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Threat/reward-sensitivity and hypomanic-personality modulate cognitive-control and attentional neural processes to emotional stimuli

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Temperamental-traits (e.g. threat/reward-sensitivity) are found to modulate cognitive-control and attentional-processes. Yet, it is unclear exactly how these traits interact with emotional-stimuli in the modulation of cognitive-control, as reflected by the N2 event-related potential (ERP), and attentional-processes, as reflected by the P2 and P3 ERPs. Here in an ERP emotional-Go/NoGo task, 36 participants were instructed to inhibit their response to Fearful- and Happy-faces. Individual-differences in threat-sensitivity, reward-sensitivity and hypomanic-personality were assessed through self-report. Hypomanic-personality was assessed, given its relationship with reward-sensitivity and relevance to mood-disorder symptoms. Concerning cognitive-control, individuals with elevated threat-sensitivity displayed more-negative N2s to Happy-NoGo (relative to Fearful-NoGo) faces, whereas both individuals with elevated reward-sensitivity and hypomanic-personality displayed more-negative N2s to Fearful-NoGo (relative to Happy-NoGo) faces. Accordingly, when cognitive-control is required (during Go/NoGo), a mismatch between one's temperament and the valence of the NoGo-stimulus elevates detection of the need for cognitive-control. Conversely, the modulation of attentional-processing was specific to threat-sensitivity, as there was no relationship between either reward-sensitivity or hypomanic-personality and attentional-processing. Elevated threat-sensitivity was associated with enhanced early (P2s) and later (P3s) attentional-processing to Fearful-NoGo (relative to Happy-NoGo) faces. These latter findings support the negative attentional-bias model relating elevated threat-sensitivity with attentional-biases toward negative-stimuli and away from positive-stimuli.

Keywords: cognitive-control; N2; P2; reward-sensitivity; threat-sensitivity; hypomanic-personality

INTRODUCTION

Elevated threat-sensitivity is associated with negative-affective states, such as anxiety and fear (Gray, 1987, 1989; Corr and McNaughton, 2008). Traditionally, elevated threat-sensitivity has been linked to particular profiles of attentional-processing. According to the negative attentional-bias model, elevated threat-sensitivity is characterized by enhanced attentional-biases toward negative-stimuli and away from positive-stimuli (Gomez and Gomez, 2002; Armstrong and Olatunji, 2012). Recently, elevated threat-sensitivity has also been viewed as enhancing the need for cognitive-control (Cavanagh and Shackman, 2014). In situations requiring cognitive-control (e.g. monitoring one's behavioral responses), individuals with elevated threat-sensitivity display stronger cognitive-control-related electroencephalogram (EEG) signals (including the N2 event-related potential; ERP) (for a meta-analysis see Cavanagh and Shackman, 2014). Such enhanced N2s are found even when neutral, non-emotional stimuli are used in cognitive-control-related tasks.

Cognitive-control and attentional-processing, however, may not solely be influenced by one's temperament, but also by the interaction between one's temperament and the emotional content of the perceived stimuli. It is unclear whether cognitive-control and attentional-processes are accentuated (or attenuated) when one's temperament is matched/mismatched with the stimulus' valence. Moreover, it is also largely unknown how positive-temperamental styles (e.g. reward-sensitivity and hypomanic-personality) that relate to positive-affective states (e.g. happiness and euphoria) modulate cognitive-control and attentional-processing to emotional stimuli. This article focuses on these questions. Given threat/reward-sensitivity and hypomanic-personality are dispositional risk-factors for affective/mood disorders (Kwapil *et al.*, 2000; Meyer and Hautzinger, 2001), examining these questions has both basic-science and clinical implications.

