Clarifying the relationship between mindfulness and executive attention: a combined behavioral and neurophysiological study

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Abstract

Mindfulness is frequently associated with improved attention. However, the nature of the relationship between mindfulness and executive attention, a core function of the attentional system, is surprisingly unclear. Studies employing behavioral measures of executive attention have been equivocal. Although neuroscientific studies have yielded more consistent findings, reporting functional and structural changes in executive attention brain regions, the observed changes in brain activity have not been linked to behavioral performance. The current study aimed to fill these gaps in the literature by examining the extent to which trait mindfulness related to behavioral and neurophysiological (indexed by the stimulus-locked P3) measures of executive attention. Results revealed that higher trait mindfulness was related to less flanker interference on accuracy and reaction time, consistent with enhanced executive attention. Critically, mediational analyses showed that the P3 accounted for the relationship between trait mindfulness and executive attention performance, elucidating a neural mechanism through which mindfulness enhances executive attention.

Key words: mindfulness; executive attention; P3; congruency effects

Introduction

Mindfulness has received accelerated interest from various sectors of society, with media, corporations and schools touting the benefits of mindfulness for work productivity, academic performance and other cognitively demanding tasks (Boyce, 2011). In response to this surging popularity, researchers have cautioned that public enthusiasm for mindfulness may be outpacing scientific progress (Van Dam et al., 2018). Indeed, mindfulness is a relatively nascent topic of scientific inquiry, and although substantial work has been devoted to understanding the effects of mindfulness, far less is known about how it works. More than ever, concerted efforts aimed at elucidating the underlying mechanisms of mindfulness are needed to both understand and validate its effects—ultimately, to determine the extent to which the ‘hype’ is warranted.

Part of the impetus behind the ‘mainstreaming’ of mindfulness is a growing scientific literature supporting its benefits to attention (see Chiesa et al. 2011; Hölzel et al., 2011; Tang et al., 2015, for reviews). Theoretically, attention is widely regarded as a core aspect of mindfulness that cuts across its different aspects as a polylithic psychological construct (e.g. state, trait, meditative practice and therapeutic intervention; Brown and Ryan, 2003; Bishop et al., 2004; Shapiro et al., 2006; Hölzel et al., 2011; Vago and Silbersweig, 2012; Tang et al., 2015). For example, mindfulness meditation typically involves moment-to-moment application, sustainment and redirection (in the event of distraction) of attention to a target object (Lutz et al., 2008). Consistent practice over time has been associated with trait-like changes in attentional brain networks, ostensibly constituting a neural mechanism through which the abilities cultivated during training transfer ‘off the cushion’ into daily life (Hasenkamp
and Barsalou, 2012). Consequently, understanding the nature of the relationship between mindfulness and attention appears pertinent for elucidating the mechanisms involved in mindfulness and its seemingly far-reaching impact on a variety of life functions (e.g. occupational performance).

Reviews have generally associated mindfulness with improved attention (Chiesa et al., 2011; Hölzel et al., 2011; Vago and Silbersweig, 2012; Tang et al., 2015). Attention, like mindfulness, however, is a complex multidimensional construct that is often divided into three distinct but interrelated networks (Petersen and Posner, 2012): (i) alerting, defined as readiness or preparation for an impending stimulus; (ii) orienting, defined as the selective targeting of specific sensory input based on modality or location; and (iii) executive attention (also referred to as conflict monitoring), defined as the goal-directed monitoring of task-relevant stimuli in the midst of competing task-irrelevant stimuli. A closer examination of the literature at the subnetwork level reveals a more nuanced state of affairs.

With regard to alerting, short-term training studies have not yielded significant effects (Jha et al., 2007; Tang et al., 2007), whereas long-term mindfulness training and intensive meditative experience appear to relate to improved alerting (Pagnoni and Cekic, 2007; MacLean et al., 2010). Improvements in orienting, on the other hand, have been reported in both short- and long-term training studies (Jha et al., 2007; MacLean et al., 2010), in addition to cross-sectional studies comparing meditators with controls (van den Hurk et al., 2010).

