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Trait Mindfulness Predicts Efficient Top-Down Attention to and Discrimination of Facial Expressions

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Abstract

In social situations, skillful regulation of emotion and behavior depends on efficiently discerning others' emotions. Identifying factors that promote timely and accurate discernment of facial expressions can therefore advance understanding of social emotion regulation and behavior. The present research examined whether trait mindfulness predicts neural and behavioral markers of early top-down attention to, and efficient discrimination of, socioemotional stimuli. Attention-based event-related potentials (ERPs) and behavioral responses were recorded while participants ($N = 62$; White; 67% female; $M_{age} = 19.09$ years, $SD = 2.14$ years) completed an emotional go/no-go task involving happy, neutral, and fearful facial expressions. Mindfulness predicted larger (more negative) N100 and N200 ERP amplitudes to both go and no-go stimuli. Mindfulness also predicted faster response time that was not attributable to a speed-accuracy trade-off. Significant relations held after accounting for attentional control or social anxiety. This study adds neurophysiological support for foundational accounts that mindfulness entails moment-to-moment attention with lower tendencies toward habitual patterns of responding. Mindfulness may enhance the quality of social behavior in socioemotional contexts by promoting efficient top-down attention to and discrimination of others' emotions, alongside greater monitoring and inhibition of automatic response tendencies.

Social situations involve unique challenges for regulating emotion and behavior. Facial expressions alone, because they are a rich source of information about others' emotions, can automatically orient behavior toward danger or safety (Darwin, 1872; Fox, 2002; Mineka & Cook, 1993; Sorce & Emde, 1981). Unpleasant facial expressions have been shown to evoke automatic withdraw-oriented processing, whereas pleasant facial expressions evoke approach-oriented processing (Hare, Tottenham, Davidson, Glover, & Casey, 2005). However, automatic responses to others' emotions may not always function adaptively when, for example, a person withdraws in the face of another's fear or anger. In many cases, goal achievement is dependent on goal-directed monitoring and regulation of automatic approach/withdraw responses to salient stimuli (Berkman & Lieberman, 2010). Successful social behavior likewise depends on regulating these responses to others' emotions (Cacioppo, 2002; Eisenberg, Fabes, Guthrie, & Reiser, 2000; Eisenberg, Spinrad, & Morris, 2002; Hare et al., 2005; Kanske, Heissler, Schonfelder, Bongers, & Wessa, 2011; Lopes, Salovey, Coté, & Beers, 2005).

Accurate discrimination of others' emotional expressions is key to understanding the skillful regulation of emotion and behavior in socioemotional contexts (Tottenham, Hare, & Casey, 2011). Because basic discrimination processes depend on early selective attention (Vogel & Luck, 2000), regulating emotion and behavior in the presence of others' emotions demands efficient top-down (voluntary) selective attention to facial expressions to discriminate one expression from another. Additionally, top-down executive attention facilitates the monitoring and inhibitory control of automatic behavioral responses. Investigating early attention to emotional information is important for understanding emotion regulation generally (Todd, Cunningham, Anderson, & Thompson, 2012), as it influences later "downstream" emotion processes, for better or worse (Sheppes & Gross, 2011). This research highlights the importance of investigating psychological factors that may influence both early attention to and discrimination of emotional facial expressions, which may thereby influence emotion regulation and behavior in socioemotional contexts.

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Both event-related potentials (ERPs) and task performance can provide the temporal precision required to study these early attention and discrimination processes. Specifically, the N100 and no-go N200 ERP components are responsive to early top-down attention to socioemotional stimuli (Ruz, Madrid, & Tudela, 2012; Zhang & Lu, 2012). Convergently, speeded behavioral responses to emotional facial expressions during an emotional go/no-go task index speed and accuracy of discrimination, inhibitory control, and emotional biasing of behaviors (Hare et al., 2005; Tottenham et al., 2011). These neural and behavioral measures are therefore well suited for the present investigation of factors that might distinctly impact top-down selective and executive attention to, as well as discernment between, socioemotional stimuli.

Mindfulness and "Upstream" Attention

The process-specific timing hypothesis of emotion regulation (Sheppes & Gross, 2011) highlights the value of early attention deployment in emotion-relevant contexts. This hypothesis posits that "upstream" regulation strategies may be more efficient and adaptive, as they involve less effort and fewer cognitive resources than strategies occurring later in the emotion generation sequence (e.g., emotional response modulation). Thus far, studies of attention deployment have focused on distraction and attentional avoidance (Sheppes & Gross, 2011), both of which have been shown to have limited value and can be detrimental to emotion regulation and emotional health over time (Sheppes & Gross, 2011). It remains an important question whether there are other "upstream" means of engaging attention that could benefit emotion regulation and related behavior without these costs.

Both theory and research on *mindfulness*, characterized in basic terms by a sustained, receptive attention to present-moment events (Anālayo, 2003; Brown & Ryan, 2003), may facilitate emotion and behavior regulation. Mindfulness concerns a quality of attention in which stimuli are attended to without a strong overlay of habitual reactions and projections (Anālayo, 2003; Teasdale et al., 2000); some measures of trait, or dispositional, mindfulness assess the tendency to attend in this way (Brown & Ryan, 2003). Although some operationalizations of dispositional mindfulness include ancillary processes (e.g., Baer et al., 2008), all measures highlight the importance of this quality of present-oriented attention (Quaglia, Brown, Lindsay, Creswell, & Goodman, 2015). Recent neuroscientific and behavioral evidence supports the idea that mindfulness promotes rapid, adaptive processing of emotional stimuli. Brown, Goodman, and Inzlicht (2013) found that two individual difference measures of mindfulness predicted attenuated neural reactivity to high-arousal pleasant and unpleasant images in the Late Positive Potential ERP component (500–900 ms after stimulus onset), an index of attention to and appraisal of motivationally salient stimuli. Behavioral evidence that mindful attention may promote adaptive emotion regulation comes from research relating individual differences in mindfulness to greater inhibitory control over automatic affective responses to socioemotional distractors (De Raedt, Baert, Demeyer, & Goeleven, 2012), as well as from research on mindfulness training showing less early attentional avoidance of pain-related stimuli among fibromyalgia patients (Vago & Nakamura, 2011). These studies provide initial evidence that mindfulness can act to regulate neural and behavioral responses to salient affective stimuli. However, research has yet to examine these responses with the necessary temporal precision to inform the role of mindfulness in early attention to and discrimination of socioemotional stimuli, processes important to emotional and behavioral regulatory success in social contexts.

The Present Research

To determine whether mindfulness warrants further consideration among taxonomies of early cognitive strategies that may facilitate emotion and behavior regulation, this study examined both processes through key ERP and task-based behavioral indices. Our hypotheses concerned the role of mindfulness in responses on ERP components relevant to early attention and discrimination, namely, the N100 and no-go N200. The visual N100 is a negative-going waveform indexing early top-down attention to visual stimuli (Luck & Kappenman, 2011; Ruz et al., 2012) and is found in tasks requiring discrimination between stimuli (Vogel & Luck, 2000), including between valences of emotional facial expressions (Luo, Feng, He, Wang, & Luo, 2010). Thus, the visual N100 is ideal for examining the role of mindfulness in early attention during facial discrimination, such as in the emotional go/no-go task (Hare et al., 2005). Consistent both with the conception of mindfulness as a sustained, receptive form of attention and with previous ERP research showing greater attention to and dampened appraisals of pleasant and unpleasant valenced emotional stimuli (e.g., Brown et al., 2013), we hypothesized that dispositionally mindful individuals would show larger (more negative) N100 amplitudes across stimulus valence in the emotional go/no-go task.

