Zoning In and Out: EEG Alpha Correlates of Mind-Wandering During a Focused-Attention Meditation-Analog Task

James M. Broadway
Michael D. Mrazek
Michael S. Franklin
and
Jonathan W. Schooler

University of California, Santa Barbara

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Please address correspondence to:

James M. Broadway
Department of Neurosciences
University of New Mexico
Albuquerque, NM 87106
Email: jbrodaay@salud.unm.edu
Phone: 404-788-5355
Abstract

EEG spectral power in the "upper" alpha frequency band (10 - 12 Hz) was examined in relation to self-reported states of mind-wandering versus focused attention in a "breath-focus" meditation-analog task. Participants were instructed to close their eyes and focus their attention on the sensations of their breathing, and to notice when distracting thoughts emerged, while EEG was recorded. Participants were intermittently cued to self-report whether their attention was focused on their breath or on task-unrelated thoughts. Upper alpha power was greater when participants were breath focused relative to mind wandering, consistent with a proposed role of EEG alpha as supporting internally-focused attention and inhibiting distraction. Moreover, greater tendencies to mind-wander in daily life were positively related to alpha power during the breath focus task. Thus, results link EEG alpha to both inter- and intra-individual variation in focused attention. Theoretical and practical implications are discussed.

KEYWORDS: alpha, attention, EEG, meditation, mindfulness, mind-wandering
Mind-wandering is a common everyday state of consciousness in which attention becomes disengaged from current goal-directed interactions with the environment, and becomes instead focused on elaborating a series of task-unrelated and stimulus-independent thoughts (Schooler, Smallwood, Christoff, Handy, Reichle, & Sayette, 2011; Smallwood, 2013; Smallwood & Schooler, 2006; 2014). Not surprisingly, mind-wandering tends to interfere with perception, cognition, and action, in a wide range of task- settings (Mooneyham & Schooler, 2013; Randall, Oswald, & Beier, 2014; Smallwood & Schooler, 2006; 2014). Seeking effective remedies for mind-wandering, researchers have increasingly looked toward the training of attentional-control skills associated with meditation or "mindfulness" practices (Mrazek, Broadway, Phillips, Franklin, Mooneyham, & Schooler, 2014).

Meditation is a method that can lead to a different state of consciousness, likewise available in everyday life, induced by relatively simple psychological and/or physical disciplines (Tart, 2008; Vaitl et al., 2005). There are many styles of meditation, each with different emphases for attention training (Cahn & Polich, 2006; Lomas, Ivtzan, & Fu, 2015; Lutz, Jha, Dunne, & Saron, 2015). Main elements forming a common core of teachings across many traditions of meditation include: 1) stably maintaining concentration on a single object (focus), 2) noticing when distracting thoughts arise (meta-cognitive awareness, or meta-awareness, of mind-wandering, Lutz et al., 2015; Schooler et al., 2011), and 3) then returning attention to the target object without "following" the arising thoughts (re-focus). One's own respiration is commonly chosen as the object of attentional focus, often with the instruction to count respiration-cycles
The meditation practice of selecting the breath as the target object of attention is called "breath-focus" (BF) in this article.

Recently, Hasenkamp and colleagues (Hasenkamp, Wilson-Mendenhall, Duncan, & Barsalou, 2012) presented a model of the time-course of fluctuations between mindfulness and mind-wandering as constituting a set of relatively discrete stages of a cyclical process. According to this framework, one invariably (eventually) mind-wanders from the object of attention (e.g., one’s breath) after maintaining stable focus for a time; then at some later time one becomes aware of one’s mind-wandering, which then prompts one to return the focus of attention to the target object, thus initiating a replay of the full cycle (focus, mind-wandering, meta-awareness, and return to focus). These hypothetical stages were associated with activation in different brain networks. Specifically, during the stage of becoming meta-aware of mind-wandering, increased activations were observed in the "salience network" comprising bilateral anterior insula and dorsal anterior cingulate cortex. During the next phase, shifting attention away from distraction back to the breath, increased activations were observed in the "executive network" comprising lateral prefrontal and lateral inferior parietal cortices, right-hemisphere dominant. While maintaining focused attention, dorsolateral prefrontal cortex remained active from the preceding phase of shifting attention. And while mind-wandering, classical default-mode network areas were active, comprising posterior cingulate and medial prefrontal cortices, as well as posterior tempo-parietal cortex and the parahippocampal gyrus. These findings supported the authors' neurocognitive framework (Hasenkamp et al., 2012; for recent reviews of meditation-related neuroimaging see also Fox, Dixon, Nijeboer, Girn, Floman, Lifshitz, ... , & Christoff, 2016; and Mooneyham, Mrazek, Mrazek, & Schooler, 2016). Lomas and colleagues (2015) similarly conceptualized these stages, cycling from focused attention to mind-wandering,
as being supported by different attentional networks, i.e., for sustaining attention, inhibiting
distractions, disengaging from distraction, and re-orienting attention (see e.g., Posner &

In addition to cultivating basic attentional control, different schools or teachings on
mindfulness-meditation also emphasize the development of motivational or attitudinal
characteristics, such as compassion, openness to experience, embracing impermanence and
change, non-judging, and so on (Lutz et al., 2015). However, basic attentional control, the focus
of the present work, is generally regarded as foundational for these ethical and ‘soteriological’
components of mindfulness-meditation practice. Additionally, in contrast to styles of meditation
in which an object of attention is selected ("focused attention"), other styles referred to as "open-
monitoring" do not involve the selection of a specific object for focusing attention, but rather
involve the constant application of meta-awareness to whatever one is experiencing, feeling, or
thinking on a moment-to-moment-basis (Lutz et al., 2015). According to some authors (Cahn &
Polich, 2006), mindfulness practices in particular “involve allowing any thoughts, feelings, or
sensations to arise while maintaining a specific attentional stance: awareness of the phenomenal
field as an attentive and nonattached observer without judgment or analysis” (p 180).