Interestingly, studies on the relationship between executive attention and mindfulness have been the most equivocal and inconclusive. Of the five prospective training studies reviewed in Chiesa et al. (2011), three studies reported positive outcomes (Tang et al., 2007; Wenk-Sormaz, 2005; Jha et al., 2007), but the other two reported no change (Polak, 2009; Anderson et al., 2007). More recent randomized controlled studies are also mixed. Semple (2010) and Jossefsson et al. (2014) did not detect changes in behavioral measures of executive attention, whereas Smart and Segalowitz (2017) reported faster reaction times in addition to cross-sectional studies comparing meditators with non-meditators (Tang et al., 2007; Wenk-Sormaz, 2005; Jha et al., 2007), but the other two reported no change (Polak, 2009; Anderson et al., 2007). More recent randomized controlled studies are also mixed. Semple (2010) and Jossefsson et al. (2014) did not detect changes in behavioral measures of executive attention, whereas Smart and Segalowitz (2017) reported faster reaction times in addition to cross-sectional studies comparing meditators with controls (van den Hurk et al., 2010).

Indeed, neuroimaging research appears to support the existence of a relationship between mindfulness and executive attention (Tang et al., 2015). Specifically, Tang et al. (2015) noted that mindfulness training studies of attention have most consistently detected changes in the anterior cingulate cortex (ACC)—a region that has been extensively implicated in executive attention (Botvinick et al., 2004; Bush et al., 2000; Posner et al., 2007; Peterson and Posner, 2012). Cross-sectional designs yield similar findings, reporting enhanced ACC activation (Hölzel et al., 2007; Gard et al., 2012) and cortical thickness (Grant et al., 2010) in experienced meditators relative to novice controls. Moreover, other longitudinal training studies have found activation changes in the prefrontal cortex (Allen et al., 2012; Hölzel et al., 2013; Zeidan et al., 2013), another key region of executive attention (Kane and Engle, 2002).

Although these studies have yielded considerable evidence supporting mindfulness-related changes in executive attention brain regions, crucial questions remain about whether or how these changes relate to behavioral measures of executive attention. Further complicating matters is that, as summarized above, behavioral measures of executive attention have not been reliably linked to mindfulness. We view these issues as a by-product of two long-standing interrelated challenges associated with neurocognitive mindfulness research. First, it is difficult to obtain precise measures of the interplay between brain and behavior. For example, the oft-discussed temporal constraints of functional magnetic resonance imaging preclude a time-sensitive mapping between mindfulness-related changes in regional activation and online task performance. Second, this limitation is compounded by the polythetic nature of mindfulness as a construct, such that reported effects (or lack thereof) may be confounded by a variety of idiosyncratic (e.g. trait mindfulness and meditative experience), training (e.g. didactics, practice frequency and duration) and task-related confounds (e.g. engaging in state mindfulness during a ‘non-mindful’ task condition). That is, in order to obtain consistent findings and draw meaningful conclusions about the nature of the mindfulness–executive attention relationship, it may be prudent for studies to examine the interplay between brain and behavior while accounting for confounds associated with construct heterogeneity. Consequently, a reasonable first step may be to examine the extent to which trait mindfulness, in a meditation-naïve sample, relates to behavioral and neural indices of executive attention. This approach leverages natural variability in trait mindfulness while minimizing confounds associated with the other aspects of mindfulness (e.g. meditative experience).

Indeed, the purpose of the current study was to explore the relationship between trait mindfulness and executive attention by utilizing a combined behavioral and neurophysiological paradigm. Toward this end, we leveraged the versatility and temporal precision of electroencephalography to record neural activity during performance of the Eriksen Flankers task (Eriksen and Eriksen, 1974), a classic executive attention task (Rueda et al., 2005). In the flanker task, the task-relevant (target) and task-irrelevant (flankers) stimuli either elicit the same response (congruent) or opposite responses (incongruent). A primary axiom is that executive attention is needed to resolve competing response representations elicited from the flanking arrows. Consequently, behavioral indices of executive attention are typically computed as the relative performance...
In this light, executive attention exhibits considerable theo-
retical overlap with mindfulness, such that present moment
conscious awareness cuts across both constructs. During
mindfulness meditation, present moment awareness is directed
toward arising internal experience in the midst of cognitive
distraction (e.g. rumination and elaboration); during the flan
kler task, awareness is repeatedly directed toward the central
target stimulus in the midst of flanking stimuli. As such, we
advance the position that executive attention is a core aspect
of mindfulness that cuts across its different facets. Not only is
executive attention recruited during mindfulness training and
possibly strengthened as an effect of training, but individuals
with higher levels of trait mindfulness are also expected to
possess superior executive attention ability relative to those
who are less dispositionally mindful.