Peaking shortly after the N100, the no-go N200 component of the ERP waveform is thought to reflect conflict monitoring of the discrepancy between prepotent responses and task demands during go/no-go tasks (Donkers & Van Boxtel, 2004), and specifically conflict monitoring of the prepotent go response when faced with no-go stimuli (Nieuwenhuis, Yeung, Van Den Wildenberg, & Ridderinkhof, 2003). Following from research reviewed earlier linking dispositional mindfulness to greater inhibitory control (De Raedt et al., 2012), we hypothesized that higher mindfulness would predict larger (more negative) no-go N200. Our particular interest was in the no-go N200 for happy nontargets, since automatic approach-oriented responses to happy faces make them harder to inhibit than neutral or fearful faces (Hare et al., 2005).

We also conducted an exploratory analysis on whether mindfulness would predict larger no-go P300. The P300 component is a positive-going deflection often studied in the context of go/no-go tasks (Polich, 2007). As with the no-go N200, the no-go P300 is found for trials that require inhibition of the prepotent go response to no-go stimuli (Donkers & Van Boxtel, 2004). Relative to the no-go N200, the no-go P300 may be more directly related to response inhibition (Albert, López-Martín, Tapia, Montoya, & Carretié, 2012; Bruin & Wijers, 2002). For target (go) trials during emotional go/no-go tasks, the go P300 could reflect motivated attention to affective stimuli rather than voluntary attentional control (Zhang & Lu, 2012). Thus, although go and no-go P300 centrally implicate goal-relevant attention, support for the role of top-down attention in no-go P300 is stronger than for go P300.

We also predicted that mindfulness would be related to behavioral indices of attention and inhibitory control relevant to the regulation of socioemotional behavior. Consistent with research showing that greater mindful attention affords perceptual discrimination (Jensen, Vangkilde, Frokjaer, & Hasselbalch, 2012; Moore, Gruber, Derose, & Malinowski, 2012), we hypothesized that dispositional mindfulness would predict faster response time (RT) to all target stimuli on the emotional go/no-go task. However, previous research has demonstrated that fearful go stimuli result in slower RTs because of the mismatch between approach behavior (button press) and the automatic, withdraw-oriented emotional response (Hare et al., 2005). Therefore, we anticipated that mindfulness would more strongly predict RT to fearful faces, since greater top-down attention should help override task-inconsistent emotional responses. Relatedly, we expected that mindfulness would predict less overall RT variability, reflecting more sustained attention and less emotional involvement during the task. We also hypothesized that dispositional mindfulness would predict fewer false alarms (FAs) to all nontargets, reflecting greater top-down inhibitory control generally. Because it is harder to inhibit responses to happy than neutral or fearful faces (Hare et al., 2005), we expected that mindfulness would more strongly predict FAs for happy nontargets.

We controlled for both social anxiety and attentional control in this study to test the specificity of the hypotheses concerning mindfulness. Greater early sensitivity and enhanced attention to emotion-related social stimuli characterize social anxiety (e.g., Rossignol et al., 2012; Schmidt, Richey, Buckner, & Timpano, 2009), and social anxiety symptoms have been inversely related to dispositional mindfulness (Brown & Ryan, 2003). Neural and behavioral markers of attention may also be predicted by focused attentiveness, and mindfulness has been associated with dispositional attentional control (Brown et al., 2013).

METHOD

Participants

A sample of 62 undergraduate students (67% female; $M_{\text{age}} = 19.09$ years, $SD = 2.14$ years) from a large mid-Atlantic university received course credit for participation. Only Caucasian students were eligible for participation to minimize variation in response to the multiracial facial stimuli and examine questions pertaining to race (to be reported separately). All prospective participants were screened for right-handedness, medical or neurological conditions, drug use, and recent psychiatric diagnoses. Four subjects were excluded from all analyses: Two fell asleep and two sessions involved disruptive environmental events. Additionally, one participant was excluded from the N100 analyses and four participants were excluded from the no-go N200 and P300 analyses because of technical problems. The final numbers of participants included in each analysis were 58 for behavioral, 57 for N100, and 53 for N200 and P300.

Materials

Self-Report Measures. In a battery of psychological measures, participants completed the following study-relevant scales.

Mindfulness. A basic form of dispositional mindfulness was measured by the 15-item Mindful Attention Awareness Scale (MAAS; Brown & Ryan, 2003). The MAAS, derived from classical and clinical conceptualizations of basic mindfulness, has high reliability and validity, and it has been used extensively in prior research (sample item: "I find myself doing things without paying attention"). Higher scores reflect higher mindfulness on a Likert scale ranging from 1 (*almost always*) to 6 (*almost never*). The sample Cronbach's alpha was .82.

Attentional Control. The Attentional Control Scale (ACS; Derryberry & Reed, 2002) measures dispositional attentional control (AC) on 4-point scale (*almost never* to *almost always*). An example item is "It takes me a while to get really involved in a new task." The sample alpha was .81.

Social Anxiety. The 24-item Liebowitz Social Anxiety Scale (LSAS; Baker, Heinrichs, Kim, & Hofmann, 2002) measures fear and avoidance components of social anxiety (SA). LSAS scores have been associated with heightened "upstream" attention to social stimuli (Rossignol et al., 2012). The sample alpha was .93.

Stimulus Materials. The social stimuli were selected from the NimStim Face Stimulus Set (Tottenham et al., 2009), previously used in an emotional go/no-go task (Hare et al., 2005). To examine questions pertaining to race (to be reported separately) as well as pleasant and unpleasant emotional facial expressions, 12 models from the NimStim Set (i.e., 6, 8, 10, 11, 12, 14, 28, 36,

