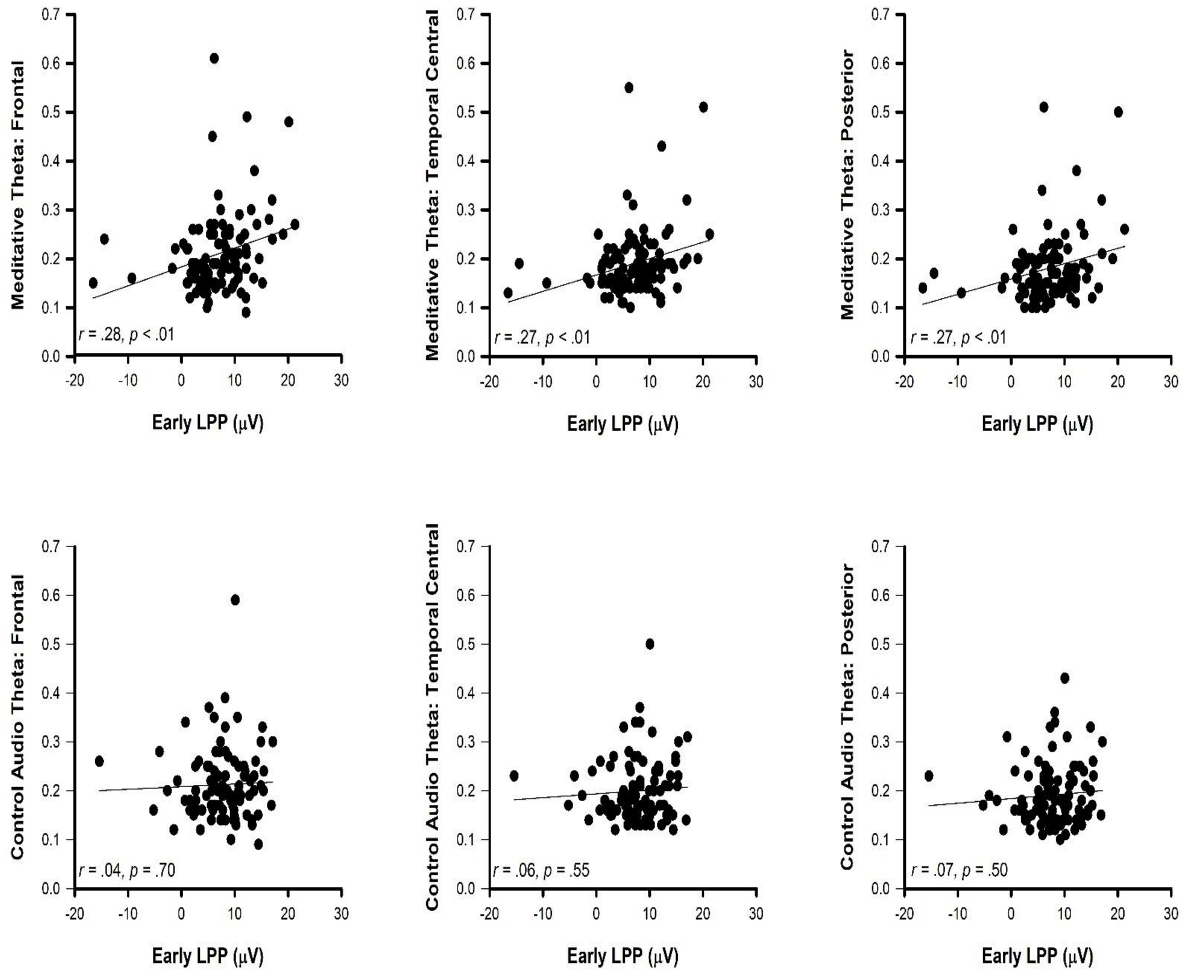
Note. Stimulus-locked grand average waveforms depicting the LPP for control (top left) and meditation (bottom left) groups. Grand average waveforms are computed by averaging each participant's waveforms across negative (dark line) and neutral (grey line) trials at electrode site Pz, and then averaging across group participants. Time 0 represents the onset of the stimulus. Head map provides scalp topography of difference in response amplitude between negative and neutral trials across the 1000-5000 ms time window for control (top right) and meditation (bottom right) groups.

Figure 5. Meditative alpha and control audio alpha by post-pre NAS ratings.