One critical caveat, however, is that trait mindfulness is itself
a diverse, polythetic construct and its measurement subject
to considerable debate (Grossman, 2011). In response to the
varied semantic definitions of mindfulness and accompanying
methodological challenges, the Five-Factor Mindfulness Ques-
tionnaire (FFMQ; Baer et al., 2006) was developed to capture
the different facets of trait mindfulness: observing, describing,
acting with awareness, non-judging and non-reactivity. Among
these facets, the acting with awareness subscale (FFMQ-AA)
measures the propensity to attend to the present moment. Given
our theoretical framework, the FFMQ-AA, or what we deem
trait mindful awareness, appears to be the most relevant facet of
trait mindfulness in the broader mindfulness–executive attention
relationship. Specifically, items on the FFMQ-AA pertain to the
degree of attentional awareness in everyday life (e.g. ‘It seems
I am “running on automatic” without much awareness of what
I’m doing’), as opposed to technical abilities or personal qualities
developed through contemplative training (Brown and Cordon,
2009; Goodman et al., 2015). Equally important, the FFMQ-AA has
been shown to relate to neural measures of motivated attention
(Brown et al., 2012; Lin et al., 2016) and behavioral measures of
executive attention (Di Francesco et al., 2017), demonstrating its
sensitivity to multimodal measures of attention.

Therefore, we expected that trait mindful awareness would
be related to improved behavioral and neural measures of exec-
utive attention. Specifically, trait mindful awareness should be
related to smaller flanker interference effects on RTs and accu-
<snip>
could minimize potential gender-related confounds in the broader mindfulness-executive attention relationship. Three participants were excluded from the analyses because of a failure to follow instructions regarding the stimulus-response mapping (see below) that resulted in an error rate exceeding 50%. The final sample consisted of 60 participants. Psychopathology and medication use were not assessed for inclusion in the study. No participants discontinued their involvement after consenting.

Flanker task
Participants completed an arrow version of the Eriksen flankers task (Eriksen and Eriksen, 1974). Participants were seated ∼60 cm in front of a computer monitor and instructed to respond to the center arrow of a five-arrow string in which the target was either congruent (e.g. <<><<> <> or >><><>) or incongruent (e.g. <<><<> or >><><>) with the surrounding (i.e. flanking) arrows. Characters were displayed in a standard white font on a black background and subtended 1.3 degrees of visual angle vertically and 9.2 degrees horizontally. The task was administered on a Pentium P4 Dual Core computer using E-Prime software (Psychology Software Tools, Inc. Sharpsburg, PA 15215-2821 USA), which facilitated stimuli presentation and response measurement.

During each trial, arrows were presented for 200 ms. Participants were given 950 ms to respond before the next intertrial interval began. During the intertrial interval, a fixation cross (∼) was displayed and varied in duration between 600 and 1000 ms. The experimental session included 512 trials grouped into 8 blocks of 64 trials. Half of the trials in each block were congruent and half were incongruent. Participants were instructed to respond as quickly and accurately as possible using either their right index or middle finger to select the left and right mouse buttons, respectively, that corresponded with the target direction. To encourage speed, accuracy and sufficient error commission, performance-based feedback was presented at the end of each block. If performance accuracy fell below 75%, participants were instructed to respond more accurately. When performance was above 90%, participants were instructed to respond faster. Accuracy in between 75% and 90% elicited the feedback ‘You’re doing a great job’.

Trait mindfulness
Trait mindful awareness was measured by scores on the acting with awareness subscale on the FFMQ (Baer et al., 2006). Scores on the other four facets were used to measure (i) observing (FFMQ-O), defined as noticing internal and external experiences; (ii) describing (FFMQ-D), defined as verbal articulation of internal experiences; (iii) non-judging (FFMQ-NJ), defined as adopting a non-evaluative perspective towards thoughts and feelings; and (iii) non-reactivity (FFMQ-NR), defined as allowing inner experiences to pass without attachment or elaboration. Participants responded to the 39-item subscale using a 5-point Likert scale ranging from 1 (never or very rarely true) to 5 (very often or always true).