Interestingly it has been suggested that meta-awareness would be the hypothetical element that
distinguishes mindful open-monitoring from "ordinary" stream-of-consciousness or mind-
wandering (Lutz et al., 2015). The distinct form of meditation known as "mindfulness" has been
suggested to "involve an admixture of focused attention and open-monitoring" (Lomas et al.,
2015; p 402). However, it is recognized that open-monitoring depends on the development of
focused-attention as a foundational ability in order to maintain the desired “attentional stance” of
meta-awareness (Lutz et al., 2015).
Regardless of meditation style, a large and growing body of research suggests that meditation can lead to benefits for psychological health and well-being (Ivanoski & Malhi, 2007; Keng, Smoski, & Robins, 2011; Witkiewitz, Lustyk, & Bowen, 2013), and cognitive functioning (Chiesa, Calati, & Serretti, 2011; Sedlmeier et al., 2012); and is possibly associated with lasting structural changes in the brain (Fox et al., 2014). Moreover, the core conscious predisposition resulting from many meditation styles, termed "mindfulness" in some traditions, has been shown "opposed" to the state of mind-wandering in several respects (Mrazek, Smallwood, & Schooler, 2012). Thus mindfulness-meditation has been proposed as an "antidote" to mind-wandering (Mrazek et al., 2014). As Brandmeyer and Delorme (2013) noted however, for a variety of reasons it can be difficult for many individuals to develop and maintain a consistent meditation practice; thus the potential benefits of meditation do not reach them. As a potential solution to this problem, Brandmeyer and Delorme (2013) proposed using neurofeedback to help more individuals develop a regular meditation practice and thus receive its potential benefits.

Real-time neurofeedback to develop better concentration on a moment-to-moment basis has garnered much attention in recent years using fMRI (Awh & Vogel, 2015; deBettencourt, Cohen, Lee, & Turk-Browne, 2015). However EEG is a relatively lower-cost method and, moreover, a direct measure of brain activity; thus EEG-neurofeedback is a somewhat more promising approach for widespread use. Indeed there are already some commercially available systems for this purpose (e.g., Muse™, Emotiv™). However, it is difficult to evaluate these products because there is little publicly available information about their development and validation, the signal(s) and algorithms underlying their function, how artifacts are dealt with, their efficacy at enhancing attentional skills, or their ability to discriminate meditation from mind-wandering states. (For two recent efforts in these directions, see Steinhubl and colleagues...
Thus to contribute to the further development of EEG-neurofeedback as an aid to meditation, we conducted a basic investigation into the neural underpinnings of meditation and mind-wandering states as reflected in the EEG.

The majority of EEG studies of meditation involve one or more of the following comparisons: 1) meditators versus non-meditators, 2) meditators in the meditation state versus the state of rest, or 3) individuals before and after meditation training, versus controls. (An exception is the EEG study by Braboszcz & Delorme (2011), discussed below). Recent reviews (Cahn & Polich, 2006; Chiesa & Serretti, 2010; Fell, Axmacher, & Haupt, 2010; Ivanovski & Malhi, 2007; Lomas et al., 2015) support the conclusion that meditation promotes higher spectral power in the alpha frequency band (8 - 12 Hz) across these comparisons. Placing the present work in this context, we examined alpha power in a single session of a meditation-analog task, contrasting states of focused attention versus mind-wandering. Thus while similar in this respect to the fMRI study by Hasenkamp and colleagues (2012) and the EEG study by Braboszcz & Delorme (2011)-- our study can be seen as somewhat analogous to previous EEG studies comparing meditation states to resting states. Indeed the resting state is frequently identified with the mind-wandering state, and both are associated with greater activation in the default mode network (for a recent review, and a more nuanced perspective, see Fox, Spreng, Ellamil, Andrews-Hanna, & Christoff, 2015). However, here we sought to discriminate fluctuations between focused attention and mind-wandering as they occur within a single session of meditation, rather than as they appear in contrasts between meditation and rest.

Unlike previous EEG studies that have compared brain activity in a meditation session versus a discrete resting-state session, we sought to capture variance associated with shorter-term
fluctuations between focused attention and mind-wandering, more in the manner of the fMRI study by Hasenkamp and colleagues (2012). However, instead of requiring participants to recognize their own mind-wandering in order to obtain measurements of distraction, we presented "thought-probes" periodically during the single session of "breath-focus" meditation. Previous meditation-related EEG studies do not shed much light on neural correlates of momentary changes in conscious state (i.e., focused-attention versus mind-wandering), within a single meditation session. One exception is a previous study addressing momentary state-related changes in attentional focus during meditation, Braboszcz and Delorme (2011) had participants perform breath-focus meditation with eyes-closed while high-density EEG was recorded. Participants, presumably novices to meditation (prior experience not reported), were instructed to count their breath-cycles (up to 10, repeating), and to press a key whenever they noticed that they were mind-wandering (i.e., they noticed they had lost count). The act of pressing the key operationalized the termination of a mind-wandering episode and a return of attention to breath-focus. Thus EEG data were segmented around these self-initiated key-presses: EEG data preceding the key-presses were labeled as mind-wandering, or off-task, while EEG data following the key-presses were labeled breath-focused, or on-task. Among several findings, it was shown that that EEG spectral power was reduced in the alpha frequency band (9 - 12 Hz) when individuals were mind-wandering versus focused on breath-counting; which was interpreted to reflect differences in alertness.

