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Mindful Acceptance Dampens Neuroaffective Reactions to External and Rewarding Performance Feedback

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Previous research on mindfulness has suggested that individuals high in trait mindfulness show heightened sensitivity to visceral and internally generated stimuli. However, when mindful individuals are exposed to external stimuli—such as pictures or faces—their emotional responses are typically attenuated. In the current study, we tested how trait mindfulness relates to reactivity in response to a different type of external stimulus, namely, performance feedback. Using electroencephalography, we recorded participants' neuroaffective reactions to rewarding, aversive, and neutral feedback, as indexed by the feedback-related negativity (FRN). The FRN is a brain response that peaks approximately 250 ms after feedback presentation, and it is thought to differentiate feedback indicating favorable versus unfavorable outcomes. Our findings suggest trait mindfulness predicts less differentiation of rewarding from neutral feedback, but does not predict brain differentiation of aversive from neutral feedback. This was the case particularly for individuals who scored highly on the "acceptance" facet of mindfulness, a facet that assesses the nonjudgmental acceptance of thoughts and emotions. We discuss the implications of these findings for current theory on mindfulness and emotion regulation.

Keywords: mindfulness, affect, emotion, acceptance, external feedback, reward

The concept of mindfulness has permeated popular culture. And with this surge of interest, psychological scientists have begun to explore precisely what it means to be mindful. Mindfulness, or the philosophy of living in the present moment, seems to have two key components that have long been discussed theoretically (Davids, 1900) and, more recently, empirically (e.g., Cardaciotto, Herbert, Forman, Moitra, & Farrow, 2008). Simply put, mindfulness encompasses two facets: (a) the behavior that is conducted (acknowledging all thoughts and feelings), known as awareness; and (b) the way in which this behavior is conducted (openly accepting those thoughts and feelings), known as acceptance. The richness of mindfulness practice has inspired researchers to ask how mindfulness might relate to psychological processes, and how being mindful might have positive consequences for individuals.

One area of particular interest has been the connection between mindfulness, affective reactivity, and emotion regulation (Williams, 2010; Teper, Segal, & Inzlicht, in press). This particular topic has received much interest from the scientific community because of its clinical implications for mood disorders, such as depression and anxiety (Teasdale et al., 2002; Goldin & Gross, 2010). Research about this topic has varied, with some studies documenting a negative correlation between mindfulness and emotional reactivity (Ortner, Kilner, & Zelazo, 2007), and others suggesting that mindfulness might be related to heightened affective reactivity (Teper & Inzlicht, 2013). The precise nature of the relationship between mindfulness and emotion regulation, therefore, is still unclear, with a number of important questions unanswered. For instance, what sorts of stimuli elicit quelled affective reactions among mindful individuals and what sorts elicit greater reactivity? In the current article, we aimed to address this question by exploring how trait mindfulness might correlate with individuals' neuroaffective reactions to external performance feedback, and to discuss the implications of this relationship for current theories of mindfulness and emotion regulation.

Mindfulness and Emotion Regulation

The cornerstone of mindfulness practice is being able to attend to all thoughts and emotions, but to attend to them nonjudgmentally (Kabat-Zinn, 1994). In other words, practitioners of mindfulness recognize the emotion that they are feeling without getting caught up in the internal stories related to it. Not surprisingly, numerous studies have suggested that mindfulness may result in improved emotion regulation (Lutz, Brefczynski-Lewis, Johnstone, & Davidson, 2008; Perlman, Salomons, Davidson, & Lutz, 2010).

There is plenty of evidence suggesting that mindfulness fosters quelled emotional reactions, particularly to external stimuli. For instance, one study found that mindfulness meditation training reduced skin conductance responses to both pleasant and unpleasant pictures (Ortner et al., 2007). A similar pattern was found using EEG, such that when viewing highly arousing images, both negative and positive in valence, individuals high in trait mindfulness

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exhibited a lower *late positive potential* (Brown, Goodman, & Inzlicht, 2013), an event-locked electrical brain potential that is thought to represent sustained attention to emotional stimuli (Hajcak, Dunning, & Foti, 2009). Finally, a study using functional magnetic resonance imaging (fMRI; Creswell, Way, Eisenberger & Lieberman, 2007) found that while labeling emotional faces, trait mindfulness was related to decreased right amygdala activation, a brain region thought to represent the processing of emotional stimuli. However, the results of this study also indicated that participants high in mindfulness also experienced greater activation in the prefrontal cortex, a brain area responsible for emotion regulation, suggesting that these individuals may have exhibited a decreased emotional reaction to these stimuli because they actively regulated their reactions to them (Creswell et al., 2007).

Taken together, this research provides important insight into the linkage between mindfulness and emotion regulation, suggesting that mindful individuals may be particularly effective at regulating their emotions to external stimuli. Indeed, mindfulness theorists have emphasized the importance of inhibiting elaborative reactions to external stimuli, and instead focusing on internal sensations (Bishop et al., 2004). As such, another set of empirical studies has suggested the relationship between mindfulness and internal stimuli may be quite different.