Psychophysiological recording and data reduction
Participants were fitted with a 64-channel stretch-lycra cap. Continuous electroencephalographic activity was recorded using the BioSemi ActiveTwo system (BioSemi, Amsterdam, the Netherlands). Recordings were taken from 64 Ag–AgCl electrodes placed in accordance with the 10/20 system. Two additional electrodes were placed on the left and right mastoids. Electrooculogram activity generated by eye movements and blinks was recorded at FP1 and at three electrodes placed inferior to the left pupil and on the left and right outer canthi ∼1 cm from the pupil. During data acquisition, the common mode sense active electrode and driven right leg passive electrode formed the ground, as per BioSemi’s design specifications. All signals were digitized at 1024 Hz.

Offline analyses were conducted using BrainVision Analyzer 2 (BrainProducts, Gilching, Germany). Scalp electrode recordings were referenced to the numeric mean of the mastoids and band-pass filtered with cutoffs of 0.1 and 30 Hz (12 dB/oct roll-off). Ocular artifacts were corrected using the regression method developed by Gratton et al., (1983). Physiological artifacts were detected using a computer-based algorithm such that trials in which the following criteria were met were rejected: a voltage step exceeding 50 μV between sampling points, a voltage difference of > 300 μV within 200 ms intervals, voltage exceeding ± 200 μV or a maximum voltage difference > 0.5 μV within 100 ms intervals. ERPs were locked to stimuli (i.e. flankers) onset, with a 200 ms pretrial baseline correction. In accordance with the literature, only correct responses were included in the final average for P3 measurement (Frühholz et al., 2011; Clayson and Larson, 2011; Rietdijk et al., 2014). In line with the collapsed localizer method (Luck and Gaspelin, 2017), the P3 was then quantified as the average activity occurring between 450 and 650 ms post-stimulus onset at the centro-parietal recording site Cpz—where the amplitude was maximal (Figure 1). A voltage map for the incongruent–congruent difference wave for the P3 is also presented in Figure 1.

Overview of analyses
Behavioral and ERP measures were statistically analyzed using SPSS software (version 23.0). Specifically, behavioral data were submitted to repeated measures analyses of variance (rANOVs) and paired t-tests. Partial eta squared (η²) is reported as an estimate of effect size in ANOVA models where 0.05 represents a small effect, 0.1 a medium effect and 0.2 a large effect (Cohen, 1973). Overall numbers of errors were submitted to a paired t-test to compare performance accuracy as a function of stimulus type (congruent vs incongruent). Overall RTs were submitted to a two stimulus-type (congruent vs incongruent)–two accuracy (correct vs error) rANOVA. When significant interactions emerged, follow-up t-tests were conducted to aid in the interpretation of results. Degrees of freedom varied slightly among the F-tests because of performance variability (e.g. a participant making no errors on congruent trials is excluded from analyses involving congruency). As is standard, congruency effects on accuracy and RTs were computed as the difference in errors and difference in correct response RTs between incongruent and congruent trials, respectively. For ERP analyses, a paired t-test was used to compare P3 amplitudes as a function of stimulus type (congruent vs incongruent) to confirm the well-established effect that P3 amplitudes are larger on incongruent relative to congruent trials. In subsequent analyses, AP3 was quantified as the difference in amplitude between incongruent and congruent stimuli.

To achieve the primary aim of the current study, correlational analyses involving associations among FFMQ-AA, behavioral performance measures (i.e. congruency interference effects
Fig. 1. Left: stimulus-locked, grand average waveforms depicting congruent P3, incongruent P3 and ΔP3 amplitudes at electrode CPz. Time 0 is the stimulus onset. Right: scalp topography depicting voltages of the ΔP3, quantified as the average activity between 450 and 650 ms following stimulus onset.

on error rate and RTs) and ΔP3 were conducted to determine the extent to which trait mindfulness related to behavioral and neural measures of executive attention. Moreover, two mediation models were tested to examine whether online neural processing (ΔP3) mediated the expected relationships between mindfulness and behavior. The analyses were performed using the SPSS macro from Preacher and Hayes (2008). In accordance with the recommendations outlined in Preacher and Hayes (2004), a bootstrapping procedure involving 5000 samples with a 0.95 confidence interval (CI) was used to test indirect effects. To explore the relationships between executive attention and the other facets of trait mindfulness, the analyses were repeated separately for FFMQ-O, FFMQ-D, FFMQ-NJ and FFMQ-NR.

