Dispositional mindfulness and semantic integration of emotional words:

Evidence from event-related brain potentials

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Abstract

Initial research shows that mindfulness training can enhance attention and modulate the affective response. However, links between mindfulness and language processing remain virtually unexplored despite the prominent role of overt and silent negative ruminative speech in depressive and anxiety-related symptomatology. Here, we measured dispositional mindfulness and recorded participants’ event-related brain potential responses to positive and negative target words preceded by words congruent or incongruent with the targets in terms of semantic relatedness and emotional valence. While the low mindfulness group showed similar N400 effect pattern for positive and negative targets, high dispositional mindfulness was associated with larger N400 effect to negative targets. This result suggests that negative meanings are less readily accessible in people with high dispositional mindfulness. Furthermore, high dispositional mindfulness was associated with reduced P600 amplitudes to emotional words, suggesting reduced post-analysis and attentional effort which possibly relates to a lower inclination to ruminate. Overall, these findings provide initial evidence on associations between modifications in language systems and mindfulness.

Keywords: mindfulness; language; emotions; attention; N400; P600
Highlights

- High mindfulness is linked to larger N400 effect to negative than positive targets
- Mindfulness disposition is inversely related to P600 mean amplitudes
- Dispositional mindfulness is associated with changes in semantic processing
Introduction

Mindfulness, in its secular form, is often described as a meditation-based practice developing a mode of awareness, which involves the ability to monitor and intentionally bring attention to the present-moment experience with an attitude of acceptance and curiosity (Kabat-Zinn, 2003). However, there is no broadly agreed definition of mindfulness and discussions about what mindfulness is often highlight differences between secular and Buddhist notions of mindfulness (Dorjee, 2010; Dreyfus, 2011; Dunne, 2011). While the conceptual questions about mindfulness remain open, outcome-focused research over the last two decades documented beneficial effects of secular mindfulness programs, such as mindfulness-based stress reduction (MBSR) and mindfulness-based cognitive therapy (MBCT), across a wide range of clinical conditions ranging from anxiety and recurrent depression (Hofmann et al., 2010; Piet & Hougaard, 2011) to cancer (Shennan et al., 2011). Initial evidence also highlights well-being enhancing and illness preventing potential of mindfulness training in contexts such as education (Meiklejohn et al., 2012). With increasing rigor and sophistication of studies evaluating mindfulness-based interventions, there is also growing interest in cognitive and neural mechanisms underlying their therapeutic and well-being enhancing effects.

Neurocognitive research into mindfulness has so far mostly focused on modifications in attention and emotion processing, mirroring theoretical proposals conceptualizing attention and attitude (the affective quality) as the two main aspects of mindfulness (Bishop et al., 2004). Specifically, it has been shown that secular mindfulness training
improves selective attention (Jha et al., 2007; Jensen et al., 2012), diminishes negative effects of stress on working memory capacity (Jha et al., 2010), and enhances efficient use of limited cognitive resources (Moore et al., 2012). With regard to emotion processing, training in MBSR has been found to regulate over-reactivity of the amygdala in participants with social anxiety disorder (Goldin & Gross, 2010), and decrease gray matter density in the right amygdala concurrent with a reduction in perceived stress (Hölzel et al., 2010). Disposition to mindfulness has also been associated with less neural reactivity to highly arousing positive and negative stimuli (Brown et al., 2013).

Overall, increased activation in lateral and medial prefrontal areas (PFC), linked to attention monitoring and executive control, seems to underpin the positive effects of mindfulness (e.g., Cresswell et al., 2007; Goldin et al., 2013), even though the underlying mechanisms may differ amongst beginners and experienced meditators (Taylor et al., 2011). Tang and Posner (2009), in particular, suggested that improvement in executive control resulting from meditation-based training is distinct from other attention enhancing methods in its broad impact on cognition, including attention and emotion regulation (see also Teper et al., 2013), which in turn translates into better regulation of the autonomous nervous system and overall in better self-control. In the case of secular mindfulness training, the improvement in executive control likely reflects enhancement in the ability to monitor mental processes and voluntarily shift attentional focus from emotionally salient contents and thoughts to non-elaborative perceptions such as sounds and bodily sensations (Bishop et al., 2004) coupled with the development of de-centered metacognitive
perspective of cognition -- perceiving mental phenomena as transient events rather than facts (Teasdale et al., 2002).