Thus, this singular EEG study (Braboszcz & Delorme, 2011) demonstrated that momentary changes in conscious state can be observed in alpha power based on self-reports about mind-wandering. However, noting the dependence of these results on participants "catching themselves" mind-wandering highlights certain ambiguities. Catching oneself mind-
wandering is notoriously hard to do (Awh & Vogel, 2015; Schooler et al., 2011); indeed this is one reason for the proposal of developing neurofeedback programs to facilitate meditation practice and better attentional control. Thus, the EEG correlates of mind-wandering versus focused attention identified through a self-catching procedure may not be as directly useful to the purpose of developing EEG-neurofeedback to remediate mind-wandering and facilitate meditative concentration. Moreover, because the self-catching method in Braboszcz and Delorme (2011) required individuals to notice when they were mind-wandering, which is something that individuals frequently fail to do (Schooler et al., 2011), an untold number of mind-wandering states were likely allowed to pass unobserved (i.e., when the participant was "zoned-out") (Schooler et al., 2011). Furthermore, it could be doubted that the EEG in the seconds preceding the participants' key-presses reflected an unmixed mind-wandering state: it could have reflected to some extent a mixture of mind-wandering plus a transition to meta-awareness (Schooler et al., 2011), and not only mind-wandering. It is also reasonable to doubt that the EEG in the seconds following the key-press reflected an unmixed return to a state of focused attention (i.e., an individual might sometimes return to mind-wandering after pressing the key).

To address these issues, the present EEG study used an alternative method of obtaining self-reports about momentary changes in conscious state, that did not require individuals to "self-catch" their own mind-wandering. Rather, mind-wandering episodes were "probe-caught" (Schooler et al., 2011), by frequent but randomly occurring cues prompting individuals to report whether their attention had been focused on their breathing or on unrelated thoughts, in the moments just prior to the cue. This experience-sampling "probe-caught" measure of mind-
wandering should resolve some of the ambiguities mentioned concerning the "self-caught" mind-wandering measure in previous work (Braboszcz & Delorme, 2011).

EEG power in the alpha frequency band was selected in the present work as the dependent variable of interest, based on consistent findings in the meditation-related EEG literature (Cahn & Polich, 2006; Chiesa & Serretti, 2010; Fell et al., 2010; Ivanovski & Malhi, 2007; Lomas et al., 2015); as well as a hypothesized role of alpha in supporting internally-focused attention (Bazanova & Vernon, 2014; Benedek, Schickel, Jauk, Fink, & Neubauer, 2014; Fell et al., 2010; Fink & Benedek, 2014). Spectral power over a selected time interval, using a Fast Fourier Transform (FFT) was chosen as the method of decomposition of the EEG (rather than e.g., time-frequency analysis), to be consistent with the bulk of practice in the EEG/meditation literature (see e.g., Lomas et al., 2015).

Moreover, it has become a relatively frequent practice in current alpha research to distinguish among narrower frequency bands within the classical, broad 8 - 12 Hz alpha range (Fink, Grabner, Neuper, & Neubauer, 2005; Shaw, 2003). Indeed the selection of boundaries for alpha is somewhat variable across the human EEG literature. For example, Braboszcz and Delorme (2011) examined alpha in the 9 - 12 Hz range. The present work focused specifically on so-called "upper" alpha (alpha2; 10 - 12 Hz). Alpha2 has been identified as a consistent EEG marker of tonic alertness (Sadaghiani, Scheeringa, Lehongre, Morillon, Giraud, & Kleinschmidt, 2010) and has shown to be an effective signal for brief neuro-feedback training to improve cognitive functioning (Escalano, Navarro-Gil, Garcia-Campayo, & Minguez, 2014; Zoefel, Huster, & Hermann, 2011). Moreover, brief meditation training enhances alpha2 (Fan, Tang, Tang, & Posner, 2014). These findings recommended alpha2 as the frequency band of interest in this study.
Additionally, alpha2 power was examined in relation to individual differences in the tendency to be mindful (trait-MF) and to mind-wander in daily life (trait-MW). With respect to such individual differences, a recent review (Lomas et al., 2015) suggested that longitudinal decreases in alpha power were related to more mindfulness practice in multiple studies. We speculated that this result might have an analogue, with respect to individual differences, in trait-like tendencies to be mindful or to mind-wander.

Method

Ethics Statement

The research was conducted in accordance with the Declaration of Helsinki and with the approval of the Institutional Review Board of the University of California, Santa Barbara. Participants gave written informed consent and were compensated with cash payment at a rate of $10 per hour.

Participants

Participants were recruited from a university-wide paid subject pool. Participants were not recruited from a pool of individuals known to have prior or ongoing experience with meditation. The study was listed with the title “Relaxation & Attention.” Deliberately, there was no mention of mindfulness or meditation in the study description, to minimize self-selection biases and demand characteristics, which could interact with meditation-analog task and questionnaires in the study. Prospective participants were informed they would perform computer-based attention and memory tasks while physiological measures would be recorded, and respond to questionnaires. Participants were not screened or selected for prior meditation experience. A total of 26 undergraduate students (14 female) participated in the experiment (age $M = 20.29$ years, $SE = .24$). Participants reported normal or corrected-to-normal vision and were
proficient in written and spoken English. All participants reported to be right-handed with the exception of one left-handed individual.

**Procedure**

Tasks were programmed in E-prime (Schneider, Eschman, & Zuccolotto, 2002) and presented on a computer in the following order. The experimenters were two male senior undergraduate research assistants with prior experience conducting research into mindfulness/meditation and mind-wandering.