Results

Descriptive statistics for behavioral, ERP and FFMQ are presented in Table 1.

### Establishing basic effects of behavioral and ERP measures of executive attention

Overall flanker task accuracy was relatively high (M percent correct = 87.47%, s.d. = 4.60%). As expected, participants made an average of 59.13 errors (s.d. = 21.79), with more errors on incongruent trials (M = 43.67, s.d. = 17.23) than congruent trials [M = 15.47, s.d. = 8.45, t(59) = 13.51, P < 0.01, d = 1.96].

The analysis of s.d.s revealed main effects of accuracy and congruency, such that RTs on correct trials (M = 43.67, s.d. = 17.23) than congruent trials [M = 15.47, s.d. = 8.45, t(59) = 13.51, P < 0.01, d = 1.96].

As expected, P3 amplitudes were larger on incongruent trials (M = 4.74, s.d. = 2.58) relative to congruent trials [M = 2.71, s.d. = 2.25, t(59) = 9.48, P < 0.01, d = 0.83; see Figure 1].

In summary, behavioral and ERP measures reflected the expected effects of executive attention in the flanker task (i.e. stimulus congruency), such that a greater number of errors, slower RTs and a larger P3 characterized incongruent stimuli.

### Relationships between behavioral performance and trait mindful awareness

Consistent with expectations, higher trait mindful awareness was associated with better executive attention such that higher

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<table>
<thead>
<tr>
<th>Variable</th>
<th>M</th>
<th>s.d.</th>
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<tbody>
<tr>
<td>Number of errors</td>
<td>59.13</td>
<td>21.79</td>
</tr>
<tr>
<td>Number of corrects</td>
<td>445.40</td>
<td>24.43</td>
</tr>
<tr>
<td>Incongruent errors</td>
<td>43.67</td>
<td>17.23</td>
</tr>
<tr>
<td>Congruent errors</td>
<td>15.47</td>
<td>8.45</td>
</tr>
<tr>
<td>Δ Errors</td>
<td>28.20</td>
<td>16.17</td>
</tr>
<tr>
<td>Error RT (ms)</td>
<td>335.64</td>
<td>56.34</td>
</tr>
<tr>
<td>Correct RT (ms)</td>
<td>421.22</td>
<td>44.38</td>
</tr>
<tr>
<td>Incongruent error RT (ms)</td>
<td>340.61</td>
<td>64.48</td>
</tr>
<tr>
<td>Incongruent correct RT (ms)</td>
<td>345.12</td>
<td>46.68</td>
</tr>
<tr>
<td>Congruent error RT (ms)</td>
<td>321.55</td>
<td>52.99</td>
</tr>
<tr>
<td>Congruent correct RT (ms)</td>
<td>395.35</td>
<td>43.39</td>
</tr>
<tr>
<td>Δ RT (ms)</td>
<td>55.78</td>
<td>17.98</td>
</tr>
<tr>
<td>Incongruent P3 amplitude (μV)</td>
<td>4.74</td>
<td>2.58</td>
</tr>
<tr>
<td>Congruent P3 amplitude (μV)</td>
<td>2.71</td>
<td>2.25</td>
</tr>
<tr>
<td>Δ P3 amplitude (μV)</td>
<td>2.03</td>
<td>1.66</td>
</tr>
<tr>
<td>FFMQ-AA</td>
<td>26.23</td>
<td>5.93</td>
</tr>
<tr>
<td>FFMQ-O</td>
<td>26.80</td>
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<tr>
<td>FFMQ-D</td>
<td>27.69</td>
<td>7.91</td>
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<tr>
<td>FFMQ-NJ</td>
<td>26.95</td>
<td>5.88</td>
</tr>
<tr>
<td>FFMQ-NR</td>
<td>19.73</td>
<td>4.34</td>
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Note: Δ Errors, Δ RT and Δ P3 denote the difference in errors, RT and P3 amplitude, respectively, between incongruent and congruent trials.
FFMQ-AA scores were associated with a smaller incongruent–congruent difference in errors ($r = -0.30, P = 0.02$) and RTs ($r = -0.35, P = 0.01$). Follow-up analysis demonstrated that these relationships were primarily driven by performance on incongruent trials such that high FFMQ-AA participants committed fewer errors ($r = -0.30, P = 0.02$) and were faster ($r = -0.35, P = 0.01$) on incongruent trials relative to lower FFMQ-AA participants. See Figure 2 for scatter plots of the reported correlations.