Such changes in executive control induced by mindfulness arguably impact on language processing as well. Monitoring mental contents involves awareness of thoughts expressed in silent speech while shifting of attention towards bodily sensations often includes disengagement from ruminative overt or silent speech. Indeed, there is a documented inverse relationship between mindfulness and rumination (Brown & Ryan, 2003; Feldman et al., 2007). Importantly, a decrease in rumination is considered one of the primary mediators of improvement in psychological distress (Jain et al., 2007) and depressive symptomatology after mindfulness training (Shahar et al., 2010). This is not surprising given that overt and silent negative ruminative speech plays a pivotal role in development and maintenance of depressive and anxiety-related symptoms (e.g., Nolen-Hoeksema, 2000; Watkins, 2008).

A decrease in uncontrollable rumination, rather than rumination in general, seems to be at the core of the positive effects of mindfulness on depression (Raes & Williams, 2010) -- evidence which makes the possible links between the enhancement of executive control and the modulation of language processing more explicit. This raises interesting hypotheses about the impact of mindfulness practice on language, particularly with regards to the processing of negative ruminative contents. It is for example possible that de-centred monitoring of overt and silent ruminative speech and shifting of attention from negative rumination to bodily sensations result in
diminished activation of semantic representations of negative words both in terms of intensity and frequency.

The current study aimed to investigate neural differences in semantic processing associated with dispositional mindfulness in order to evaluate their semantic integration and cognitive appraisal by participants. Event-related brain potentials (ERPs) locked to the onset of positive and negative words embedded in congruous and incongruous word pairs targeted the N400 and P600 components. The N400 is a negative wave peaking around 400 ms post-stimulus onset and is sensitive to meaning integration across sensory and coding modalities (e.g., written words, pictures or environmental sounds; Hagoort, 2008). It also reflects ease of lexical access from long-term memory (Kutas & Federmeier, 2000; Lau et al., 2008). Target stimuli unrelated in meaning to preceding stimuli elicit more negative N400 amplitudes than semantically related stimuli. This effect is enhanced by a mismatch in emotional valence (Zhang et al., 2006).

The other ERP component of interest -- the P600 -- is a positive wave peaking approximately 600 ms after stimulus onset. The P600 is a marker of attention processing and is part of the P300 family indexing attention-related stimulus reevaluation and working memory updating (Sassenhagen et al., 2014). Specifically, increased P600 amplitude is observed for both syntactic (Kaan et al., 2000) and semantic (Van Herten et al., 2005) reprocessing of information within a given context. Late positivity in the P600 range has also been linked to affective processing, with more positive amplitudes elicited to negative words (Holt et al.,
2009). And a possible link to ruminative processing has been suggested in a study with fibromyalgia patients who showed more positive responses to pain-related words in comparison to healthy participants (Sitges et al., 2007).

Several previous studies have successfully used associations between mindfulness disposition and neurocognitive indices of emotion processing (Cresswell et al., 2009; Brown et al., 2013). Dispositional mindfulness reflects individual differences in the spontaneous propensity to mindfulness which are measurable even without mindfulness training. The present study is the first to investigate the relationship between dispositional mindfulness and processing of emotionally valenced words. Self-report questionnaires assessed levels of dispositional mindfulness, and we recorded the ERPs elicited by the second word (target) in emotionally valenced pairs. Target words were either congruous in meaning and emotional valence with the primes (e.g., holiday-sun or coffin-funeral), or incongruous (e.g., holiday-funeral, coffin-sun). We have predicted that higher mindfulness would be associated with more negative N400 amplitudes to negative words, because of weaker associations between negative semantic representations and other items in the mental lexicon due to less negative rumination. We have also expected reduced P600 amplitudes in participants with higher mindfulness disposition due to less reliance on rumination and thus, less stimulus reevaluation.
Material and methods

Participants

Thirty five healthy young adults, undergraduates at Bangor University, participated in the study. They had no prior training in meditation including secular mindfulness practices. All participants were native speakers of English, had normal or corrected-to-normal vision and normal hearing, and reported no reading difficulties. All participants, except one, whose data were excluded from the study, stated that they were not taking any medication, which could influence their performance and did not have psychiatric problems. According to the self-report results of the Edinburgh Handedness Inventory (Oldfield, 1971), all but two participants were predominantly right-handed. To ensure homogeneity of the sample, the data from the two left-handed participants were excluded. Additionally, data from two participants had to be excluded because of high loss of experimental trials due to excessive movement. One more participant was excluded due to at chance performance on the task. The final group consisted of 29 participants (average age 21.8, age range 18-28 years; 16 women). The study was approved by the ethics committee at Bangor University prior to participant recruitment and all participants provided informed consent before the start of their experimental sessions. Participants received payment for their participation.