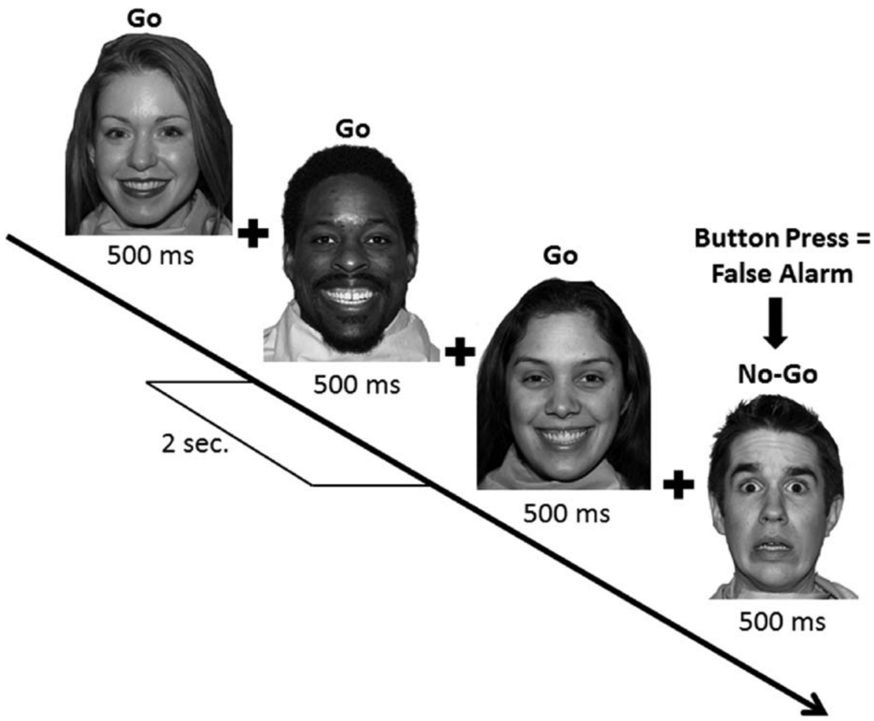

Figure 1 Temporal sequence of the emotional go/no-go task. In this variation, targets (go) are happy facial expressions and nontargets (no-go) are fearful facial expressions.

37, 38, 40, 43) included three each of African American and Caucasian males and females expressing happy, neutral, or fearful facial expressions. Prior to use, they were grayscaled and normalized for luminance.

Emotional Go/No-Go Task. Following Hare and colleagues' (2005) procedure (see Figure 1), a fixation cross was presented for 2,000 ms on a 19-in. flat-screen LCD monitor at a distance of approximately 34 in., with a vertical visual angle of 20°. The cross was followed by a face stimulus for 500 ms. Participants were instructed to use their dominant (right) hand to press a key on a button box in response to each occurrence of a particular type of facial expression, indicated prior to each block. Half the participants (randomly assigned) first responded to fearful targets, presented randomly on 70% of trials (30% of the stimuli were happy or neutral faces, in alternating blocks, counterbalanced). After eight blocks of 60 trials each, these participants responded to eight blocks of happy targets/fearful nontargets and neutral targets/fearful nontargets. The other half of the participants received the same conditions in reverse order. Thus, all participants completed 336 fearful, 168 happy, and 168 neutral target (go) trials, and 144 fearful, 72 happy, and 72 neutral nontarget (no-go) trials. The asymmetry in the number of trials per emotional facial expressions followed prior emotional go/no-go procedures (Hare et al., 2005) and was accounted for in all FA analyses. Participants completed 20 practice trials before each condition, and blocks were separated by short rest breaks.

Procedure

An online questionnaire assessed inclusion and exclusion criteria. Qualifying participants reported individually to a laboratory, where the study purpose and procedure were outlined. After informed consent, the self-report measures were completed. Within 3 weeks, participants returned to the lab for the emotional go/no-go task. Upon task completion, participants were debriefed and dismissed.

Electrophysiological Recording, Artifact Rejection, and Component Specification. All electrophysiological signals were acquired using a Neuroscan (El Paso, Texas) NuAmps Express 40-channel system. Electrode positions were based on the 10–20 international system with a forehead ground and two monopolar mastoid references. The electro-oculogram (EOG) was recorded with monopolar electrodes located below and on the outer canthus of each eye. Offline, the monopolar EOG channels were combined into bipolar channels. All Electroencephalography (EEG)/EOG electrode impedances were below 10 kΩ. EEG and EOG were acquired at a gain of 20K (3.75 μV/mm equivalent) for a frequency bandwidth of 0.3–100 Hz (24 dB/octave).

Electromyography (EMG) was acquired at a gain of 20K for an initial bandwidth of 30–1000 Hz. The digital band-pass filter settings were as follows: EOG at 0.3–4 Hz, EEG at 0.3–20 Hz, and EMG at 30–250 Hz. The timing, presentation, and synchronization of stimulus presentation and the continuous EEG recording were controlled by Stim2 software (Neuroscan; El

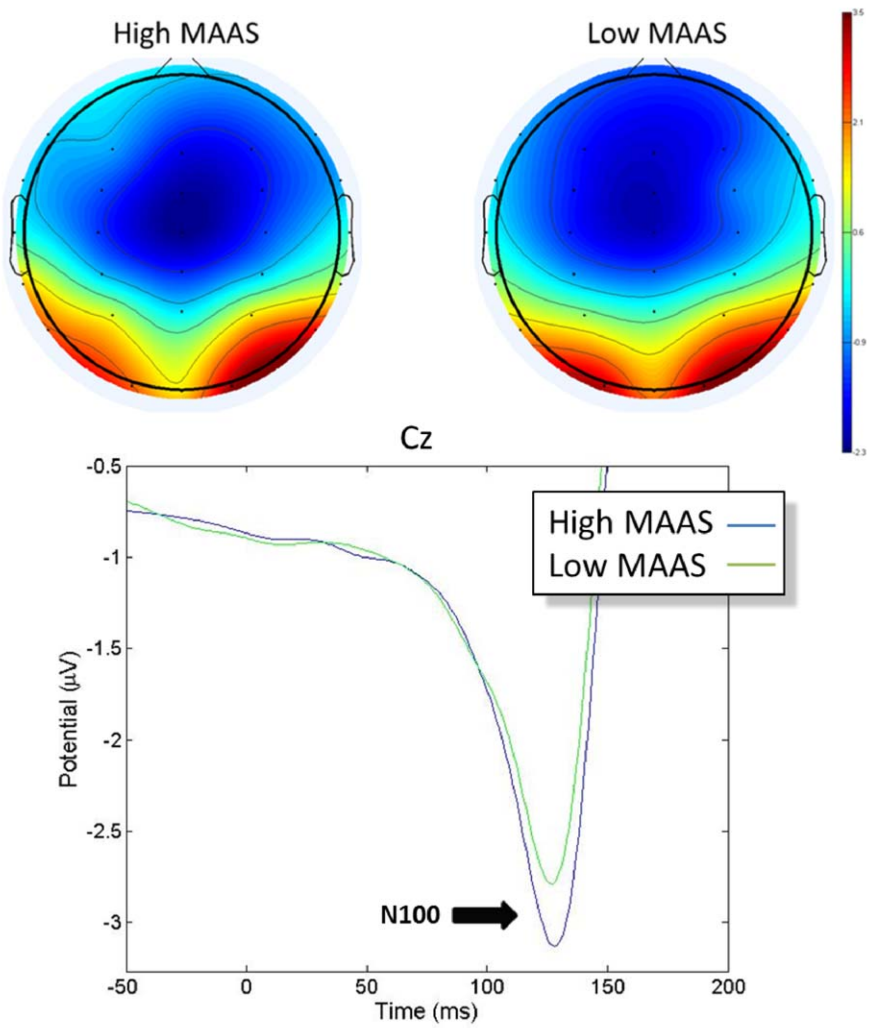

Figure 2 Top: Scalp topographies based on median split of MAAS (high on left) for 100–150 ms following stimulus onset during the emotional go/no-go task. Darker blue indicates more negative activation. Bottom: Grand average waveform at Cz for high (blue) versus low (green) MAAS between –50 and 200 ms following all conditions and stimulus types.

Paso, Texas). The continuous EEG signal was time-locked to the visual presentation of task stimuli.