Mindfulness Enhances Sensitivity to Internal Stimuli

An important aspect of some mindfulness practices (e.g., Segal, Williams, & Teasdale, 2002; Bishop et al., 2004) is that mindfulness fosters an experiential way of being that may heighten visceral sensations, but reduces the narrative that is built around these sensations (Williams, 2010). Because many meditative traditions require practitioners to focus on internal sensations, such as breathing, it is not surprising that mindfulness may result in enhanced sensitivity to internal stimuli. Recent work that has suggested mindfulness is related to enhanced visceral awareness (Gu, Zhong, & Page-Gould, 2013) as well as emotional awareness (Teasdale et al., 2002; Niemiec et al., 2010) is particularly supportive of this idea. Related research has shown that when individuals who completed a mindfulness course passively viewed emotional stimuli, they displayed increased activations in the anterior insula, a region of the brain involved in visceral and somatosensory processing (Farb et al., 2010). Experienced meditators typically display activations in these same brain regions during practice (Lazar et al., 2005; Hölzel et al., 2008). Related research with a clinical sample found that individuals who completed a mindfulness course displayed stronger short-term amygdala activation to negative self-beliefs, but that these reactions were also quickly extinguished (Goldin & Gross, 2010). Finally, although meditators exhibit decreased activity in the amygdala (a region associated with the evaluation of affect) while experiencing pain, they show increased activity in the anterior cingulate cortex (ACC), thalamus, and insula—regions implicated in primary pain processing (Grant, Courtemanche, & Rainville, 2011). Taken together, these findings imply that mindful individuals may be particularly attuned to internal emotional stimuli.

The results of a recent EEG study have spoken particularly well to the idea that mindfulness may be related to enhanced affective reactivity. Researchers found that individuals who are active meditators and who are high in trait mindfulness exhibited significantly stronger neuroaffective reactions in response to their own errors, as indexed by the error-related negativity (ERN; Teper & Inzlicht, 2013). The ERN (Gehring, Goss, Coles, Meyer, & Donchin, 1993) is thought to be generated by the ACC (Dehaene, Posner, & Tucker, 1994) and occurs about 50−100 ms after error commission. Although there is some debate about what this brain potential represents, it is often conceptualized as a preconscious response that is associated with motivation (Hajcak, Moser, Yeung, & Simons, 2005), negative affect (Bartholow, Henry, Lust, Saults, & Wood, 2012; Inzlicht & Al-Khindi, 2012), and conflict monitoring (Yeung, Botvinick, & Cohen, 2004). In some ways, it can be thought of as an internal feedback signal (Horan, Foti, Hajcak, Wynn, & Green, 2012) because it is generated in response to an individual's own recognition of error commission, rather than being generated in response to external feedback about his or her performance. Because errors are internally generated stimuli (Horan et al., 2012), and are often felt viscerally before they actually occur, it is not entirely surprising that mindfulness would amplify the neural reaction associated with them.

It is not clear, however, what such findings mean for the relationship between mindfulness and neural affective reactivity to external stimuli. Although past work on mindfulness has suggested that mindful individuals display dampened emotional responses to external stimuli, such as pictures (Ortner et al., 2007; Brown et al., 2013) and faces (Creswell et al., 2007), it is not clear how mindfulness relates to affective reactions to diagnostic feedback, which although external is also self-relevant.

Feedback-Related Negativity: A Neural Correlate of Reactivity to External Feedback

Previous research has suggested that mindful individuals may have enhanced sensitivity to internally generated feedback (Teper & Inzlicht, 2013). To extend these findings, we wanted to test for the relationship between trait mindfulness and neural affective reactivity in response to feedback that is produced by an external source. In doing this, we hoped to elucidate the relationship between mindfulness and emotion regulation, and to provide insight into the ways in which trait mindfulness may modulate reactions to different types of stimuli.

For the current study, we examined the feedback-related negativity (FRN), which is a negative deflection in the event-related potential (ERP) that peaks approximately 250 ms after feedback presentation, and is thought to differentiate feedback indicating rewarding versus nonrewarding outcomes. The FRN may be analogous to the ERN in that both components play important roles in performance monitoring. However, while the ERN indexes internal response monitoring, the FRN represents reactions to external feedback (Horan et al., 2012). Because there is evidence that mindful individuals exhibit enhanced ERNs (Teper & Inzlicht, 2013), we thought that investigating the FRN would provide a clear comparison between the effect of mindfulness on internal and external feedback reactivity.

Traditional models of the FRN have classified this component as a negative-going deflection that occurs in response to aversive feedback or nonreward (Holroyd & Coles, 2002; Hajcak, Moser, Holroyd, & Simons, 2006). According to this view, the FRN stems from the ACC (e.g., Bellebaum & Daum, 2008; Gehring & Willoughby, 2002; Holroyd & Coles, 2002; Luu, Tucker, Derryberry, Reed, & Poulsen, 2003; but see Nieuwenhuis, Slagter, von Geusau, Heslenfeld, & Holroyd, 2005; van Veen, Holroyd, Cohen, Stenger, & Carter, 2004) and acts as a signal of error detection that facilitates behavioral adjustment. This process is thought to be modulated by phasic decreases in mesencephalic dopamine activity during expectations of loss (Bellebaum & Daum, 2008).