Assessment of mindfulness

A one-dimensional measure of mindfulness, the Mindful Attention Awareness Scale (MAAS; Brown & Ryan, 2003), was used to collect ratings of self-reported
mindfulness. The scale consists of 15 items assessing mindful experience and uses a 6-point Likert scale. Mindfulness scores assessed with MAAS have been shown to correlate negatively with measures of rumination, anxiety and depression in a healthy adult sample (Brown & Ryan, 2003). The MAAS score has been used as a measure of mindfulness disposition in previous ERP and fMRI studies (e.g., Cresswell et al., 2009; Brown et al., 2013).

**Materials**

The experimental stimulus set consisted of 140 pairs of words. Half of the word pairs were words related in meaning and matched in terms of emotional valence and the other half comprised unrelated and emotionally mismatched words. So the stimuli consisted of 35 word pairs in each of the four conditions: (1) positive related (e.g., laughter-joke), (2) negative related (e.g., panic-fear), (3) positive-negative unrelated (e.g., laughter-fear), and (4) negative-positive unrelated (panic-joke). Since semantic relatedness and emotional valence matching were co-manipulated, we called the corresponding independent variable ‘congruency’, with congruent pairs being those that are related in meaning and matched for emotional valence and incongruent pairs those that are unrelated and mismatched for emotional valence. Reaction times, judgment accuracy and brain responses were recorded in reference to the onset of the second word in each pair (the target). Target words were selected from the Affective Norms for English Words (ANEW) database (Bradley & Lang, 1999), which provides emotional valence and arousal ratings from a large sample of participants using a scale from 1 to 9 (1 low pleasure, 9 high pleasure; 1 low arousal, 9 high arousal). The average emotional valence ratings of targets in this study were
2.49 for negative words and 7.8 for positive words (p < .0001). Positive and negative targets did not significantly differ in arousal ratings (average arousal 5.7 for both positive and negative targets; p > .1), word frequency (average frequency was 40.6 for positive and 42.6 for negative targets based on the Celex database; Davis, 2005; p > .1), length (average length in letters was 5.6 for positive and 5.8 for negative targets, range 3-9; p > .1) and concreteness (418 for positive targets and 407 for negative targets according to the MRC database, Coltheart, 1981; p = .74). Primes were selected from the Edinburgh Associative Thesaurus (MRC database, Coltheart, 1981) from among the top three semantic associates of each target word matching the target’s valence. Ratings from the ANEW database showed a significant difference between positive and negative primes on valence (p < .0001), but not for arousal (p > 0.09).

Procedure

The 140 word pairs were pseudo-randomly presented on a computer screen in black ink on a white background. Participants were comfortably seated 1.2 m from the centre of a computer screen. Each trial started with a fixation cross presented for 200 ms, followed by a 300 ms blank screen. The prime word was displayed for 500 ms followed by presentation of the target word for 500 ms after a fixed inter-stimulus-interval of 500 ms. The inter-trial interval was 1500 ms. The experiment took approximately 9 minutes and was divided into two blocks presented in counterbalanced order across participants with a pause between blocks. Participants were asked to indicate whether the words in a pair were related or unrelated in meaning. They responded by pressing keys on a response box providing reaction
time data and accuracy rates. To avoid response bias with the dominant hand, the assignment of response keys was counterbalanced across participants. Event-related brain potential responses were locked to the onset of target words.