EEGLAB 12.0 (Delorme & Makeig, 2004) and MATLAB (MathWorks, www.mathworks.com) were used for offline EEG processing. Bad channels were detected and removed with the automatic detection algorithms provided by EEGLAB, after which all electrodes were rereferenced to the common average. Continuous EEG was locked to feedback stimuli, and data epochs were extracted using a –500 ms to 1,500 ms window. Epochs containing nonstereotypical artifacts were detected and rejected using native EEGLAB artifact detection algorithms sensitive to abnormal values, distributions, spectra, and linear trends. After rejecting epochs contaminated with paroxysmal artifacts, independent components analysis (ICA) was conducted using the infomax algorithm. Visual inspection of component scalp maps, power spectrum, and raw activity identified exemplar ICA components representing stereotypical artifacts (eye blinks, electrocardiograms, eye movements).

Exemplar artifactual components were passed to CORRMAP, an EEGLAB plug-in that identifies clusters of highly correlated ($r > .80$) ICA components sample-wide. Component clusters representative of stereotypical artifacts were pruned from the raw EEG signal (Viola et al., 2009), and artifact-free epochs were baseline corrected by subtracting the average amplitude between –500 ms and 0 ms.

N100. Visual inspection of grand average waveforms revealed an N100 peaking around 130 ms at electrode Cz, consistent with previous research (e.g., Campanella et al., 2002; Kubota & Ito, 2007; Rossignol, Philippot, Douilliez, Crommelinck, & Campanella, 2005). The N100 was indexed by the average amplitude at Cz in a 50 ms window (Vogel & Luck, 2000), between 100 and 150 ms. Average amplitudes for go and no-go trials and for each stimulus valence were computed separately.

N200. Visual inspection of the grand average waveform revealed an N200 component peaking around 260 ms, maximal at frontocentral site FCz, consistent with previous research (e.g., Bruin & Wijers, 2002; Nieuwenhuis et al., 2003; Zhang & Lu, 2012). This component was defined as the peak (most negative) amplitude between 200 and 350 ms post-stimulus at FCz (Donkers & van Boxtel, 2004). The N200 was computed for go and no-go trials for comparison, but only trials involving no-go stimuli constitute the no-go N200 (Amodio, Master, Yee, & Taylor, 2008; Nieuwenhuis et al., 2003).

P300. Visual inspection of the grand average waveform revealed a P300 component peaking around 525 ms, maximal at centroparietal site Pz for both go and no-go trials, consistent with where this component is observed in go/no-go tasks (Katayama & Polich, 1998; Polich, 2007). The P300 was indexed by the peak (most positive) amplitude at Pz (Donkers & van Boxtel, 2004; Hagen et al., 2005) between 350 and 600 ms. The P300 was computed for go and no-go trials, and as with the no-go N200, only trials involving no-go stimuli constitute the no-go P300.

Behavioral Data Preparation. Only RTs for correct trials were included in analyses. To ensure that differences in RT variability were not due solely to differences in RT, the coefficient of variation (standard deviation RT/mean RT) was used to index RT variability (Hendricks & Robey, 1936). Before averaging, RTs reflecting anticipatory or delayed responding ($<$ 200 ms or $>$ 1,500 ms, respectively) were removed (cf. Vago & Nakamura, 2011). FA rate (frequency divided by the number of trials for each stimulus type) was highly skewed and kurtotic; natural log transformations normalized this variable.

RESULTS

ERPs

N100. To test the hypothesis that dispositional mindfulness would predict larger N100 amplitudes to social stimuli, repeated-measures multilevel models with restricted maximum likelihood estimation (Bryk & Raudenbush, 1992) were used. There were no specific hypotheses pertaining to condition or stimulus type, and an initial model including repeated-measures predictors revealed that neither variable, nor their interaction, significantly predicted N100. Both variables were included as control variables in subsequent models.[1]

Dispositional mindfulness significantly predicted more negative N100 amplitude, $F(1, 54) = 10.23$, $p = .002$, explaining 10% of between-subjects variance.[2] Figure 2 presents the topographic maps and grand average waveforms highlighting this association using a MAAS median split (the continuous score was used in all analyses). Models also tested whether mindfulness predicted N100 after controlling for either AC or SA, neither of which were significant predictors of the N100 ($ps > .10$). Mindfulness remained a significant predictor of N100 in both models ($ps < .02$). See Supplementary Tables 1–4 for detailed results of these models.

Decrements in N100 have been found to correspond with task time in previous research (Boksem, Meijman, & Lorist, 2005). Therefore, we conducted a follow-up analysis to probe whether dispositional mindfulness would predict a significant interaction with task time, reflecting more sustained attention. However, we expected mindfulness to remain a significant independent predictor of N100 amplitude after accounting for any interaction with task time. To examine this, we grouped N100 amplitudes according to the 16 blocks of the emotional go/no-go task. A multilevel model was tested, including block alongside condition and stimulus type as repeated-measures factors. Block was not a significant predictor of the N100 ($p > .40$). Interestingly, condition became a significant predictor after accounting for block, $F(2, 100) = 3.67$, $p = .03$. Tukey-Kramer post hoc tests revealed that the amplitude of the N100 to happy faces was significantly more negative than neutral faces ($p = .01$) and marginally more negative than fearful faces ($p = .06$). After accounting for block, dispositional mindfulness remained a significant predictor of the N100, $F(1, 48) = 11.49$, $p = .001$; there was no Mindfulness $\times$ Block interaction. Thus, the relation earlier reported between mindfulness and N100 did not simply reflect differences in sustained attention.

N200. To test the hypothesis that higher mindfulness would predict greater no-go N200 amplitude, an initial multilevel model tested the main effect of condition and stimulus type on the N200 amplitude. Stimulus type significantly predicted N200, $F(1, 56) = 4.62$, $p = .03$, but condition did not ($p > .50$). There was also a marginally significant interaction between stimulus type and condition, $F(2, 112) = 2.70$, $p = .06$. Tukey-Kramer post hoc tests revealed that the amplitude of the N200 was more negative for no-go than go stimuli, $t(1, 56) = 2.15$, $p = .03$, and an interaction plot confirmed that the N200 was most negative for happy no-go stimuli, consistent with previous research. Subsequently, a multilevel model tested mindfulness as a predictor of N200, including stimulus type and condition as covariates. Dispositional mindfulness predicted more negative N200 generally, $F(1, 55) = 5.57$, $p = .02$, as presented in Figure 3 using a MAAS median split. However, there was no significant interaction between mindfulness and stimulus type or condition ($ps >$ .30). The effect of mindfulness on N200 accounted for 6% of between-subjects variance. After controlling either AC or SA, which were not significant predictors of the N200, mindfulness continued to predict N200 amplitude ($ps < .03$).