Recent evidence has emerged, however, suggesting that the FRN may also arise as a *positivity* in the waveform that is particularly responsive to rewards (e.g., Carlson, Foti, Mujica-Parodi, Harmon-Jones, & Hajcak, 2011; Foti, Weinberg, Dien, & Hajcak, 2011; Kujawa, Smith, Luhmann, & Hajcak, 2013). In one study, mesocorticolimbic dopamine structures, including the basal ganglia, ventral striatum, caudate, amygdala, medial prefrontal cortex (MPFC), and orbitofrontal cortex, were activated during fMRI in response to rewards compared with losses during a gambling task (Carlson et al., 2011). This pattern of activity was associated with positive deflections in FRN amplitude following rewards as opposed to losses. Related research has found that the MPFC is more active in response to gain relative to losses (Fujiwara, Tobler, Taira, Iijima, & Tsutsui, 2009) and to pleasant versus unpleasant images (Sabatinelli, Bradley, Lang, Costa, & Versace, 2007). Thus, if the MPFC is at least in part responsible for giving rise to the FRN, then it follows that the FRN may be especially sensitive to rewarding or positive feedback.

Taken together, the current research suggests that the FRN likely represents two separate, but overlapping processes. The first is a negativity in the waveform that is influenced by losses, or aversive feedback, and stems from brain regions implicated in negative affect, such as the ACC (Holroyd & Coles, 2002) and periaqueductal gray (An, Bandler, Ongur, & Price, 1998). The second is a positivity that is elicited by rewarding feedback, and stems from the mesocorticolimbic dopamine reward system (Bernat, Nelson, Steele, Gehring, & Patrick, 2011; Carlson et al., 2011). As such, theorists have recommended calculating and interpreting the FRN as a difference score, which would index reward versus nonreward differentiation (Weinberg, Luhmann, Bress, & Hajcak, 2012).

Current Study

Mindfulness practices emphasize the importance of inhibiting elaborate reactions to external stimuli, and instead focusing on internal signals, or the primary somatic representations of such stimuli (Segal et al., 2002; Bishop et al., 2004). Because the FRN is produced by external stimuli (Horan et al., 2012) and because recent evidence has supported the notion that the FRN might have a motivational or affective component (Hajcak et al., 2006; Foti et al., 2011), we predicted that trait mindfulness would be associated to neural response attenuation, indicating the ability either to regulate or to be less reactive to external stimuli. Specifically, we were interested in discerning whether this predicted response attenuation would be driven by decreased reactivity to rewarding feedback, aversive feedback, or both. Given past research linking mindfulness to a decrease in reactivity to both negative and positive external stimuli (e.g., Ortner et al., 2007; Brown et al., 2013), we hypothesized that mindful individuals might exhibit response attenuation to both rewarding and aversive external feedback. We also wondered how the two discrete facets of mindfulness (awareness and acceptance) would be associated with neuroaffective reactions to feedback. Because the acceptance facet of mindfulness encompasses the *nonjudgmental* acceptance of emotions, and because suppressing emotions has previously been linked with enhanced arousal (Campbell-Sills, Barlow, Brown, & Hoffman, 2006), we hypothesized that this facet specifically might be especially related to greater FRN response attenuation.

For the current study, participants were brought into the laboratory for an EEG experiment. Participants completed several questionnaires, including the Philadelphia Mindfulness Scale (PMS; Cardaciotto et al., 2008) and the Big Five Inventory (John & Srivastava, 1999), and then proceeded to complete a time-estimation task (Miltner, Braun, & Coles, 1997), during which we recorded electroencephalographic (EEG) activity.

Method

Participants

Forty-seven participants (27 men, M_{age} = 19.26 years, SD = 1.82) were recruited from the University of Toronto Scarborough participant pool to participate in a psychology study in exchange for course credit. We report how we determined our sample size, all data exclusions, all manipulations, and all measures in the study. We decided, a priori, to terminate data collection at the end of the term, provided that we had upward of 40 participants at that point. Two participants were excluded from all brain analyses due to missing EEG data, leaving 45 participants in the sample.

Mindfulness and Individual Difference Measures

Prior to the recording of brain activity, all participants completed several demographic questions (e.g., age, sex). In addition, participants completed the 20-item PMS (Cardaciotto et al., 2008). Items were ranked on a 5-point Likert scale, ranging from *strongly disagree* to *strongly agree*. The PMS (α = .66) consists of two subscales: Mindful Awareness, which assesses present-moment awareness (e.g., I am aware of what thoughts are passing through my mind; α = .70), and Mindful Acceptance, which assesses the acceptance of thoughts and emotions (e.g., I try to distract myself when I feel unpleasant emotions; α = .72). Descriptive statistics for these scales revealed that we had a sufficient range of scores for both the Mindful Awareness subscale (range: 2.40–4.70, M = 3.85, SD = 0.43) and the Mindful Acceptance subscale (range: 1.70–4.10, M = 2.57, SD = 0.58). Participants also completed the Big Five Inventory (John & Srivastava, 1999), which assesses for trait extraversion (α = .83), agreeableness (α = .78), conscientiousness (α = .74), neuroticism (α = .80), and openness (α = .56). Items were ranked on a 5-point Likert scale, ranging from *strongly disagree* to *strongly agree*.

Procedure

We used a time-estimation task to elicit the FRN (Miltner et al., 1997). A central fixation cross was presented for 250 ms, followed by a blank screen. Participants were instructed to press a response key when they believed that 1 s had passed since the appearance of the cross. Visual performance feedback was provided 2 s after the initial fixation cue, resulting in an approximately 1 s interval between responses and feedback. This feedback remained on the screen for

1 s and was followed by an intertrial interval varying between 1 and 2 s. Participants completed 20 practice trials before the experimental phase of the study. The experimental phase consisted of 168 trials, divided into four equal blocks, separated by short breaks. Participants received either rewarding (a plus sign) or aversive (a minus sign) feedback, depending on whether their response was within a predefined time window centered on 1 s after the appearance of the fixation cross. This time window, initially set at 100 ms, was made smaller after a correct response (−10 ms) and larger after an incorrect response (+10 ms), such that the number of rewarding (M = 51.84, SD = 9.62) and aversive (M = 56.6, SD = 8.18) feedback signals were approximately equal across all participants. Additionally, uninformative neutral feedback (a question mark) was randomly presented on a third of the trials (M = 54.42, SD = 6.96).[1] These neutral trials served as our control trials.[2] By adjusting the time window, we ensured that the global probability of rewarding, aversive, and neutral feedback stimuli was approximately 33%.