**Relationships between P3 amplitude and trait mindful awareness**

Furthermore, we found a significant negative relationship between trait mindful awareness and the $\Delta$P3, such that higher FFMQ-AA scores were associated with smaller $\Delta$P3 amplitudes ($r = -0.29, P = 0.03$). Follow-up analysis revealed that this relationship was driven by higher FFMQ-AA scores relating to smaller P3 amplitudes on incongruent trials ($r = -0.26, P = 0.05$), but not congruent trials ($r = -0.08, P = 0.54$). See Figure 3 for scatter plots of the reported correlations.

**The mediating role of the $\Delta$P3 in the relationship between trait mindful awareness and performance**

The mediation analyses revealed significant indirect effects for both models, such that smaller $\Delta$P3 amplitudes mediated the observed negative relationship between trait mindful awareness and smaller flanker interference effects on behavioral performance (indirect effect on errors: $B = -0.34$ and 95% CI, $-0.76, -0.09$; indirect effect on RTs: $B = -0.27$ and 95% CI, $-0.75, -0.02$). See Figure 4 for a visual depiction of the models with effect sizes of the direct and indirect paths.

**Relationships between executive attention and the other facets of trait mindfulness**

FFMQ-D, FFMQ-NJ and FFMQ-NR did not relate to the incongruent–congruent difference in errors ($r_s < 0.09$, $P_s > 0.48$), RTs ($r_s < 0.15$, $P_s > 0.25$) or $\Delta$P3 ($r_s < 0.08$, $P_s > 0.56$). Interestingly, FFMQ-O was positively correlated with the incongruent–congruent difference in errors ($r = 0.26, P = 0.05$) but not in RT ($r = 0.09, P = 0.47$), or $\Delta$P3 ($r = 0.22, P = 0.10$). Mediation analyses were not conducted because the prerequisite conditions (i.e.
Fig. 3. Scatterplots depicting P3 amplitude as a function of trait mindfulness (FFMQ-AA). Left: negative correlation between congruency difference (incongruent–congruent) in P3 amplitude (ΔP3) and FFMQ-AA, such that as FFMQ-AA increases, ΔP3 decreases. Right: significant negative correlation detected between FFMQ-AA and P3 amplitudes elicited on incongruent (dotted line), but not congruent trials (solid line). As FFMQ-AA increases, P3 amplitudes elicited on incongruent trials decreases.

Fig. 4. Mediation models depicting the relationship between trait mindfulness (FFMQ-AA) and the congruency (incongruent–congruent) difference in errors (Δerrors) and RT (ΔRT), as mediated by the congruency difference in P3 amplitude (ΔP3). The value in the parentheses indicates the relationship between FFMQ-AA and ΔP3 after controlling for ΔAP3. Statistical significance is demarcated by asterisks (*P < 0.05, **P < 0.01).

causal variable significantly correlating with both outcome and mediator) were not met (Baron and Kenny, 1986).

Discussion

Despite numerous studies, the relationship between mindfulness and executive attention remains unclear. The present study sought to clarify the nature of this relationship by examining the relationship between trait mindful awareness and behavioral and online neural measures of executive attention. Moreover, we leveraged our multimodal approach to fill a pertinent gap in the literature—namely, to delineate a specific neural mechanism through which mindfulness improves behavioral measures of executive attention.

Broadly, our findings support the presence of a positive relationship between mindfulness and executive attention. First, trait mindful awareness was related to less congruency interference on accuracy and RT, reflecting enhanced executive attention. These reductions in congruency interference effects were primarily driven by improved performance on incongruent trials. Second, analysis of the P3 revealed that higher trait mindful awareness was associated with smaller congruency interference on P3 amplitudes (i.e. ΔP3). Similar to performance accuracy, the negative association between trait mindful awareness and ΔP3 was likewise driven by smaller P3 amplitudes on incongruent, but not congruent trials. Indeed, trait mindful awareness was most related to performance and neural activity on incongruent trials—a trial type that inherently demands greater recruitment of executive attention, thereby illustrating the specificity of the relationship between mindful awareness and executive attention.