**BF task.** EEG was recorded during the BF task, which was devised as an analog meditation task. Instructions were designed to contain minimal jargon related to mindfulness/meditation, and to inform participants of task requirements in secular, Western lay-psychological terms (reproduced in Appendix A). Participants were instructed to close their eyes and focus attention on specific sensations of their breathing. They were not instructed to count their breaths as in other reported procedures (e.g., Braboscz & Delorme, 2011; Levinson, Stoll, Kindy, Merry, & Davidson, 2014), but simply to maintain a "vivid awareness" of the sensations of their breathing, more similar to the procedure in Hasenkamp and colleagues (2012). Instructions were intended to express the core components of mindfulness meditation practice, i.e., focusing attention on an object, becoming aware of when one is having distracting thoughts, and then non-judgmentally returning attention to the target object. We viewed these emphases to approximate the "admixture" of focused-attention and open-monitoring said to characterize mindfulness practice (Lomas et al., 2015; Lutz et al., 2015).

Participants were instructed to respond to occasional "thought-probe" tones (with either left- or right-mouse-click), in order to report whether their attention had been focused on breathing (BF-on), or on unrelated thoughts (BF-off), in the moments just before the tone.
Specifically, participants were instructed to report (yes or no) whether their "attention was filled with a vivid sensation of the breath." The auditory thought-probe tone was chosen to be unobtrusive, 44100 Hz sinusoidal wave, played for a brief 100 ms duration. Left/right response-mapping for mouse-clicks was counterbalanced across participants. Participants practiced the response-mapping for thought-probes before beginning the task. Thought-probes occurred during the task randomly after 25, 30, or 35 seconds. Inter-probe times were varied in this manner so that probes would not be perfectly temporally predictable, yet the range of variation was limited with the intention to avoid introducing another variable into the design. The schedule of presenting thought-probes approximately every 30 seconds, with minor variation, was chosen to maximize the number of observations that could be obtained, for sorting the EEG data into on- versus off-task states, while still allowing individuals ample time to drift away from the task; and this presentation rate had yielded serviceable (and plausible) response rates (showing that individuals reported mind-wandering for approximately 1/3 of the probes on average) in our previous work with event-related potentials (Broadway, Franklin, & Schooler, 2015).

There were 12 thought-probes in a block of trials (each inter-probe-interval occurring four times). Participants were instructed that there was "no correct answer" to the thought-probes and were asked to simply respond as accurately and honestly as possible (see Appendix A). There were 8 blocks of trials (= 96 thought-probes). Participants were given self-paced rest-breaks between blocks. After the BF task, participants responded to the following questionnaires about their daily life habits of mind-wandering and mindfulness.

**Mind-wandering Questionnaire** (MWQ; Mrazek, Phillips, Franklin, Broadway & Schooler, 2013) is a five-item questionnaire to measure individual differences in the tendency to mind-wander during daily life. Using a 6-point scale (1 = Almost never, 6 = Almost always),
participants endorsed the degree to which various statements described their own experiences and behaviors (e.g., "I have difficulty maintaining focus on simple or repetitive work"). The mean rating across items was computed. Higher scores indicated greater tendencies to mind-wander in daily life.

**Mindful attention and awareness scale** (MAAS; Brown & Ryan, 2003) is a widely used 15-item questionnaire to measure individual differences in the tendency to be mindfully attentive during daily life activities (trait-MF). Using a 6-point scale (1 = Almost always, 6 = Almost never), participants endorsed the degree to which various statements described their own experiences and behaviors (e.g., "I rush through activities without being really attentive to them"). The mean rating across items was computed. Higher scores indicated greater tendencies to be mindful in daily life. After the questionnaires participants were excused.

**EEG recording and off-line processing**

Continuous EEG was recorded during the BF task using Biopac MP-150 amplifier with six AgCl-AgCl scalp electrodes placed at the International 10-20 system locations F3, F4, C3, C4, P3, P4, referenced to an electrode placed on the nose-tip, with a ground electrode at location Fpz. EEG was recorded with a high-pass filter of .1 Hz. Horizontal eye movements (HEOG) were recorded as a single channel by two electrodes in bipolar montage, one placed on the outer canthus of each eye. Electrode impedances were below 5 kΩ on average, across electrodes and participants (\(M = 3.23, SE = .57\)). EEG was recorded with a sampling rate of 250 Hz. Data were processed off-line using EEGLAB software (Delorme & Makeig, 2004). EEG data were down-sampled offline to 250 Hz sampling-rate and re-referenced to the average reference. A low-pass filter of 30 Hz was applied.
We segmented the EEG data to examine brain activity in the interval preceding the thought-probe, binning "backward" according to the participant's response. For each thought-probe event, EEG data were segmented into two 10-second epochs, corresponding to "early" and "late" time-windows (in relation to thought-probe onset, -30 to -20 sec and -10 to 0 sec, respectively) during the time interval preceding the thought-probe (25, 30, or 35 seconds). These early and late epochs were both labeled as on- versus off-task (BF-on, BF-off) according to the participant's response to the subsequent thought-probe. We examined "early" and "late" time-windows, for each data segment labeled BF-on versus BF-off, to explore how far "back" in time alpha2 would be sensitive to the difference between focused attention and mind-wandering.