Neurophysiological Recording and Processing

EEG activity during the time-estimation task was recorded using a stretch Lycra cap (Electro-Cap International, Eaton, OH) embedded with 32 tin electrodes. Recordings were digitized at 512 Hz using ASA acquisition software (Advanced Neuro Technology B.V., Enschede, The Netherlands) with digital average-ear reference and forehead ground. EEG activity was analyzed with Brain Vision Analyzer 2.0 (Brain Products GmbH, Munich, Germany). EEG data were corrected for vertical electro-oculogram artifacts (Gratton, Coles, & Donchin, 1983) and digitally filtered offline between 0.1 and 30 Hz (Fast Fourier Transform [FFT] implemented, 24 dB, zero-phase-shift Butterworth filter). The signal was baseline corrected by subtracting the average voltage occurring 200−0 ms before the feedback. An automatic procedure was employed to detect and reject artifacts. The criteria applied were a voltage step of more than 25 μV between sample points, a voltage difference of 150 μV within 150-ms intervals, voltages above 85 μV and below −85 μV, and a maximum voltage difference of less than 0.50 μV within 100-ms intervals. These intervals were rejected from individual channels in each trial. ERP epochs were created by examining continuous EEG 200-ms prefeedback and 800-ms post feedback. ERP averages were then created by separately averaging rewarding, aversive, and neutral feedback trials. Because the FRN is maximal at frontal electrode sites (e.g., Hirsh & Inzlicht, 2008), the FRN was examined at the frontal midline electrode (Fz) and was quantified as the average activity (area) between 200 and 350 ms after feedback.[3]

Results

To ensure that we did isolate the FRN, we ran a multilevel model to examine the differences between areas for feedback (effect coded [EC]) for rewarding (EC = 1), aversive (EC = −1), and neutral feedback trials (EC = 0). We used a variance components covariance matrix to estimate a random intercept for each participant. Our results suggest the feedback-related negativity differed significantly among the three trial types, $F(2, 90) = 13.81$, $p < .001$. We observed a significantly more negative-going deflection in the FRN for aversive feedback trials (M = 752.77, SD = 545.33) than for rewarding trials (M = 1024.63, SD = 840.25), $b = -255.25$, $SE = 72.72$, $t(90) = -3.51$, $p = .001$, and a significantly more negative-going deflection for neutral trials (M = 633.82, SD = 682.80) than for rewarding trials (M = 1024.63, SD = 840.25), $b = -373.88$, $SE = 72.72$ $t(90) = -5.14$, $p < .001$. However, we did not find significant difference in FRN amplitude in response to feedback on aversive and neutral trials, $b = 118.64$, $SE = 72.72$, $t(90) = 1.63$, $p > .10$ (see Figure 1a). These results suggest that we did isolate the FRN.

Difference Wave Analyses

Recent recommendations in ERP methods (see Luck, 2005) have advised examining ERP components as difference waves because absolute ERP amplitudes may by contaminated by other components. For instance, a decrease in the amplitude of one component can result from the superposition of a component with opposite polarity. Furthermore, because the FRN is thought to be a function of two independent, yet overlapping, processes (one sensitive to reward and the other sensitive to aversive feedback), Weinberg et al. (2012) have suggested that it may be most useful to compute the FRN as a difference score, and interpret the score as differentiation between two different feedback types. To explore precisely how mindfulness influences neuroaffective reactions to rewarding and aversive performance feedback, we ran a series of multilevel models with mindfulness (mean-centered) as a predictor. We calculated two difference scores by subtracting ERP amplitudes for neutral feedback trials from the ERP amplitudes of rewarding and aversive feedback trials, respectively (Holroyd & Krigolson, 2007) (see Figure 1b). These difference scores capture the differentiation of reward versus neutral, and aversive versus neutral, respectively (Weinberg et al., 2012). We chose to use neutral trials as a point of comparison for our difference waves because this would allow us to discern whether mindfulness predicted reactivity to rewarding or to aversive feedback trials.

We ran a multilevel model analysis in which we entered the two computed difference scores as within-subjects factors, and trait mindfulness as a between-subjects factor. Mindfulness was mean-centered, and the difference waves were dummy-coded (rewarding/neutral = 1, aversive/neutral = −1). Results revealed a main effect for difference wave type, $F(1, 43) = 13.17$, $p = .001$. However, there was no main effect for trait mindfulness, $F(1, 43) = .62$, $p >$ .43. We did, however, find a significant interaction between difference wave type and mindfulness, $F(1.43) = 5.72$, $p < .05$. To further probe these results, we ran simple effects tests. The results of our analyses revealed that trait mindfulness was a significant predictor of response differentiation when comparing rewarding and neutral feedback, $b = -392.08$, $SE = 182.81$, $t(83.64) = -2.15$, $p < .05$. In other words, individuals who reported high levels of mindfulness

[1] We report the postartifact detected and corrected average number of trials per feedback type.