P300. Due to the similarity of no-go N200 and no-go P300 (Albert et al., 2012; Bruin & Wijers, 2002), we also explored whether the hypothesized interaction between mindfulness and stimulus type for the N200 would be evident in the P300. An initial multilevel model tested the main effect of condition and stimulus type on the P300 amplitude, and stimulus type

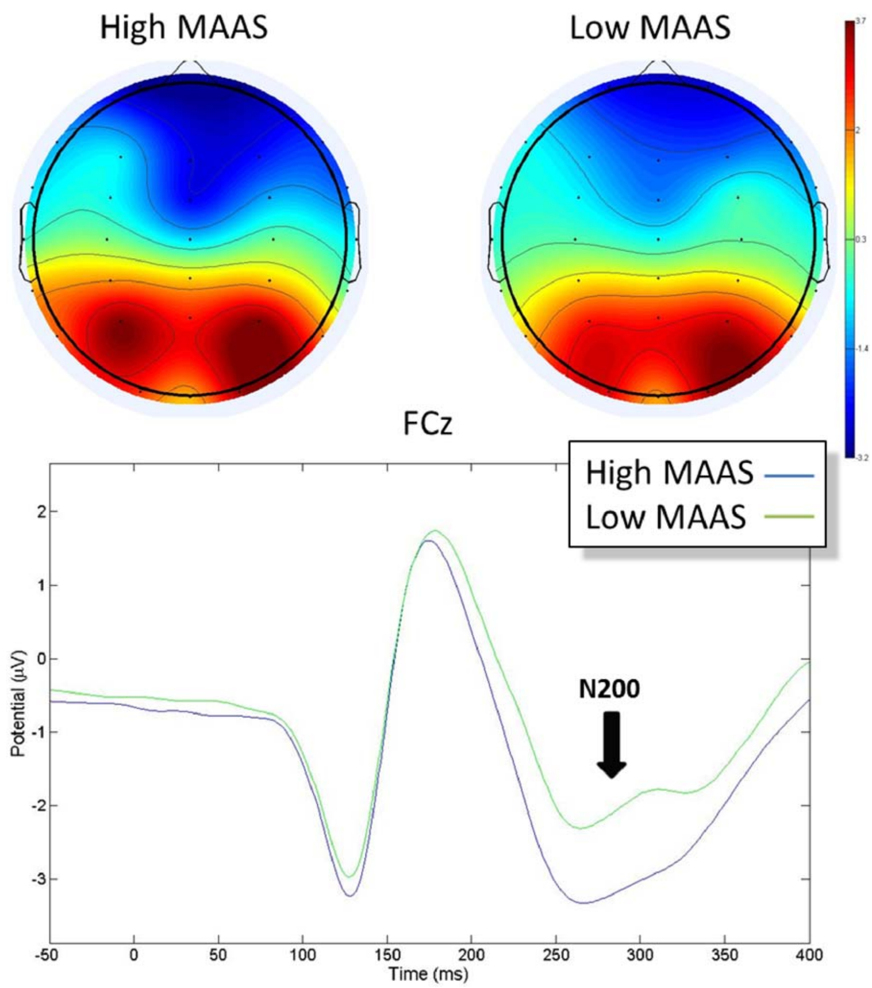

Figure 3 Top: Scalp topographies based on median split of MAAS (high on left) for 200–350 ms following stimulus onset during the emotional go/no-go task. Darker blue indicates more negative activation. Bottom: Grand average waveform at FCz for high (blue) versus low (green) MAAS between –50 and 400 ms following all conditions and stimulus types.

significantly predicted P300, $F(1, 52) = 7.02$, $p = .01$, but condition did not ($p > .60$). Subsequently, a multilevel model tested mindfulness as a predictor of both the go and no-go P300 by retaining these variables as covariates and assessing any interaction with mindfulness. Mindfulness did not predict more positive P300 generally; however, dispositional mindfulness predicted more positive no-go P300, evident in a significant Mindfulness × Stimulus Type interaction, $F(1, 255) = 4.14$, $p = .04$. An interaction plot confirmed that mindfulness predicted P300 more strongly for no-go than go stimuli, with the effect of mindfulness on no-go P300 accounting for 5% of between-subjects variance. Figure 4 presents the topographic maps and grand average waveforms highlighting this association using a MAAS median split. No significant Mindfulness × Condition interaction was observed ($p > .10$). After controlling for either SA or AC, which were not significant predictors of the P300, the Mindfulness × Stimulus Type interaction remained significant (*p*s $< .05$). Given the exploratory nature of these analyses, however, the results should be interpreted with caution.

Behavioral Responses

Multilevel models tested the hypotheses that mindfulness would predict faster RT and less RT variability, with condition as the repeated-measures factor and mindfulness as an individual-level predictor. Regarding RT ($M = 496.58$, $SD = 114.59$), an initial model found no main effect of condition, $F(2, 116) = .40$, $p = .67$, indicating no emotional stimulus modulation of RT. Next, a multilevel model assessed whether mindfulness predicted faster RT. Dispositional mindfulness predicted faster RT, $F(1, 57) = 5.53$, $p = .02$, explaining 9% of between-subjects variance. Controlling for SA or AC, which were not significant predictors of RT (*p*s $> .20$), mindfulness remained a significant predictor of RT (*p*s $< .02$). Mindfulness was not a significant predictor of RT variability ($p > .40$). Figure 5 presents the RT for each target emotion, for high versus low MAAS.

Accuracy. A preliminary multilevel model found that condition predicted the number of FAs, $F(2, 107) = 9.11$, $p < .001$.

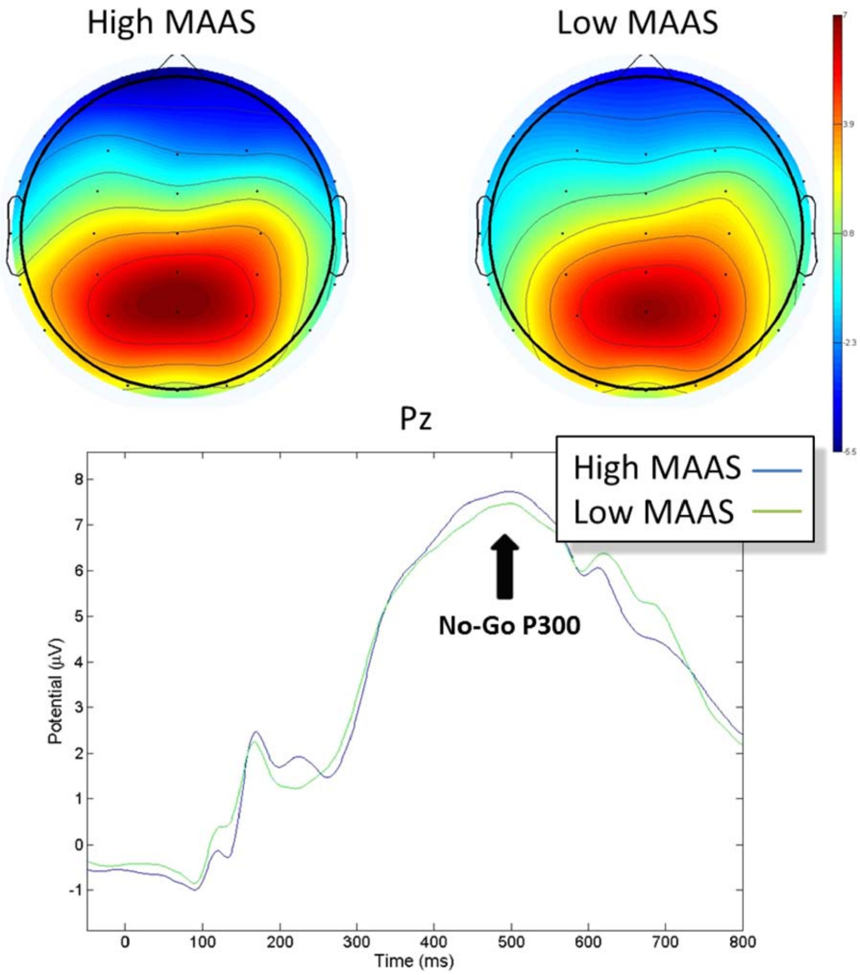

Figure 4 Top: Scalp topographies based on median split of MAAS (high on left) for 350–600 ms following no-go stimuli during the emotional go/no-go task. Darker blue indicates more negative activation. Bottom: Grand average waveform at Pz for high (blue) versus low (green) MAAS between –50 and 800 ms following all no-go stimuli.