**EEG recording, processing and statistical analysis**

Neuroscan SynAmp2 amplifiers and Scan 4.5 software (www.neuroscan.com) were used to record EEG data while participants were performing the semantic judgment task. The EEG signal was recorded at the rate of 1kHz using 32 Ag/AgCl electrodes positioned according to the 10-20 international convention in the EasyCap (www.easycap.de). Two additional electrodes were placed above and below the left eye to monitor for eye blinks. Impedances were reduced to and maintained below 7kΩ throughout the recording. Online recording was referenced to the left mastoid with FPz as the ground. The EEG data was bandpass filtered online between 0.01 and 200 Hz and later low pass filtered by 30 Hz, 48dB/Oct slope, with a zero phase shift. Eye blinks were regressed out of the signal using a mathematical algorithm in Scan 4.3 which was based on a model computed individually for each participant’s data set from representative eye-blinks. Additional muscle and eye-movement artefacts were rejected manually upon data inspection. Subsequently, 1.1 s long epochs starting 100 ms before target word onset were created from the continuous EEG recording. Baseline correction using the pre-stimulus activity was performed on the epochs before calculating the grand averages for the four conditions (congruous and incongruous pairs with positive targets, congruous and incongruous pairs with negative targets) and re-referenced to averaged mastoids.
The ERP analyses focused on the N400 and P600 peaks because of their sensitivity to semantic integration and stimulus re-evaluation, respectively. The N400 amplitude was measured between 400-480 ms over fronto-central, central and centro-parietal electrodes reflecting the typical N400 distribution (Kutas & Federmeier, 2011). The signal was maximal at Cz, where peak latencies were measured, and nine electrodes selected based on the expected N400 distribution were included in the mean amplitude analyses: FC3, FC4, FCz, C3, C4, Cz, CP3, CP4, CPz. The P600 amplitude was measured between 510 and 610 ms over the centroparietal region were it was predicted to be maximal (e.g., Van Herten et al., 2005). Latency was measured at CPz and mean amplitude was analysed at CP3, CP4, CPz, P3, P4 and Pz. Greenhouse-Geisser corrections were applied in the ERP analyses when sphericity of data could not be assumed. All the statistical tests reported are two-tailed.

Results

Dispositional mindfulness

Averaged scores on the MAAS ranged from 2.47 to 4.73. Based on a median split, participants were divided into low and high dispositional mindfulness (LM and HM) groups. An independent samples t-test comparing the mindfulness scores of the two groups showed that they were significantly different, $t(27) = 6.67$, $p < .0001$, 95% CI [0.62, 1.16]. The two groups were not significantly different in mean age ($t(27) = 0.17$, $p > .1$) or gender distribution ($\chi^2(1, N = 28) = 1.27$, $p = .26$).
Reaction time and semantic relatedness judgment

Comparisons of LM and HM groups on semantic relatedness, accuracy and reaction time assessed possible associations between mindfulness and behavioural measures of semantic processing. Average accuracy rate across the four conditions was 95%. A mixed analysis of variance (ANOVA) on accuracy with congruency (congruent, incongruent), target word emotional valence (positive, negative), and group (LM, HM) as factors revealed a significant main effect of congruency, $F(1, 27) = 7.27, p = .01$, with accuracy being higher for incongruent word pairs. There was also a significant interaction between semantic relatedness and group, $F(1, 27) = 4.89, p = .04$, indicating larger differences in accuracy between related and unrelated word pairs in the low mindfulness group. Other main effects and interactions were not significant (all $p$s > .1). Error and no-response trials were removed from reaction time (RT) analyses as were any RTs above or below 2.5 standard deviations from each participant’s mean RT. A mixed ANOVA with congruency, emotional valence and group as factors showed a significant main effect of congruency on RT, $F(1, 27) = 8.98, p = .006$, with participants responding significantly faster to congruent pairs. No other main effects or interactions were significant (all $p$s > .1).