[2] Although we used uninformative neutral feedback as a control, previous work has found that such feedback elicits similar amplitude feedback-related negativities to negative or aversive feedback (Holroyd et al., 2006; Hirsh & Inzlicht, 2008), suggesting that neutral feedback may be processed as a "nonreward."

[3] Although we only report analyses for the frontal midline electrode (Fz), we found the same pattern of significant correlations for electrode sites frontal central (FCz) and central (Cz).

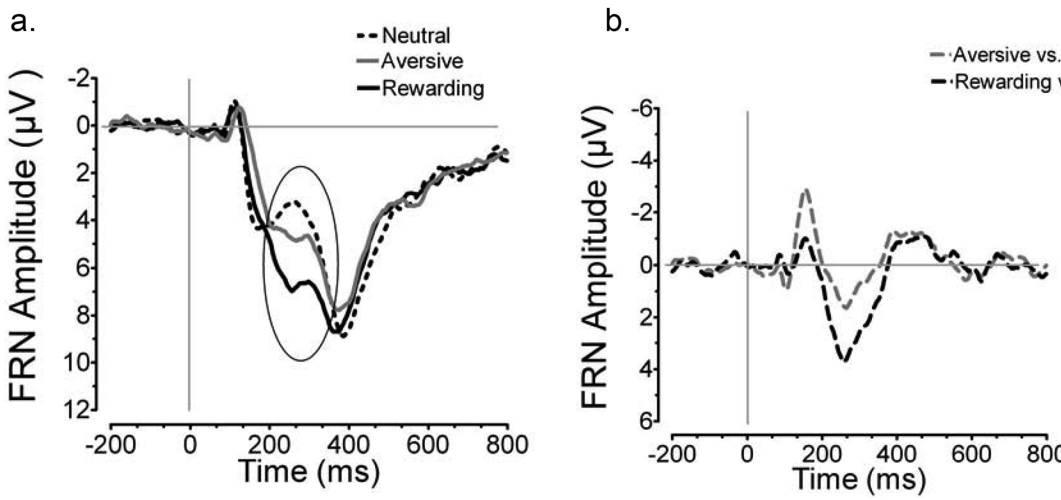

Figure 1. Event-related potentials at the electrode site Fz for neutral, aversive, and rewarding feedback trials. Feedback-related negativity (FRN) is highlighted (a). The FRN difference wave for aversive and rewarding feedback trials (b).

displayed significantly less neuroaffective reward/neutral differentiation than individuals who reported low levels of mindfulness. Next, we tested whether mindfulness predicted neuroaffective differentiation between aversive and neutral feedback. Surprisingly, we found that mindfulness was not a significant predictor of FRN differentiation for aversive versus neutral feedback trials, $b = 171.87$, $SE = 182.81$, $t(83.64) = .94$, $p > .30$. In sum, trait mindfulness seems to affect reward versus neutral feedback differentiation, but not aversive versus neutral feedback differentiation.

To further probe these effects, we tested whether the two separate facets of mindfulness—acceptance and awareness—would predict FRN amplitudes. We first examined mindful acceptance (mean-centered) as a predictor of response differentiation. Results revealed a main effect for difference wave type, $F(1, 43) = 14.80$, $p > .001$, as well as a main effect for mindful acceptance, $F(1, 43) = 5.14$, $p < .05$. We also found find a significant interaction between difference wave type and acceptance, $F(1.43) = 9.35$, $p < .01$. To further probe these results, we ran tests of simple effects and found that mindful acceptance was a significant predictor of rewarding versus neutral feedback differentiation, $b = -398.68$, $SE = 107.45$, $t(83.98) = -3.71$, $p < .001$. In other words, individuals who reported high levels of mindful acceptance displayed significantly less neuroaffective reward/neutral differentiation than individuals who reported low levels of mindful acceptance (see Figures 2a and 3a). Mindful acceptance, however, was not a significant predictor of neuroaffective differentiation between aversive and neutral feedback, $b = 28.44$, $SE = 107.45$, $t(83.98) = .27$, $p > .79$ (see Figures 2b and 3b). Finally, we wanted to examine the role that mindful awareness plays in FRN response differentiation. We found a main effect for difference wave type, $F(1, 43) = 9.61$, $p < .01$. However, there was no main effect for mindful awareness, $F(1, 43) = 2.57$, $p < .12$, nor did we find a significant interaction between awareness and difference wave type, $F(1, 43) = 0.00$, $p < .98$.[4] These results suggest that the acceptance facet of mindfulness was primarily responsible for driving the associations with overall mindfulness and the FRN.

Table 1 shows all correlations between main study variables. To ensure the effect of self-perceived acceptance on FRN differentiation for rewarding versus neutral feedback was not being driven by extraneous variables, we separately controlled for age, sex, and all facets of the Big Five Inventory. Even when controlling for these variables, the relationship between acceptance and FRN remained significant (ps $< .05$) (see Table 2).

The results of our analyses using difference scores could signify one of two possibilities: (a) that mindfulness predicts larger negativities in response to neutral feedback, and does not predict FRN amplitude for positive feedback, or (b) that mindfulness predicts smaller positivities to rewarding feedback, and does not predict FRN amplitude for neutral feedback. To discern precisely how trait mindfulness affects reactivity to various feedback valences, we conducted additional analyses using absolute FRN values.