Trials on which participants required more than two seconds to respond to thought-probes were discarded. Epochs containing artifacts, identified by visual inspection of HEOG as well as scalp electrode EEG tracings, were discarded. Data from 8 participants were excessively contaminated by artifacts and were discarded from analyses. Data from 4 individuals were identified as bivariate outliers, by visual inspection of the scatterplot of the relationship between alpha2 power in on- versus off-task states, and were excluded. Therefore there were data from 14 participants contributing to the following analyses. Across time-windows there were on average 416 seconds of data per individual in the BF-on condition (number of 10-sec epochs, $M = 41.57$, $SE = 2.86$), and 278 seconds of data per individual in the BF-off condition (number of 10-second epochs, $M = 27.79$, $SE = 3.50$). This difference between numbers of epochs for on- versus off-task responses was statistically significant, $t_{(13)} = 2.92$, $p = .01$. (We checked that this variance did not contribute to alpha2 power differences between on- versus off-task states, see Note 1 in Results).
FFT was performed on the segmented EEG data using the Welch method. Mean EEG spectral power was computed for each electrode for the alpha2 frequency band (10 - 12 Hz). Due to the low spatial density of the electrode array, alpha2 power was averaged across frontal (F3, F4) and parietal (P3, P4) electrodes to form a single global variable representing alpha2 power for each BF condition (BF-on, BF-off) and time-window (early, late). Frontal (F3, F4) and posterior electrodes (P3, P4) were included in this total measure because these sites have been shown to be sensitive to differences in alpha, related to attention and affect, in previous meditation studies (Lomas et al., 2015). Central electrodes (C3, C4) over left and right motor areas were not included in the total measure because brain activities at these sites were expected to reflect the sensorimotor alpha rhythm, rather than alpha related to cognitive, emotional, and attentional states. The alpha2 averages were then log-transformed for statistical analyses.

Results

The proportion of on-task responses in the BF task did not vary as a function of presentation times for thought-probes (25 sec, 30 sec, 35 sec) in a repeated-measures ANOVA, \( F (2, 12) = 1.24, p = .32, \eta^2_p = .17 \). Therefore we combined EEG data across the presentation times for thought-probes in order to increase signal-to-noise ratio. A 2 x 2 repeated-measures ANOVA was conducted on alpha2 (10 - 12 Hz) power, depending on the within-subjects variables BF (BF-on, BF-off) and Time-Window (Early, Late). Of key interest, the main effect of BF was significant, \( F (1, 13) = 5.54, p = .04, \eta^2_p = .30 \). However, the main effect of Time-Window was not significant, \( F < 1 \); neither was the interaction of BF with Time-Window, \( F (2, 26) = 2.21, p = .16, \eta^2_p = .15 \). The effect of mind-wandering on alpha2 power was numerically less pronounced in the early time-window (\( M_{D} = .16, SE = .08 \)) versus the late one (\( M_{D} = .28, SE = .12 \)) but this difference was not significant, \( p > .05 \) (Figure 1). Results indicate that EEG alpha2 power was
greater when individuals were consciously focused on the task-relevant object of attention versus having task-unrelated thoughts\(^1\).

Next, individual differences in trait-MF and trait-MW were examined for relationships with alpha\(2\) power, separately for BF condition but averaged across time window\(^2\) (Table 1). Of main interest, alpha\(2\) power for BF-on was significantly negatively correlated with mean responses to MAAS, \(r = -.55, p = .04\), and positively correlated with mean responses to MWQ, and \(r = .56, p = .04\). Greater tendencies to be mindful in daily life were associated with less alpha\(2\) power overall, and greater tendencies to mind-wander in daily life were associated with more alpha\(2\) power overall. These relationships were somewhat stronger when individuals were focused on their breathing rather than having task-unrelated thoughts, suggesting that when individuals were on-task in the BF task, the neural measure of interest (alpha\(2\) power) was more strongly related to the trait-like cognitive correlates of interest (trait-MW, trait-MF). Scatterplots are shown in Figure 2.

As might be expected, trait-MF and trait-MW were negatively inter-correlated, \(r = -.59, p = .03\), prompting the re-examination of the above relationships in partial-correlations. Controlling for trait-MF, the relationship between alpha\(2\) power (BF-on) and trait-MW was much reduced and no longer significant, \(r = .33, p = .28\). Controlling for trait-MW, the relationship between alpha\(2\) power (BF-on) and trait-MF was similarly reduced and no longer significant, \(r = -.35, p = .24\). Finally, controlling for alpha\(2\) power (BF-on), the relationship between trait-MF and trait-MW was reduced and no longer significant, \(r = -.41, p = .17\).

Together these results mean that trait-MF, trait-MF, and alpha\(2\) power (BF-on) captured much overlapping variance among individuals. These results then motivated the re-examination
of the BF effect on alpha2 power, observed in the preceding ANOVA, by accounting for these individual differences in ANCOVAs.

Including trait-MF (MAAS) as a covariate in ANCOVA reduced the BF effect observed in the preceding ANOVA, which was no longer significant, $F < 1$. The interaction of trait-MF with BF effect was not significant, $F < 1$. The interaction of trait-MF with time window was not significant, $F_{(1, 12)} = 2.10, p = .17, \eta^2_p = .15$. The three-way interaction was not significant, $F < 1$. Likewise, including trait-MW (MWQ) as a covariate reduced the BF effect observed in the preceding ANOVA, which was no longer significant $F < 1$. The interaction of trait-MW with BF effect was not significant, $F < 1$. The interaction of trait-MW with time window was not significant, $F < 1$. The three-way interaction was not significant, $F < 1$. These results suggest that the BF effect on alpha2 power in the original ANOVA was substantially accounted for by relationships linking alpha2 power when individuals were on-task to individual differences in the tendencies to be mindful or to mind-wander in daily life.