N400 modulation with mindfulness disposition

The N400 peaked at 433 ms on average, was maximal at Cz and had the expected central topography reported previously. The N400 analyses of mean amplitudes were conducted using a mixed $2 \times 2 \times 2 \times 9$ ANOVA with congruency, target word valence, group and electrode as factors. As expected, there was a significant N400 congruency main effect, $F(1, 27) = 20.33, p < .001$, showing that N400 mean
amplitudes were more negative in the incongruent compared to the congruent conditions (See Fig. 1A). While emotional valence and group factors showed no significant main effects (both ps > .1), there was a significant interaction between congruency, target emotional valence, and group, $F(1, 27) = 6.06, p = .02$. Follow up t-tests revealed a significantly larger N400 congruency effect (calculated as a subtraction of the amplitudes to targets in the incongruent condition from amplitudes to targets in the congruent condition) to negative targets than to positive targets in the HM group, $t(13) = 3.36, p = .005$, while the LM group showed no difference for this contrast ($p > .6$) (See Fig. 1B). A correlation analysis further revealed a relationship between mindfulness scores of all participants and the difference in the N400 effect to positive and negative targets, $r(29) = .38, p = .04$ (see Fig. 1C). The main factor of electrode, $F(3, 84) = 12.14, p < .001$, and the interaction between the electrode factor and congruency were significant, $F(3, 82) = 3.97, p < .01$. The main effect of group factor and remaining interactions were non-significant (all ps > .1). There were no significant main effects or interactions in a mixed 2 (congruency) x 2 (valence) x 2 (group) ANOVA on N400 latency (all ps > .07).
Figure 1. The N400 effect and mindfulness. (A) N400 event-related potentials at the Cz electrode for the High mindfulness and Low Mindfulness groups in the four priming conditions (P – prime, T- target); (B) Size of the N400 effect (calculated by subtracting the mean amplitudes to the same targets in the incongruous condition from the mean amplitudes in the congruous condition) for the positive and negative targets in high and low mindfulness groups; (C) Correlation between the N400 effect difference (calculated using mean amplitudes as a subtraction of the N400 effect to positive targets from the N400 effect to negative targets) and mindfulness scores of all participants.
**P600 modulation with mindfulness disposition**

The P600 was maximal at the CPz and peaked at 558 ms on average with centro-parietal distribution as expected. A mixed 2 x 2 x 2 x 6 ANOVA conducted on P600 mean amplitudes with congruency, emotional valence of the target word, group and electrode as factors revealed a significant main effect of group, $F(1, 27) = 4.53, p = .04$, showing that P600 mean amplitudes were overall lower in the HM group compared to the LM group across conditions (Fig. 2A). A relationship between P600 mean amplitudes and dispositional mindfulness scores was further supported by a correlation analysis, $r(29) = -.41, p = .03$ (Fig. 2B). There was also a significant main effect of electrode, $F(3, 12) = 4.64, p = .006$, but no significant main effects of congruency and valence (both $p$s > .1). In addition, the interaction between congruency and valence was significant, $F(1, 27) = 4.95, p = .04$. Follow-up t-tests showed that pairs of related negative words elicited the most positive P600 mean amplitudes: There was a significant difference between negative-negative and positive-negative word pairs ($t(28) = 2.37, p = .02$) and between negative-negative and positive-positive word pairs ($t(28) = 2.02, p = .05$), whereas negative-negative word pairs failed to elicit a P600 different from negative-positive pairs ($p = .085$). No other interactions were significant (all $p$s > .06).
Figure 2. The P600 modulation and mindfulness. (A) P600 event-related potentials at the CPz electrode for the High mindfulness and Low Mindfulness groups in the four priming conditions (P – prime, T- target); (B) Correlation between the summed P600 (sum of P600 mean amplitudes across the four conditions) and mindfulness scores of all participants.

Finally, a mixed ANOVA with factors of congruency, valence and group revealed a main effect of congruency on P600 latency, F(1, 27) = 9.85, p = .004, with earlier peaks in the congruent (M = 551 ms, s.d. = 21.7) than in the incongruent condition (M = 565 ms, s.d. = 19.1). There were no other significant main effects or interactions (all ps > .09).
Discussion

In our exploration of dispositional mindfulness in relation to ERP indices of semantic processing and post-analysis, we found manifestations of links between mindfulness and the neural implementation of language. First, the results showed that participants scoring higher on a mindfulness self-report questionnaire produced larger N400 effect to negative target words, whereas participants with lower mindfulness scores presented comparable N400 modulations for both positive and negative target words. Secondly, we found that higher mindfulness was associated with an overall reduction in P600 mean amplitudes. Importantly, in both cases the interpretation of a link between variables was further supported by correlation analyses.