Raw Score Analyses

Although using difference scores can inform us about the way in which mindfulness affects response differentiation, these scores cannot reveal how mindfulness predicts responsivity to specific feedback types. For this reason, we examined raw FRN scores as a function of mindfulness. To test for associations between mindfulness and neuroaffective reactions to various feedback types, we modeled FRN amplitude as a function of trial type and trait mindfulness. Within our multilevel analysis, trial type was entered as a within-subjects factor and mindfulness was entered as a between-subjects factor. Prior to analysis, mindfulness was centered at the mean, and trial type was effect-coded (reward = 1,

[4] We also tested how the two facets of mindfulness predicted feedback-related negativity differentiation for rewarding versus aversive feedback trials, and found that, although mindful acceptance was a significant predictor of reward versus nonreward differentiation, $b = 0.42$, $t(43) = 3.06$, $p < .01$, $\eta^2 = .18$, mindful awareness was not, $b = -0.002$, $t(43) = -0.02$, $p > .98$.

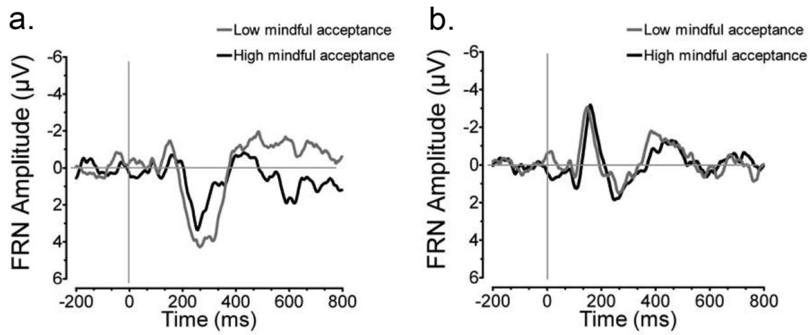

Figure 2. The feedback-related negativity (FRN) difference wave for rewarding feedback trials (a) and aversive feedback trials (b) for participants high (M = 3.00) and low (M = 2.13) in mindful acceptance, as determined by a median split.

neutral = 0, aversive = −1). We found a main effect for trial type, $F(2, 86) = 17.86$, $p < .001$, as well as a marginal effect for trait mindfulness, $F(1, 43) = 2.90$, $p = .096$. Of import, we found a significant interaction between overall trait mindfulness and trial type $F(2, 86) = 4.09$, $p = .02$. To probe this interaction further, we conducted tests of simple effects, which revealed that although trait mindfulness predicted a smaller positivity in the waveform in response to rewarding feedback, $b = -773.99$, $SE = 291.78$, $t(59.83) = -2.65$, $p = .01$, it had no such effect for negative, $b = -210.04$, $SE = 291.78$, $t(59.83) = -2.65$, $p > .47$, or neutral feedback trials, $b = -381.91$, $SE = 291.78$, $t(59.83) = -2.65$, $p = .19$. This suggests that trait mindfulness may be related to less neuroaffective reactivity to external rewarding feedback.

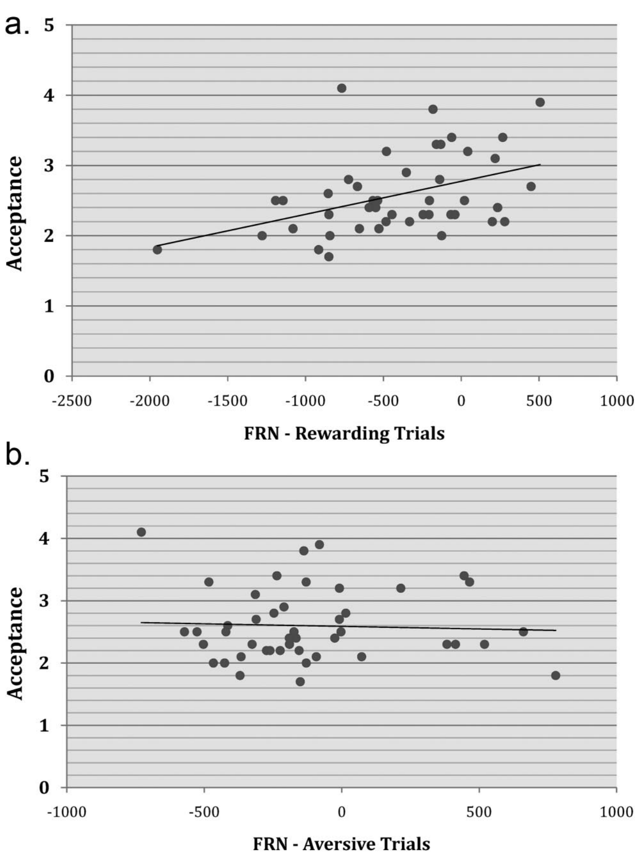

Figure 3. Scatterplot of the relationship between mindful acceptance and feedback-related negativity (FRN) difference wave for rewarding feedback trials (a). Scatterplot of the relationship between mindful acceptance and FRN difference wave for aversive feedback trials (b).