**Discussion**

There have been many studies of EEG correlates of states and traits associated with mindfulness and meditation, comparing: 1) meditators versus non-meditators, 2) meditators in the meditation state versus the resting-state, or 3) meditation-naive individuals before and after meditation training, versus no-training controls. According to some commentators, the most consistent finding across this heterogeneous literature is one of increased alpha power in association with meditation states (Cahn & Polich, 2006; Fell et al., 2010), which appears to apply across different levels of prior experience (Lomas et al., 2015). This is consistent with a proposed role for alpha in supporting control of internally-focused attention and inhibiting distractions (Fell et al., 2010). By categorizing EEG data according to self-reports about
attentional state, obtained through frequent experience-sampling "thought-probes," the present work examined EEG alpha in terms of momentary changes between focused attention versus mind-wandering, within a single meditation session. Results from using this method in the present work were straightforwardly consistent with core findings in the meditation-related EEG literature regarding alpha, i.e., greater alpha power was associated with greater concentrative focus on the instructed object of attention. Thus, the present results extend existing findings concerning meditation-related states at the level of shorter-term fluctuations in attention. Results were consistent with a previous effort to examine EEG correlates of momentary changes in attention during a BF task, but which required individuals to "self-catch" their own mind-wandering (Braboszcz & Delorme, 2011), and which also required participants to count their breath-cycles. Thus, it appears that EEG alpha power is robustly sensitive to changes in attentional-focus versus mind-wandering across meditation-like tasks, and whether self-reports about one’s conscious state are "probe-caught" or "self-caught" (Schooler et al., 2011). These findings were obtained even with an extremely sparse array of electrodes in the present work, further attesting to the robustness of the relationship between EEG alpha power and attention.

Moreover, the present work examined individual differences in EEG alpha, in relation to individual differences in mindfulness and mind-wandering: Greater tendencies to be mindful in daily life (trait-MF) were negatively related to alpha2 power overall, and greater tendencies to mind-wander (trait-MW) in daily life were positively related to alpha2 power overall, and these relationships substantially moderated the state-related alpha effect of being focused on one’s breathing rather than on task-unrelated thoughts. Although EEG alpha has previously been shown to be predictive of general alertness (e.g. Sadaghiani et al, 2010), this study documents its specific association with a chronic tendency to mind-wander. The findings that alpha2 power
was higher with increased tendencies to mind-wander in everyday life, and with decreased
tendencies to be mindful, appear paradoxical next to the state-related differences in alpha2
power, in which alpha2 power was greater when individuals were focused on the breath versus
mind-wandering. The trait-related individual differences in alpha2, with respect to individual
differences in mind-wandering, were in a sense opposite in direction to the state-related effect of
mind-wandering on alpha2 (i.e., higher tendencies to mind-wander in everyday life were
associated with higher alpha2 power, whereas mind-wandering in the meditation-analog task was
associated with lower alpha2 power). This relationship seems counter-intuitive, that greater
state alpha would be enhanced for being on-task in the meditation-analogue task, while greater
trait alpha was enhanced for more mind-wandering in daily life. However, these individual
differences may have a parallel with a similar inverse relationship observed in the literature, such
that more mindfulness practice was associated with longitudinal decreases in alpha power
(Lomas et al., 2015). It seems plausible that alpha2 may correspond to the effortful maintenance
of attention (see further discussion below) and that individuals with a propensity for focused
attention (either naturally arising or trained through meditation) may be less reliant on this form
of cognitive control.

Some authors have suggested that mind-wandering and mindfulness should be considered
"opposing constructs" (Mrazek et al., 2012), implying that low mindfulness is equivalent to high
mind-wandering, and vice-versa. Other authors have argued that mind-wandering and
mindfulness should not be considered as simply inverse versions of each other (e.g., Vago &
Zeidan, 2016). Regarding this controversy, the present results present a "glass half full"
situation, showing that tendencies to be mindful shared much common inter-individual variance
with tendencies to mind-wander, and these in turn shared much common inter-individual
variance with alpha2 power. The significant common variance among these constructs could be seen as support for the "opposing constructs" view. However, because the strengths of these relationships in no way approached unity, the present results can be seen as support for the "not opposing" view. This question merits further investigation.

The functional meanings of EEG alpha oscillations remain controversial (Shaw, 2003). One traditional view is that increased alpha reflects so-called "cortical idling" (Palva & Palva, 2007; Ward, 2003), based in part on the ubiquitous observation that alpha power is reduced with eyes-opened versus eyes-closed (the classic "Berger effect") (Bazanova & Vernon, 2014). However, current understanding is converging on the view that increased alpha reflects some kind of attentional filtering, via the active inhibition or suppression of distracting information, to support selective attention to target information (Knyazev, 2007; Palva & Palva, 2007; Ward, 2003), controlling access to "the knowledge system" (Klimesch, 2012). Suppression of internal and external distractions appears to be especially important to forms of cognition involving internal representations such as in memory and imagination (Fink & Benedek, 2014; Luckmann, Jacobs, & Sack, 2014; Ward, 2007). Thus EEG alpha has been proposed as a general index of "internal attention" (Benedek, Schickel, Jauk, Fink, & Neubauer, 2014; Fink & Benedek, 2014). The present findings are most consistent with this attentional-filtering interpretation of EEG alpha, in which higher alpha power reflected the active inhibition of unrelated thoughts during BF meditation.

Limitations and caveats

The present finding, of greater alpha2 power in on-task versus off-task states in focused-attention analog-task is overall consistent with the bulk of related investigations, showing greater alpha power in a meditation state versus a resting state (Lomas et al., 2015). However the
present results should considered within the context of the following limitations. First, approximately 50% of participant data were excessively contaminated with artifacts, resulting in much data-loss and consequently a small sample of individuals. Although this substantial level of data loss did lessen the statistical power of the present study, the resulting sample size nevertheless was similar to that of related studies (e.g.), Moreover, while our discard rate was high it has precedence even with studies using highly sophisticated equipment (e.g., Frishkoff, Tucker, Davey, and Scherg, 2004).