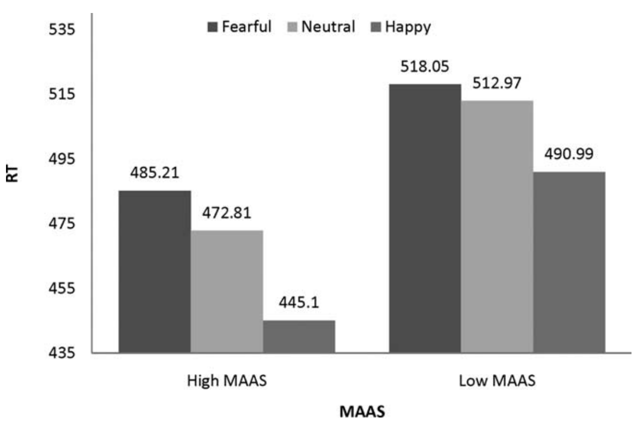

Figure 5 Response time for fearful, neutral, and happy face targets for high versus low MAAS (median split). Though average response times were higher for fearful compared to neutral or happy targets, differences were not significant. MAAS was a significant predictor of faster overall response time.

Tukey-Kramer post hoc tests revealed that compared to fearful no-go stimuli, the number of FAs was higher for both neutral and happy faces (both *p*s $< .01$), which did not differ from each other ($p > .10$). This is consistent with previous research suggesting more accurate inhibition of go responses to fearful no-go stimuli (Hare et al., 2005). Mindfulness did not predict fewer FAs for any no-go stimulus type (*p*s $> .10$).

Speed-Accuracy Trade-Off? A final model tested the association between dispositional mindfulness and RT, controlling for the number of FAs. FAs predicted RT, consistent with a speed-accuracy trade-off, $F(1, 56) = 12.24$, $p = .0009$, and mindfulness was a significant predictor, $F(1, 56) = 4.72$, $p = .03$, indicating that faster RT among more mindful individuals was not due to lower accuracy (FAs).

DISCUSSION

This study investigated the role of mindfulness in "upstream," or early, processing of socioemotional stimuli. Consistent with hypotheses, higher dispositional mindfulness was first associated with more negative N100 to all stimuli, an ERP component linked to early top-down attention (Luck & Kappenman, 2011; Ruz et al., 2012). Further, this relation remained significant after controlling for AC and SA (the latter of which also predicted more negative N100), as well as after accounting for potential differences in sustained attention. These findings suggest that mindfulness distinctly influences processing very early following stimulus onset, and the N100 may thus serve as a neural indicator of the heightened attention to moment-by-moment experience that helps to characterize mindfulness (Brown & Ryan, 2003; Kabat-Zinn, 1990).

Individual differences in mindfulness were also evident in the N200, even after controlling for AC and SA. Importantly, although we observed the typical enhancement of N200 amplitude for no-go relative to go trials (Nieuwenhuis et al., 2003; Zhang & Lu, 2012), mindfulness predicted greater N200 amplitude generally. Though we did not hold an a priori hypothesis regarding mindfulness and go N200 due to some uncertainty regarding the functional implication of this amplitude during socioemotional discrimination tasks (Zhang & Lu, 2012), expecting larger mindfulness-related N200 to go (in addition to no-go) stimuli is reasonable in the context of mindfulness predicting greater conflict monitoring generally (cf. Nieuwenhuis et al., 2003).

In an exploratory analysis, we found a significant relation between mindfulness and no-go P300, suggesting that mindfulness not only involves greater conflict monitoring, but may also involve greater inhibition of the prepotent go response (Alberts et al., 2012; Bruin & Wijers, 2002). However, this finding should be interpreted cautiously, given its exploratory basis, and replication is needed to substantiate it. That mindfulness was related to electrophysiological correlates of more efficient selective attention and discrimination (N100), as well as greater conflict monitoring (N200) and perhaps also inhibitory control (no-go P300), is consistent with theory that mindfulness promotes moment-by-moment monitoring of sensory as well as psychological events (e.g., Brown, Ryan, & Creswell, 2007). The relations between mindfulness and N200 support the primary assertion that mindfulness entails greater early top-down attention in socioemotional contexts; specifically, these findings add further neurophysiological support that mindfulness promotes greater monitoring of automatic psychological tendencies.

The task-based behavioral results were also generally consistent with hypotheses, demonstrating that dispositional mindfulness predicted more efficient discrimination of facial expressions, even after controlling for AC and SA. Importantly, faster RT among more mindful individuals was not explained by trade-offs in accuracy. This is important, as rapid and accurate discrimination of others' emotional facial expressions affords social behavior that does not require slowing down to respond appropriately, or risking errors by responding quickly (Tottenham et al., 2011). Together, these results suggest that mindfulness may facilitate adaptive social behavior that is efficient (i.e., timely and accurate).

The present findings contribute to a growing body of literature (e.g., Brown et al., 2013; Lutz et al., 2013; Moore et al., 2012; Vago & Nakamura, 2011) proposing that mindfulness may be an adaptive form of attention deployment that promotes efficient processing of task-relevant emotional stimuli. Efficient top-down attention to and discrimination of others' emotional expressions differ from habitual evaluation (or appraisal) of stimuli as pleasant or unpleasant. Here, discrimination reflects accurate discernment between stimuli, which may occur independently of automatic emotional responses. This efficient top-down attention and discrimination could afford greater explicit access to the attended information during subsequent processing, facilitating social functioning via more conscious regulation of emotional and behavioral responses in social contexts (e.g., Barnes, Brown, Krusemark, Campbell, & Rogge, 2007; Brown, Weinstein, & Creswell, 2012; Quaglia, Goodman, & Brown, 2014).

The present findings also inform an understanding of neural and cognitive mechanisms of mindfulness. Effort can boost attention performance (e.g., Jensen et al., 2012), but efficient top-down attention to and discrimination of sensory and psychological events may enhance performance without the cognitive cost of attentional effort (cf. Zanesco, King, MacLean, & Saron, 2013). This represents an important target for further empirical work that may help to explain the cognitive benefits of sustained, present-oriented attention thought to characterize mindfulness.