To explore this effect further, we ran two additional multilevel model analyses, testing the effects of the two separate facets of mindfulness—acceptance and awareness (mean-centered)—on neuroaffective reactivity to feedback. Analyses revealed a significant main effect of trial type, $F(2, 86) = 20.58$, $p < .001$, but no main effect of mindful acceptance, $F(1, 43) = 1.90$, $p > .17$. We did, however, find a significant interaction with acceptance and trial type, $F(2, 86) = 8.03$, $p = .001$. When examining the effects of awareness on trial type, we found a significant main effect for trial type, $F(2, 86) = 14.95$, $p > .001$, but no main effect of awareness, $F(1, 43) = 0.80$, $p > .37$, or interaction between awareness and trial type, $F(2, 86) = 0.73$, $p > .4$. This suggests that the acceptance facet of mindfulness was largely responsible for driving our effect. Because the omnibus test with awareness was not significant, post hoc tests of simple effects were conducted with acceptance exclusively. As it turns out, trait mindful acceptance was associated with a significantly smaller positivity in the waveform in response to rewarding feedback, $b = -504.37$, $SE = 179.72$, $t(58.18) = -2.81$, $p > .01$, but had no such effect for negative, $b = -77.25$, $SE = 291.78$, $t(58.18) = -0.43$, $p > .66$, or neutral feedback trials, $b = -105.69$, $SE = 291.78$, $t(58.18) = -0.59$, $p = .55$. These results imply that individuals who report higher levels of mindful acceptance also exhibit smaller neuroaffective reactions to rewarding feedback, but that trait levels of acceptance may not be associated with reactivity to aversive feedback.

General Discussion

The results of the current experiment suggest that trait mindfulness is linked to less neuroaffective reactivity in response to rewarding feedback. Surprisingly, however, mindfulness did not predict response attenuation to aversive feedback. Furthermore, our results suggest that although highly mindful individuals exhibited less response differentiation between rewarding and neutral feedback, they did not show any differentiation between aversive

Table 1
Correlations for Main Study Variables

	FRN (reward)	FRN (aversive)	Mindfulness	Acceptance	Awareness	EXTRA	AGREE	CONS	NEUR	OPEN
FRN (reward)		.12	$.27^{***}$	$.44^{**}$	−.15	−.15	$-.28^{***}$	−.04	.07	.02
FRN (aversive)			−.18	−.05	−.23	−.14	.12	$.36^{**}$	.08	−.05
Mindfulness				$.80^{**}$	$.57^{**}$	.16	−.15	−.11	−.15	.22
Acceptance					−.04	.06	$-.32^{*}$	$-.26^{***}$	−.24	−.04
Awareness						.18	.18	.18	.07	$.41^{**}$
EXTRA							.03	−.04	$-.45^{**}$	.17
AGREE								.14	−.09	$.30^{*}$
CONS									.22	.15
NEUR										.15
OPEN										

Note. Sample size is 47, but 45 for all correlations with the FRN difference scores. FRN = feedback-related negativity; FRN (reward) = rewarding- vs. neutral-feedback difference wave; FRN (aversive) = aversive- vs. neutral-difference wave; EXTRA = extraversion; AGREE = agreeableness; CONS = conscientiousness; NEUR = neuroticism; OPEN = openness.
* $p < .05$. ** $p < .01$. *** $p < .08$.

and neutral feedback. This was particularly the case for individuals high in self-perceived mindful acceptance. This suggests that individuals who report a high level of nonjudgmental acceptance of thoughts and emotions display less neuroaffective reactivity to immediate rewards. Of note, we found no such pattern for individuals who reported high present moment awareness. Furthermore, we found no significant relationship between trait mindfulness and aversive versus neutral feedback differentiation, nor did we find a significant relationship between trait mindfulness and neuroaffective reactivity to aversive performance feedback. Such findings have interesting implications for our understanding of mindfulness, as it relates to affective reactivity and emotion regulation. Although past research has shown that mindful individuals are less reactive to external stimuli (e.g., Ortner et al., 2007), our study is the first to provide evidence for the possibility that mindful individuals display less reactivity to external feedback. Surprisingly, we found that this dampened reactivity was limited to positive feedback, and was not evidence for aversive performance feedback.

At first glance, the current data may seem counter to previous work that has documented a negative association between mindfulness and emotional reactivity to negative stimuli (e.g., Ortner et al., 2007; Brown et al., 2013). However, recent research has increasingly begun to support the notion that FRN reflects activity in brain regions (e.g., ventral striatum, basal ganglia) implicated in reward processing, and is specifically sensitive to gains relative to losses (e.g., Holroyd, Pakzad-Vaezi, & Krigolson, 2008; Foti et al., 2011; Holroyd, Krigolson, & Lee, 2011). Previous work (including the current data; Holroyd, Hajcak, & Larsen, 2006; Hirsh & Inzlicht, 2008), which has suggested neutral and negative feedback may produce similar amplitude FRNs, supports the notion that the FRN is primarily sensitive to rewards, as opposed to losses. This notion is consistent with past research, which has found that the FRN response may be responsive to a binary classification of outcomes (good vs. bad), and is not sensitive to the magnitude of reward or punishment (Hajcak et al., 2006). If the FRN is mainly influenced by rewarding feedback, this may explain why we observed the bulk of our movement on the positive feedback trials, and found no effect for aversive feedback trials.

Table 2
Partial Correlations Between the FRN Difference Wave for Rewarding Feedback Trials and Mindful Acceptance

Variable controlled	Partial correlation
Extraversion	$.45^{*}$
Agreeableness	$.39^{*}$
Conscientiousness	$.45^{*}$
Neuroticism	$.47^{*}$
Openness	$.44^{*}$
Age	$.45^{*}$
Sex	$.45^{*}$

Note. FRN = feedback-related negativity.
* $p \leq .01$.