The finding of a larger N400 effect to negative targets could indicate that high trait mindfulness is associated with reduced accessibility to the semantic representations of negative concepts. Considering the known N400 sensitivity to exposure frequency (Lau et al., 2008; Borovsky et al., 2012), this suggests that high dispositional mindfulness may lead to widespread weakening of semantic nodes underpinning representation of concepts with a negative connotation, possibly because mindful individuals are less likely to elaborate negative meanings. They may instead apply accepting non-elaborative attitude to negative meanings and connotations, grounding their attention on sensory experience in the present moment which can reduce negative rumination. This may result in more positive mood as supported by a meta-analysis showing that mindfulness is consistently linked to reduction in
negative affect (Giluk, 2009). Interestingly, mood induction has been shown to modulate the N400, with temporary happy mood induction resulting in larger N400 effect in comparison to the sad mood condition (Chwilla et al., 2011). Although we did not investigate links between mindfulness and emotional state in this study, previous research has documented a negative relationship between mindfulness and depression or anxiety consistent with a relative deactivation of negative representations in semantic memory (Hofmann et al., 2010). In line with the interactive cognitive subsystems model of mindfulness (Teasdale et al., 1995), our findings may reflect better ability of participants with a high mindfulness disposition to notice negative word meanings encountered in everyday life through enhanced awareness and monitoring of mental contents, and progressively reduce spreading of activation from positive meanings to negative connotations. If established as a cognitive processing strategy, this would lead to under-optimised access to negative word meanings, especially when positive words (primes in our experiment) have activated semantic networks implementing positive cognitive schemas. The resulting increased cognitive effort in accessing the meaning of negative words would explain the increase in N400 amplitude observed here.

The overall reduction in P600 mean amplitude observed in the HM group suggests a further possible relationship between activation in language systems, attention and mindfulness. Increased P600 amplitudes are typically observed in experiments involving violation of syntactic rules or semantic anomalies (Kaan et al., 2000; Van Herten et al., 2005). This has led to an interpretation of the P600 as reflecting stimulus reevaluation, triggered by conflict monitoring (Ye & Zhou, 2009). However,
the observed group difference in P600 amplitudes was consistent across both congruous and incongruous conditions, which invites a consideration beyond the semantic anomaly interpretation of the P600 in this study. Indeed, we have found that the congruous negative-negative condition showed most positive P600 amplitudes in comparison to incongruous conditions in both groups, suggesting that the P600 amplitudes reflect affective processing rather than semantic anomaly modulation in this case (in contrast, the P600 latency was sensitive to congruency with no differences across HM and LM groups). This implies that the observed pattern of more positive P600 amplitudes in the LM group might be due to differences in more general attention processes or affective modulation. Perhaps the sensitivity of the P600 to emotion regulation might be the main factor here. Systems of attention control are central to emotion regulation (Ochsner et al., 2002), and increased P600 amplitude has been reported when participants are asked to suppress an emotional response to affective pictures in a priming task. Increased P600 positivity is thus associated with less adaptive emotion processing (Deveney & Pizzagalli, 2008). Since mindfulness encourages the development of adaptive emotion regulation characterized by exposure and acceptance of both pleasant and unpleasant stimuli (Bishop et al., 2004), it is possible that the lower P600 amplitudes observed in our study relate to less rumination resulting from enhanced emotion regulation skills in the HM group.
Limitations and future research

This study investigated correlation-based associative links between mindfulness and modulations in the N400 and P600. As such, the findings do not allow for conclusive inferences about mindfulness being the only or the main factor contributing to the observed effects. Longitudinal studies examining the relationship between changes in trait mindfulness after mindfulness training and shifts in the N400 and P600 effects will be able to provide evidence about possible causal effects. The current study also outlined theoretical foundations justifying possible relationship between the N400 and P600 modulations and rumination. These can be examined in more depth in the future studies using a combination of experimental tasks, psychophysiological measures and self-report measures of rumination.

Conclusions

The present study introduced possible associations between trait mindfulness and the modulation of N400 and P600 ERP indices of language processing. These links are not only empirically interesting, they are also compatible with classical interpretations of N400 and elucidate P600 modulations by affective word meanings. They connect to the expected cognitive underpinnings of mindfulness vis-à-vis concept availability in semantic memory and emotion regulation. This is only a first step, however, and further investigations of the neural basis of interactions between language, mindfulness and well-being is needed to gain a fuller understanding of the cognitive mechanisms at work.
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