LIMITATIONS AND FUTURE DIRECTIONS

This study had several noteworthy limitations. First, while the Caucasian-only sample was intended to reduce variance due to racial match/mismatch of participants and face stimuli, the generalizability of these findings will be enhanced by investigations using a more diverse sample. Second, although we controlled for the mindfulness-correlated traits of AC and SA in an effort to rule out alternative hypotheses, the results could be due to a variable correlated with mindfulness that was not assessed. Third, although the effect sizes were small for mindfulness, we emphasize the importance of our findings by considering the potential cumulative, "downstream" effects of even small differences in early attention (cf. Wadlinger & Isaacowitz, 2010).

On a technical note, close adherence to task parameters of previous emotional go/no-go research (Hare et al., 2005) allowed for a comparison of the behavioral findings, but the use of a fixed interstimulus interval was not ideal for studying the temporal dynamics of ERP-based neural activity.

CONCLUSION

Previous research (Brown et al., 2013) has demonstrated that a basic form of dispositional mindfulness is related to neural responses occurring in a ½–1 s window that reflects attention to and appraisal of emotional stimuli (the Late Positive Potential; LPP).

The present research found that dispositional mindfulness predicted neural responses to socioemotional (facial) stimuli even earlier, evident in distinct ERP components (N100, N200) appearing within 600 ms following stimulus onset. Further, higher dispositional mindfulness predicted faster, more efficient discrimination of emotional facial expressions. These findings lend support to our fundamental understanding that variation in trait mindfulness reflects differences in the tendency to engage present-oriented attention that is less biased by habitual tendencies (Anālayo, 2003; Teasdale et al., 2000). Moreover, this study highlights the importance of individual differences in mindfulness to understanding basic processes of adaptive emotion discrimination and regulation, processes key to higher-quality social functioning in socioemotional contexts.

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Notes

1. Preliminary multilevel models assessed the role of participant sex and stimulus target sex, neither of which significantly predicted the outcomes.
2. Effect sizes were obtained using a *t*-to-*r* transformation: $R^2 = t^2 / (t^2 + DF)$ (Kashdan & Steger, 2006).

References

Albert, J., López-Martín, S., Tapia, M., Montoya, D., & Carretié, L. (2012). The role of the anterior cingulate cortex in emotional response inhibition. *Human Brain Mapping*, **33**, 2147–2160.

Amodio, D. M., Master, S. L., Yee, C. M., & Taylor, S. E. (2008). Neurocognitive components of the behavioral inhibition and activation systems: Implications for theories of self-regulation. *Psychophysiology*, **45**, 11–19.

Anālayo, B. (2003). *Satipahāna: The direct path to realization*. Birmingham, UK: Windhorse.

Baer, R. A., Smith, G. T., Lykins, E., Button, D., Krietemeyer, J., Sauer, S., et al. (2008). Construct validity of the Five Facet Mindfulness Questionnaire in meditating and nonmeditating samples. *Assessment*, **15**, 329–342.

Baker, S. L., Heinrichs, N., Kim, H.-J., & Hofmann, S. G. (2002). The Liebowitz Social Anxiety Scale as a self-report instrument: A preliminary psychometric analysis. *Behaviour Research and Therapy*, **40**, 701–715.

Barnes, S., Brown, K. W., Krusemark, E., Campbell, W. K., & Rogge, R. (2007). The role of mindfulness in romantic relationship satisfaction and responses to relationship stress. *Journal of Marital and Family Therapy*, **33**, 482–500.

Berkman, E. T., & Lieberman, M. D. (2010). Approaching the bad and avoiding the good: Lateral prefrontal cortical asymmetry distinguishes between action and valence. *Journal of Cognitive Neuroscience*, **22**, 1970–1979.

Boksem, M. A. S., Meijman, T. F., & Lorist, M. M. (2005). Effects of mental fatigue on attention: An ERP study. *Cognitive Brain Research*, **25**, 107–116.

Brown, K. W., Goodman, R. J., & Inzlicht, M. (2013). Dispositional mindfulness and the attenuation of neural responses to emotional stimuli. *Social Cognitive and Affective Neuroscience*, **8**, 93–99.

Brown, K. W., & Ryan, R. M. (2003). The benefits of being present: Mindfulness and its role in psychological well-being. *Journal of Personality and Social Psychology*, **84**, 822–848.

Brown, K. W., Ryan, R. M., & Creswell, J. D. (2007). Mindfulness: Theoretical foundations and evidence for its salutary effects. *Psychological Inquiry*, **18**, 211–237.

Brown, K. W., Weinstein, N., & Creswell, J. D. (2012). Trait mindfulness modulates neuroendocrine and affective responses to social evaluative threat. *Psychoneuroendocrinology*, **37**, 2037–2041.

Bruin, K. J., & Wijers, A. A. (2002). Inhibition, response mode, and stimulus probability: A comparative event-related potential study. *Clinical Neurophysiology*, **113**, 1172–1182.

Bryk, A. S., & Raudenbush, S. W. (1992). *Hierarchical linear models: Advanced quantitative techniques in the social sciences*. Los Angeles: Sage.

Cacioppo, J. T. (2002). Social neuroscience: Understanding the pieces fosters understanding the whole and vice versa. *American Psychologist*, **57**, 819–831.

Campanella, S., Gaspard, C., Debatisse, D., Bruyer, R., Crommelinck, M., & Guerit, J. M. (2002). Discrimination of emotional facial expressions in a visual oddball task: An ERP study. *Biological Psychology*, **59**, 171–186.

Darwin, C. (1872). *The expression of the emotions in man and animals*. Oxford: Oxford University Press.

Delorme, A., & Makeig, S. (2004). EEGLAB: An open source toolbox for analysis of single-trial EEG dynamics including independent component analysis. *Journal of Neuroscience Methods*, **134**, 9–21.

Derryberry, D., & Reed, M. A. (2002). Anxiety-related attentional biases and their regulation by attentional control. *Journal of Abnormal Psychology*, **111**, 225.

De Raedt, R., Baert, S., Demeyer, I., & Goeleven, E. (2012). Changes in attentional processing of emotional information following mindfulness-based cognitive therapy in people with a history of depression: Towards an open attention for all emotional experiences. *Cognitive Therapy and Research*, **32**, 612–620.

Donkers, F. C. L., & Van Boxtel, G. J. M. (2004). The N2 in go/no-go tasks reflects conflict monitoring not response inhibition. *Brain and Cognition*, **56**, 165–176.

Eisenberg, N., Fabes, R. A, Guthrie, I. K., & Reiser, M. (2000). Dispositional emotionality and regulation: Their role in predicting quality of social functioning. *Journal of Personality and Social Psychology*, **78**, 136–157.

Eisenberg, N., Spinrad, T. L., & Morris, A. S. (2002). Regulation, resiliency and quality of social functioning. *Self and Identity*, **1**, 121–128.

Fox, E. (2002). Processing emotional facial expressions: The role of anxiety and awareness. *Cognitive, Affective & Behavioral Neuroscience*, **2**, 52–63.

Hare, T. A., Tottenham, N., Davidson, M. C., Glover, G. H., & Casey, B. J. (2005). Contributions of amygdala and striatal activity in emotion regulation. *Biological Psychiatry*, **57**, 624–632.

Hendricks, W. A., & Robey, K. W. (1936). The sampling distribution of the coefficient of variation. *Annals of Mathematical Statistics*, **7**, 129–132.