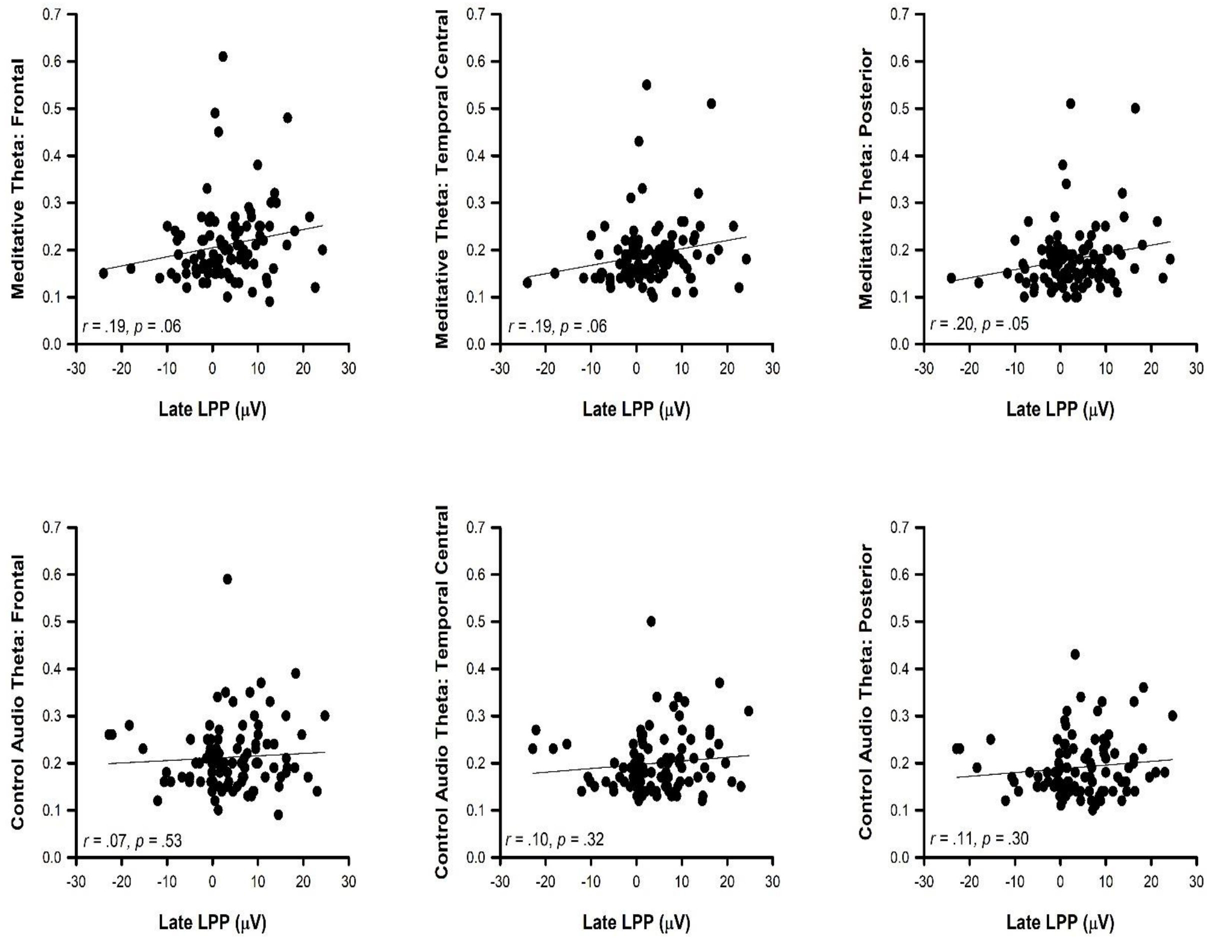
Note. Scatterplots depicting meditative alpha (top) and control audio alpha (bottom) as a function of post-pre NAS ratings across ROIs (left: frontal, middle: temporal-central, right: posterior). Meditative and control audio alpha computed as difference in log-transformed power spectral density between induction and rest. Post-Pre NAS computed as difference between post- and pre-experiment NAS ratings. Removal of two visual outliers (post-pre NAS = -11 & 29) in the meditation group rendered all correlations insignificant (frontal: $r = .14$, $p = .16$, temporal-central: $r = .09$, $p = .38$, posterior: $r = .13$, $p = .21$).

Figure 6. Meditative theta and control audio theta by early LPP amplitude.



Note. Scatterplots depicting meditative theta (top) and control audio theta (bottom) as a function of early LPP amplitude across ROIs (left: frontal, middle: temporal-central, right: posterior). Meditative and control audio alpha computed as difference in log-transformed power spectral density between induction and rest. Early LPP computed as the difference in response amplitude between negative and neutral trials occurring between 500-900 ms post stimulus onset.

Figure 7. Meditative theta and control audio theta by late LPP amplitude.



Note. Scatterplots depicting meditative theta (top) and control audio theta (bottom) as a function of late LPP amplitude across ROIs (left: frontal, middle: temporal-central, right: posterior). Meditative and control audio alpha computed as difference in log-transformed power spectral density between induction and rest. Late LPP computed as the difference in response amplitude between negative and neutral trials occurring between 1000-5000 ms post stimulus onset.

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