Our pattern of results also begs the question why might mindful individuals, who are accepting of their thoughts and emotions, be *less* responsive to rewards? Although previous work has linked mindfulness to increases in positive affect (e.g., Geschwind, Peeters, Drukker, van Os, & Wichers, 2011), there is also good reason to believe that mindfulness may attenuate the FRN response to positive feedback. For instance, larger feedback positivities have been linked to trait impulsivity in response to rewards (Onoda, Abe, & Yamaguchi, 2010), and problem gamblers have exhibited larger positivities in response to rewards in risk-taking contexts (Hewig et al., 2010), suggesting that an attentional bias to immediate rewards may, in some cases, be maladaptive. Because mindfulness has been reliably linked to improvements in self-control (Moore & Malinowski, 2009; Teper & Inzlicht, 2013) and, more specifically, enhanced attentional shifting (Jha, Krompinger, & Baime, 2007), it is possible that mindful individuals' response attenuation to immediate rewards may be a function of their effective executive functioning. Finally, our data are consistent with past work that has documented a negative relationship between mindfulness and reactivity to positive emotional stimuli (Ortner et al., 2007; Brown et al., 2013). Mindfulness, it seems, may dampen emotional reactivity to all sorts of external stimuli, and may not be something that simply dampens responses to the unpleasant.

Another intriguing implication of the current study is that the acceptance facet of mindfulness is primarily responsible for this quelled neural response among mindful individuals. At first glance, it may seem counterintuitive to think that being open and accepting of emotional experiences might actually lead to less affective reactivity. However, there is much clinical evidence to support the notion that accepting one's emotions is an important aspect of mental well-being. For instance, it is well known that emotional *suppression* has negative consequences for individuals with anxiety disorders (e.g., Iwamitsu et al., 2005), and actually produces greater levels of negative affect due to rebound effects (Campbell-Sills et al., 2006). Emotional acceptance, on the other hand, can actually minimize the maladaptive consequences of emotional reactivity (Williams, 2010).

Limitations and Future Directions

The results of our work also suggest that mindful individuals may have very different reactions to internal and external stimuli, specifically in the case of feedback. Given what we know about the influence that mindfulness has on health and wellness outcomes, it is possible that greater sensitivity to internal signals may be more adaptive than sensitivity to external signals, such as performance feedback. Although theorists in the field of mindfulness have suggested that it is important to cultivate awareness of both internal and external events (Brown & Ryan, 2004), techniques such as mindfulness-based cognitive therapy place specific emphasis on the attention to internal somatic states (Bishop et al., 2004). And although it is generally accepted that directing attention to the bodily manifestations of affect has beneficial consequences for emotion regulation (Cameron, 2001; Teper et al., in press), the consequences of sensitivity to external stimuli are less well known. Future studies might benefit from exploring the relationship between such reactivity and actual performance, because this would allow for a better understanding of the outcomes of sensitivity to external cues.

Because of past research on mindfulness and emotional reactivity to external stimuli (e.g., Brown et al., 2013), we hypothesized that trait mindfulness would predict smaller reactions to performance feedback. Although we did find that mindfulness was related to response attenuation for reward trials, it is important to consider alternative ways the data could have turned out. Mindfulness, after all, is related to stronger neural reactions to self-generated errors as measured by the ERN (Teper & Inzlicht, 2013). One possibility is that participants in the current sample were generally not as mindful as participants in the former study. After all, participants in the Teper and Inzlicht (2013) experiment were experienced meditators recruited from the community, whereas participants in the current sample were a convenience sample of college students. Although measures of trait mindfulness are commonly used to study phenomenon related to this construct, further research is needed to explore the effects that actual meditation experience might have on neuroaffective reactions to external feedback.

Another factor worth discussing is the theoretical distinction between the FRN and the ERN. Because both components may be generated by the ACC (although the FRN has also been localized to midbrain structures involved in reward processing), and some researchers have considered the ERN and FRN as analogues of one another (e.g., Horan et al., 2012), one might expect that mindfulness would have similar effects on both of these neural signals. However, there are clear differences between these two ERPs. First, the ERN occurs in response to internally generated stimuli, and the FRN in response to externally generated stimuli. In other words, the ERN is elicited by the individuals' own perception of whether they have made an error, whereas the FRN is elicited by external information about their performance. Additionally, the time course of these responses is quite different. Whereas the ERN occurs approximately 50–100 ms after error commission, the FRN peaks around 250 ms after feedback presentation. Thus, it is possible that mindful individuals display higher ERNs because of their ability to attend to shorter-term reactions (Goldin & Gross, 2010), but display lower FRNs because they are able to effectively regulate their emotional reactions by this point. Although this seems like a plausible explanation, the results of the current study cannot address whether highly mindful individuals are in fact regulating their reactions to feedback or whether they are simply less sensitive to it in the first place. Further research is required to properly explore this possibility.

Conclusion

The results of the current research suggest that trait mindfulness attenuates affective reactions to rewarding performance feedback, and that this is especially the case for individuals high in self-perceived mindful acceptance. This work implies that the ability to accept and embrace one's emotional states may have very different consequences for reactivity to external stimuli than it does for reactivity to internal stimuli. These findings have intriguing implications for our understanding of mindfulness, and provide new insight into the complex relationship between mindfulness and affective reactivity.

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