Jensen, C. G., Vangkilde, S., Frokjaer, V., & Hasselbalch, S. G. (2012). Mindfulness training affects attention—Or is it attentional effort? *Journal of Experimental Psychology: General*, **141**, 106–123.

Kabat-Zinn, J. (1990). *Full catastrophe living: Using the wisdom of your body and mind to face stress, pain, and illness*. New York: Delta.

Kanske, P., Heissler, J., Schonfelder, S., Bongers, A., & Wessa, M. (2011). How to regulate emotion? Neural networks for reappraisal and distraction. *Cerebral Cortex*, **21**, 1379–1388.

Kashdan, T., & Steger, M. (2006). Expanding the topography of social anxiety: An experience-sampling assessment of positive emotions, positive events, and emotion suppression. *Psychological Science*, **17**, 120–128.

Katayama, J. I., & Polich, J. (1998). Stimulus context determines P3a and P3b. *Psychophysiology*, **35**, 23–33.

Kubota, J., & Ito, T. (2007). Multiple cues in social perception: The time course of processing race and facial expression. *Journal of Experimental Social Psychology*, **43**, 738–752.

Lopes, P. N., Salovey, P., Coté, S., & Beers, M. (2005). Emotion regulation abilities and the quality of social interaction. *Emotion*, **5**, 113–118.

Luck, S. J., & Kappenman, E. S. (2011). ERP components and selective attention. In S. J. Luck & E. S. Kappenman (Eds.), *Oxford handbook of ERP components* (pp. 295–328). New York: Oxford University Press.

Luo, W., Feng, W., He, W., Wang, N.-Y., & Luo, Y. J. (2010). Three stages of facial expression processing: ERP study with rapid serial visual presentation. *NeuroImage*, **49**, 1857–1867.

Lutz, J., Herwig, U., Opialla, S., Hittmeyer, A., Jäncke, L., Rufer, M., et al. (2013). Mindfulness and emotion regulation—An fMRI study. *Social Cognitive and Affective Neuroscience*, **9**, 776–785.

Mineka, S., & Cook, M. (1993). Mechanisms involved in the observational conditioning of fear. *Journal of Experimental Psychology: General*, **122**, 23–38.

Moore, A., Gruber, T., Derose, J., & Malinowski, P. (2012). Regular, brief mindfulness meditation practice improves electrophysiological markers of attentional control. *Frontiers in Human Neuroscience*, **6**, 18–29.

Nieuwenhuis, S., Yeung, N., Van Den Wildenberg, W., & Ridderinkhof, K. R. (2003). Electrophysiological correlates of anterior cingulate function in a go/no-go task: Effects of response conflict and trial type frequency. *Cognitive, Affective, & Behavioral Neuroscience*, **3**, 17–26.

Polich, J. (2007). Updating P300: An integrative theory of P3a and P3b. *Clinical Neurophysiology*, **118**, 2128–2148.

Quaglia, J. T., Brown, K. W., Lindsay, E. K., Creswell, J. D., & Goodman, R. J. (2015). From conceptualization to operationalization of mindfulness. In K. W. Brown, J. D. Creswell, & R. M. Ryan (Eds.), *Handbook of mindfulness* (pp. 151–170). New York: Guilford Press.

Quaglia, J. T., Goodman, R. J., & Brown, K. W. (2014). From mindful attention to social connection: The key role of emotion regulation. *Cognition and Emotion.* Advance online publication. doi: 10.1080/02699931.2014.988124.

Rossignol, M., Campanella, S., Maurage, P., Heeren, A., Falbo, L., & Philippot, P. (2012). Enhanced perceptual responses during visual processing of facial stimuli in young socially anxious individuals. *Neuroscience Letters*, **526**, 68–73.

Rossignol, M., Philippot, P., Douilliez, C., Crommelinck, M., & Campanella, S. (2005). The perception of fearful and happy facial expression is modulated by anxiety: An event-related potential study. *Neuroscience Letters*, **377**, 115–120.

Ruz, M., Madrid, E., & Tudela, P. (2012). Interactions between perceived emotions and executive attention in an interpersonal game. *Social Cognitive and Affective Neuroscience*, **8**, 838–844.

Schmidt, N. B., Richey, J. A., Buckner, J. D., & Timpano, K. R. (2009). Attention training for generalized social anxiety disorder. *Journal of Abnormal Psychology*, **118**, 5–14.

Sheppes, G., & Gross, J. J. (2011). Is timing everything? Temporal considerations in emotion regulation. *Personality and Social Psychology Review*, **15**, 319–331.

Sorce, J. F., & Emde, R. N. (1981). Mother's presence is not enough: Effects of emotional availability on infant exploration. *Developmental Psychology*, **17**, 737–745.

Teasdale, J. D., Segal, Z. V., Williams, J. M. G., Ridgeway, V. A., Soulsby, J. M., & Lau, M. A. (2000). Prevention of relapse/recurrence in major depression by mindfulness-based cognitive therapy. *Journal of Consulting and Clinical Psychology*, **68**, 615–623.

Todd, R. M., Cunningham, W. A., Anderson, A. K., & Thompson, E. (2012). Affect-biased attention as emotion regulation. *Trends in Cognitive Sciences*, **16**(7), 1–8.

Tottenham, N., Hare, T. A., & Casey, B. J. (2011). Behavioral assessment of emotion discrimination, emotion regulation, and cognitive control in childhood, adolescence, and adulthood. *Frontiers in Psychology*, **2**, 39.

Tottenham, N., Tanaka, J. W., Leon, A. C., McCarry, T., Nurse, M., Hare, T. A., et al. (2009). The NimStim set of facial expressions: Judgments from untrained research participants. *Psychiatry Research*, **168**, 242–249.

Vago, D. R., & Nakamura, Y. (2011). Selective attentional bias towards pain-related threat in fibromyalgia: Preliminary evidence for effects of mindfulness meditation training. *Cognitive Therapy and Research*, **35**, 581–594.

Viola, F. C., Thorne, J., Edmonds, B., Schneider, T., Eichele, T., & Debener, S. (2009). Semi-automatic identification of independent components representing EEG artifact. *Clinical Neurophysiology*, **120**, 868–877.

Vogel, E. K., & Luck, S. J. (2000). The visual N1 component as an index of a discrimination process. *Psychophysiology*, **37**, 190–203.

Wadlinger, H. A., & Isaacowitz, D. M. (2010). Fixing our focus: Training attention to regulate emotion. *Personality and Social Psychology Review*, **15**, 75–102.

Zanesco, A. P., King, B. G., MacLean, K. A., & Saron, C. D. (2013). Executive control and felt concentrative engagement following intensive meditation training. *Frontiers in Human Neuroscience*, **7**, 1–13.

Zhang, W., & Lu, J. (2012). Time course of automatic emotion regulation during a facial go/nogo task. *Biological Psychology*, **89**, 444–449.

SUPPORTING INFORMATION

Additional Supporting Information may be found in the online version of this article at the publisher's web-site:

Table 1. Summary of N100 MLM Results at *Cz*.
Table 2. Summary of N200 MLM Results at *FCz*.
Table 3. Summary of P300 MLM Results at *Pz*.
Table 4. Summary of Response Time MLM Results.