A related potential limitation of the present study was our reliance on visual inspection to remove artifacts from the EEG data, and to identify bivariate outliers. This necessarily introduces subjective judgment into data-screening, and it is plausible that our results may be in part influenced by these judgments. Admittedly, the present paradigm’s reliance on noisy EEG that required careful post-experimental filtering poses challenges for the feasibility of the suggested purpose of real-time neurofeedback, for monitoring and intervention, to enhance attentional skills.

Another limitation of the present study involves some uncertainties regarding recruitment and sampling. We recruited from a pool of individuals for whom prior exposure/experience with meditation was unknown. Neither did we screen participants for this attribute, nor did we obtain such information through interviews or questionnaires in the lab. As a result of these omissions, it is unknown to what extent our sample of participants was homogenous with respect to prior exposure/experience with meditation. Although this limitation is shared by other related studies (e.g. Braboszcz & Delorme, 2011) has been cited as an area needing improvement in meditation-related research (Davidson & Kaszniak, 2015; Lomas et al., 2015).
It is reasonable to expect that our college-age sample would contain few if any advanced meditators. Given the amount of hours of deliberate practice considered necessary to attain expertise in this discipline (Davidson & Kaszniak, 2015) or more generally, such individuals are expected to be rare in the general population (even more so among 20 year-olds). We did not recruit from a pool of known meditation practitioners, and our recruitment materials were designed to minimize self-selection in this respect. Therefore we think it can be cautiously assumed that our sample contained mostly individuals without prior formal training in meditation. Still it cannot be ruled out that the sample also included individuals with beginner-level or even intermediate-level training raising the potential question of how our results could have been affected by a mixed sample of individuals with different levels of prior exposure/experience, versus a homogenous sample of meditation-naive individuals.

Some authors have concluded that the relationship between increased alpha and meditative states is consistent across different levels of experience/expertise (Lomas et al., 2015). Under this hypothesis, the present findings would not have been much affected by whether the sample was homogeneous or heterogeneous regarding prior experience. However, other authors have suggested that with increasing experience and expertise in meditation, faster frequency rhythms such as gamma become more sensitive, and slower frequency rhythms such as alpha become less sensitive, for discriminating between meditation and resting states (Fell et al., 2010). Thus under this hypothesis, a mixed sample of individuals with different levels of proficiency would have obscured the present findings, because slower frequencies would have been sensitive to state-related changes among novice and beginner-level individuals, while faster frequencies would have been sensitive among the more advanced practitioners.
Interestingly in this connection, Marzetti and colleagues (2014) investigated differences in MEG functional connectivity among default-mode and executive attention network hubs, contrasting focused-attention, open-monitoring, and resting-state in a group of Buddhist monks, advanced meditators indeed. Notably, their findings were all specific to alpha frequency, which has a plausible basis in the observation of alpha dominance in both the dorsal attention and default-mode networks in the resting-state (Mantini et al., 2007). Nevertheless, the "frequency-shift" hypothesis, of EEG differences between novices and experts in meditation, merits much further investigation. To clarify this important issue it will be necessary to obtain more complete measurement of prior exposure/experience to meditation-related concepts and practices, ideally in a consistent method across studies (Davidson & Kaszniak, 2015; Lomas et al., 2015; Lutz et al., 2015).

The presentation times for the thought-probes raise another potential limitation for generalizing results of the present study. We varied the inter-probe times around an average of 30 seconds (25, 30, and 35 seconds). This was done so that thought-probes would not be perfectly predictable in time, yet the range was restricted with the intention to avoid introducing another variable into the design. To avoid reducing the signal-to-noise ratio of the EEG data, we did not examine it separately for each inter-probe time. This raises the question of whether the alpha results were influenced by psychological processes other than focused attention, such as expectancy or anticipation. Specifically, on trials in which the thought-probe occurred later (35 seconds) than the expected time (30 seconds, the average of inter-probe times), after 30 seconds participants could have begun to anticipate the thought-probe, a process that would "ramp up" according an increasing "hazard function" (see e.g., Nobre, Correa, & Coull, 2007). Indeed previous studies have shown effects of "temporal attention" on alpha (e.g., Babiloni et al. 2004,
Gomez et al. 2004; Min et al. 2008). However, these effects were observed during inter-stimulus intervals in the range of 1 – 3 seconds, not tens of seconds as in the present study. Moreover, they were obtained in task paradigms requiring frequent overt responses (detection or decision tasks). For example, Gomez and colleagues (2004) found reduced power in all frequencies (0 - 42.9 Hz) during a 2-second foreperiod (the inter-stimulus interval between a warning signal and an imperative stimulus), relative to baseline. Min and colleagues (2008) found that pre-stimulus alpha increased in constant (1.5 seconds) versus mixed (1.5sec to 2.5 sec) inter-stimulus interval conditions. Babiloni and colleagues (2004) found greater power in lower alpha (8 - 10 Hz) during short (600 ms) versus long (1400 ms) foreperiods, but no difference for upper alpha (10 - 12 Hz). It is difficult to extrapolate from these findings, to speculate about potential effects of anticipation in the current study, considering the extreme differences between task parameters.

We think it unlikely that individuals could accurately time intervals in the tens of seconds range with the required precision, when they were ostensibly focusing attention on their breath-cycles. This issue merits further investigation.