Combining ERP and behavioral measures, the mediation analyses revealed that smaller ΔP3 amplitudes mediated the reported relationships between higher trait mindful awareness and smaller congruency interference effect on both accuracy and RT. To the extent that ΔP3 reflects modulation of attention to response conflict (Clayson and Larson, 2011; Groom and Cragg, 2015), our data show that participants with high trait mindful awareness allocated fewer attentional resources to resolve the conflict between incongruent and congruent stimuli—i.e. a smaller P3 difference between the two trial types. In turn, this reduced discrepancy in attentional processing between incongruent and congruent stimuli attenuated the subsequent interference effects on performance.

Interestingly, the ancillary analyses involving the other four facets of trait mindfulness suggested that executive attention is uniquely related to trait mindful awareness. With the exception that higher trait mindful observation (FFMQ-O) related to greater congruency interference on error rate, no other relationships were detected. Given that trait mindful observation was only related to congruency interference on accuracy, but not RT or ΔP3, in conjunction with the lack of a prior theoretical foundation to anticipate this result, we can only speculate that, (i) conservatively, trait mindful observation is unlikely related to executive attention and (ii) the unique positive directionality of the relationship may reflect the extent to which the propensity to notice internal and external stimuli detracts attention from the task.

Theoretical significance

Our findings strongly support our theoretical position that mindfulness and executive attention are overlapping constructs, insofar as trait mindful awareness, one specific facet of the broader construct of trait mindfulness, is intimately and uniquely related to executive attention. One explanatory mechanism through which trait mindful awareness attenuates ΔP3
may be via enhanced focal attention to the target. Not only have several longitudinal mindfulness training studies supported this premise (see reviews by Chiesa et al., 2011; Tang et al., 2015; Hölzle et al., 2011; Smart et al., 2016), but individuals with high trait mindfulness, in particular, have also been observed to exhibit increased functional activation in brain regions implicated in sustained attention (Dickenson et al., 2012). By increasing focal attention on the target arrow, fewer attentional resources are allocated to the flanking arrows. This, in turn, attenuates the potency of the incorrect response representations elicited by incongruent flankers and is evidenced by smaller P3 amplitudes (Clayson and Larson, 2011; Groom and Cragg, 2015). Thus, by increasing focus on the target arrow, incongruent and congruent stimuli are processed more similarly. Consequently, this reduces the congruency interference effect, culminating in improved behavioral performance of executive attention.

Our interpretation underscores the interrelated, functionally dependent nature of different attentional processes in the recruitment of executive attention (Rueda et al., 2005). Furthermore, because all measures reflected congruency interference, our findings strongly suggest a specific relationship between mindfulness and executive attention (Fan et al., 2003a; Fan et al., 2003b). As such, calls to remove executive attention from theoretical cognitive models of mindfulness appear premature and unwarranted (Joseffson and Broberg, 2014). The current study demonstrated that trait mindful awareness and executive attention, measured across multiple levels of analysis, are related constructs that reside within the same nomological network.

Methodological implications and future directions

The ambiguity surrounding the mindfulness–executive attention relationship from previous studies may be attributable to construct heterogeneity and method variance. On one hand, the porous boundaries between the different aspects of mindfulness introduce significant theoretical and methodological challenges (Vago and Silbersweig, 2012; Van Dam et al., 2018). For example, the observed effects of mindfulness training studies are likely influenced by a confluence of factors related to other aspects of mindfulness such as trait mindfulness, state mindfulness, meditative experience and meditative style. Likewise, measures of executive attention are not homogenous. The flanker and Stroop tasks, two of the most widely employed measures, demonstrate differences in behavioral performance, ERPs (Tillman and Wiens, 2011; Riesel et al., 2013), regional brain activation (Nee et al., 2007) and even genetic heritability of performance (Stins et al., 2004). Slight variations of the same task have also produced meaningful differences in outcomes (Salo et al., 2001; Lin et al., 2015). Taken together, the inconsistency among studies of mindfulness and executive attention likely speak more to construct and method variance rather than the nature of the relationship per se.