A related concern is that the results could have depended in part on a fortuitous choice of time-windows. The early and late time-windows were a convenient means of obtaining equal-length segments across the presentation times of the thought-probes, which varied among 25, 30, and 35 seconds, while trying to retain as much as possible of the original data between thought-probes. Our rationale for early and late time-windows was simply to assess how "far back" in time would alpha discriminate states of focused attention versus mind-wandering. However, results suggest there was not much difference in alpha2 power, between the first 10 seconds versus the last 10 seconds of a segment of data classified as on- versus off-task. This suggests that for the purpose of neurofeedback, tracking brain activity in real-time within 10 seconds may
be fine-grained enough to capture fluctuations between focused attention and mind-wandering states. This is consistent with previous results of Braboszcz and Delorme (2011), who reported time-frequency results showing that augmentation of alpha was at consistent levels across their time-windows.

**Summary and conclusions**

Mind-wandering is a ubiquitous feature of everyday cognition, leading to performance decrements in a wide range of task settings (Mooneyham & Schooler, 2013); and moreover, mind-wandering is frequently associated with negative affect (Killingsworth & Gilbert, 2010). Understandably, there is much interest in finding ways to remediate the widespread tendency to mind-wandering and/or ameliorate its consequences for cognition and affect. In modern society, effective pharmaceutical methods of changing cognition and affect continue to be highly prized. However, mindfulness/meditation represents an age-old antidote for mind-wandering and other psychological problems, highly portable, and recently achieving ever-increasing degrees of scientific validation (e.g., Sedlmeier et al., 2012). For these reasons, the neural underpinnings of meditation-related and mind-wandering-related states of consciousness merit further investigation, especially using direct measures of brain activation such as EEG. Present results contribute to this wider investigation, showing that EEG alpha power was greater during states of focused attention versus mind-wandering, observed in their fluctuations within a single session of a meditation-analog task. This result is consistent with the bulk of previous studies comparing EEG during meditation session versus separate session of rest (Lomas et al., 2015), and with a previous study also examining within-session changes in mind-wandering, but which used a "self-catching" method of obtaining self-reports (Braboszcz & Delorme, 2011). While discriminating between states of focused attention versus mind-wandering, alpha power was
associated individual differences in tendencies to be mindful or to mind-wander in everyday life. Notably, statistically controlling for these "trait-like" differences in alpha greatly attenuated the state-related effect. Thus, results indicate that upper alpha power would be a useful signal for covert monitoring of conscious states, particularly to develop neurofeedback programs to facilitate meditation training, and in an individualized manner (Brandmeyer & Delorme, 2013; see also Fingelkurts, Fingelkurts, & Kallio-Tamminen, 2015). Toward that end, the present research makes novel contributions in three main respects: 1) identifying EEG correlates of mind-wandering episodes that occurred within a single session of a meditation-like task, rather than comparing a session of meditation to one of rest; 2) demonstrating that these differences did not depend on participants proactively noticing that they were mind-wandering (i.e., using the probe caught rather than self caught assessment of mind wandering); and 3) documenting the paradoxical differences between the EEG markers that predict state versus trait mind wandering. Together these findings may help to advance both our understanding of the neurocognitive processes underpinning mind wandering, and the development of potential technologies to foster sustained attention.
References


Appendix A

Instructions for breath-focus meditation-analog task

In today's experiment, we will ask you to complete a mindful breathing exercise. During 10 6-minute trials, you will close your eyes and bring your awareness to the sensations of your breath. It's important that you take a comfortable but upright posture. Please try not fidget while you are completing the exercise. How do you know if you're breathing in or out? Usually there are sensations in your chest or abdomen. Simply pay attention to these sensations while you are breathing in and while you are breathing out. It's quite natural that you will become distracted from your breath. Whenever you notice this, please gently return your attention back to the breath. While you are completing this task, you will periodically hear the computer beep. Think of each beep as the computer checking-in to see where your attention was focused in that moment. If your attention was filled with a vivid awareness of the breath, you will respond by pressing the left [right] mouse button. If your attention was distracted from the breath, you will respond by pressing the right [left] mouse button. There is no need to open your eyes when you answer this question. After you provide your answer, simply return your attention back to the breath. We would like to give you a little practice to help you memorize which mouse button corresponds to which answer. [Participant practices the response-mapping for thought-probes.] Remember: If your attention was filled with a vivid awareness of the breath, you will respond by pressing the left [right] mouse button. If your attention was distracted from the breath, you will respond by pressing the left [right] mouse button. What do you press if you were vividly aware of the breath? After each 6-minute exercise, you will be given a minute to relax and stretch. You will know when each exercise is complete because a thunder sound will play. Before you press the button to begin, here's one last review of the key instructions: Close your eyes. Take a
comfortable upright posture. Pay attention to the sensation of your breath, and return your attention anytime you become distracted. When you hear the beep, answer the question and then return back to your breath. Press "b" and close your eyes to begin!
Author Notes

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Notes

Note 1. We reasoned that if the numbers of epochs were confounding for the BF effect on alpha2 power, numbers of epochs should be positively correlated with alpha2 power. However, no such correlation was significant, across time-windows and on- versus off-task states. For on-task responses, they were even consistently negative in direction, $r$s ranging from -.183 to -.367, $ps$ ranging from .196 to .532. For off-task responses, $r$s ranged from -.093 to .072, $ps$ ranged from .751 to .806. Therefore we conclude that the difference in numbers of EEG epochs between on- versus off-task states did not contribute to this result showing greater alpha2 power for on- versus off-task states.

Note 2. Correlational results were similar in direction and magnitude across BF conditions and time-windows.
### Table 1.

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*Note. N = 14. * p < .05, ** p < .01.*
Figure Captions

**Figure 1.** Mean (natural log-transformed) alpha2 power across BF conditions and time-windows (early, late). Error bars represent standard errors.

**Figure 2.** Scatterplots depicting relationship between alpha2 power and trait-MF (left panels) and trait-MW (right panels) for EEG corresponding to BF-on states (upper panels) versus BF-off (lower panels).