To this end, the current study may serve as a building block for future studies. By examining trait mindfulness in an all-female, meditation-naïve sample, we circumvented many of the aforementioned issues related to construct heterogeneity and task-related confounds (e.g. sex differences in P3 amplitudes). One obvious future direction will be to determine whether the reported effects extend to males. There is a nascent but emerging body of evidence to suggest the presence of gender differences in interest, responsivity and neural change to mindfulness interventions (Simpson et al., 2007; Chen et al., 2010; de Vibe et al., 2013; Luders et al., 2015). Given the existence of gender differences across clinical psychology (Al-Issa, 1982) and neuroscience (Cahill, 2006), consideration of sex appears pertinent toward advancing basic understanding of mindfulness and refining mindfulness-based interventions.

Although the current sample size (n = 60) is larger than most neurocognitive studies of mindfulness, the sample size is still modest and likely undermines the statistical power of the study. The sample size, in conjunction with the exploratory aspects of our study (e.g. testing mediation of the P3, repeated analysis involving the other facets of trait mindfulness) renders our findings preliminary. Consequently, we strongly caution against over interpretation and undue generalization of our data. It goes without saying that we encourage future studies to replicate our findings.

Future studies are also encouraged to adopt our task measures to determine the extent to which mindfulness training or other experimental manipulations of mindfulness (e.g. state mindfulness inductions) modulates executive attention in similar ways as trait mindfulness. Research on mindfulness and emotion processing involving the late positive potential (LPP) exemplifies the promise of this suggestion. Extending Brown et al.’s (2012) finding that high trait mindfulness relates to reduced LPP amplitude to negative emotional images, Lin et al. (2016) adopted their measures to uncover that brief mindfulness training, but not state mindfulness, attenuated the LPP similarly to individuals with high trait mindfulness. That is, measures that are sensitive to trait mindfulness may extend to experimental manipulations of mindfulness, creating the basis for a systematic research process that manages construct and method variance in an organized fashion. Toward this end, a recent study by Smart et al. (2016) offers preliminary support for the longitudinal sensitivity of the P3, finding that mindfulness training enhanced the go/no-go P3 and reduced reaction time variability in individuals with subjective cognitive decline. Although the P3 was elicited from a different task of executive function, there is nonetheless a promise that the P3 may be sensitive to extended mindfulness training and is clinically relevant. As a direct follow-up to the current study, our research team is examining whether the flanker P3 is modulated by a brief, one-time mindfulness training in a significantly larger sample (N = 200+). Future longitudinal studies are encouraged to examine the extent to which change in the P3 relates to change in behavioral performance across multiple tasks of executive attention. Such analyses would yield valuable data to test the theoretical propositions advanced here.

Indeed, incremental research involving standardized measures across studies may be a fruitful foundation from which to address the current challenges of the field (Van Dam et al., 2018). In this vein, we view our study as a direct response to two interrelated recommendations that have rapidly emerged to the top of the ‘prescriptive’ agenda for improving contemplative science (Van Dam et al., 2018; Tang et al., 2015; Lutz et al., 2015): (i) adoption of a multimodal approach so that first- (e.g. self-report) and third-person (e.g. neural) measures are analyzed to inform one another; and (ii) neuroscientific studies of mindfulness, in particular, must not solely rely on neural measures but examine the extent to which neural modalities relate to behavior. Not only does the current study demonstrate the utility of these recommendations, but it also illustrates the importance of grounding research in theory. Specifically, when examining mindfulness in relation to another construct (i.e. executive attention), it is imperative to consider the theoretical underpinnings of each construct and to identify potential areas of overlap that can inform the development of the research question, selection
of measures (e.g. FFMQ-AA and P3) and generation of specific predictions. Otherwise, there is increased susceptibility to equivocate data elicited from various measures of a construct with the construct itself, possibly leading to erroneous (and often sweeping) conclusions that are theoretically untethered.

**Applied significance and current relevance**

At a broader level, our findings represent empirical evidence for the mind–brain–behavior model which undergirds clinical neuroscience, demonstrating that individual differences in the propensity to engage in a particular psychological state modulated neural processing in ways that influence goal-directed behavior. Consonant with national health priorities (see NCCIH, 2018), understanding the neural mechanisms through which mindfulness confers its salutary effects on executive attention, is essential for identifying novel outcome measures, developing effective interventions and understanding the mind–brain relationship more broadly.

**References**