N2, cognitive-control and mismatch

Enhanced N2s are often found in cognitive-control tasks involving conflict between competing responses (Van Veen and Carter, 2002; Nieuwenhuis *et al.*, 2003; Donkers and van Boxtel, 2004). In a Go/NoGo task, for instance, participants respond to prepotent 'Go' stimuli, while withholding their response to 'NoGo' stimuli. NoGo stimuli reliably elicit negative-going N2s at frontal-central sites ~200–400 ms after stimulus-onset, and NoGo-N2s are usually more-negative than Go-N2s (Pfefferbaum *et al.*, 1985; Folstein and Van Petten, 2008). Thus, NoGo-N2s are often interpreted as reflecting the initial-detection of the need for cognitive-control, arising from evaluating whether to withhold the prepotent-response (Nieuwenhuis *et al.*, 2003).

Besides conflict between competing responses, the need for cognitive-control (as reflected by N2s) can further be modulated by a so-called 'mismatch' (Folstein and Van Petten, 2008; Cavanagh *et al.*, 2012)[1]. This mismatch occurs when attended stimuli

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[1] Although earlier research suggests a distinction between cognitive-control and mismatch N2s (Folstein and Van Petten, 2008), recent studies argue that (i) they both have a common mid-frontal substrate, and (ii) N2s in both cognitive-control and mismatch tasks reflect a realization of the need for cognitive-control (Cavanagh *et al.*, 2012; Cavanagh and Frank, 2014). Specifically, Cavanagh and colleagues showed that cognitive-control (e.g. a response-conflict Cued Simon Task) and perceptual mismatch tasks (e.g. an Oddball with Novelty task) elicit EEG signals in a similar theta phase and power that is relevant to N2s. In fact, this EEG signature has been found across situations that involve the realization of the need for cognitive-control, such as ERPs that are locked to feedbacks or responses of a reinforcement-learning task (Cavanagh *et al.*, 2012; Cavanagh and Frank, 2014). Accordingly, we view that a mismatch is a factor modulating the need for cognitive-control in a Go/NoGo task, as reflected in elevated N2s (Cavanagh *et al.*, 2012; Cavanagh and Frank, 2014).

deviate from a template/framework that one has about the stimulus, thereby signaling the need for cognitive-control. This template can be perception- or expectation-based. The Oddball-with-Novelty task, for instance, generates perception-based tempates. Here, participants respond to 'O's', but not to 'X's' or unique-shapes (Cavanagh *et al.*, 2012). These unique-shapes elicit more-negative N2s than 'X's', although both require no response. This is because 'X's' create a template for the required non-response, and the novel unique-shape signals a mismatch from this perceptual-template. Additionally, templates can be expectation-based. When playing slot-machine, for instance, if people expect to see a stimulus three-consecutive times, the first-two presentations of this stimulus would create an expectation-template. A deviation of the third stimulus from these first-two would create a mismatch, as evidenced by enhanced N2s (Donkers and van Boxtel, 2005; Folstein and Van Petten, 2008).

What is less clear is whether, in cognitive-control-demanding situations, a person's temperament can form the foundation for such templates in a manner similar to perception- or expectation-based templates. Accordingly, stimuli of a certain emotional-valence that are incongruent with one's temperament should reflect a mismatch. This mismatch (e.g. elevated threat-sensitivity mismatched with positive-emotional stimuli) should, in turn, elicit more-negative cognitive-control N2s than matching stimuli (e.g. elevated threat-sensitivity matched with negative-emotional stimuli), as mismatching stimuli are deviations from one's temperament-based template. To date, only one ERP study (Krompinger and Simons, 2009) has provided data for this question. In this emotional Go/NoGo study, undergraduates who scored high on a depression scale displayed larger N2s for positive (than negative) international affective picture system (IAPS)-NoGo photos. Given the strong relationship between depression and threat-sensitivity (Johnson *et al.*, 2003), this finding sharply contrasts with other existing data that individuals with elevated threat-sensitivity have an increased need for cognitive-control (Amodio *et al.*, 2008; Cavanagh and Shackman, 2014). That is, one would predict from these existing data that depressed individuals would have relatively stronger (not weaker) cognitive-control tendencies toward negative (than positive) IAPS-NoGo photos, given that depressed individuals often are more sensitive to negative (relative to positive) stimuli (Armstrong and Olatunji, 2012). Krompinger and Simons (2009) indicated the need for future research to interpret and replicate this effect. We, however, interpret their N2 finding as supporting the mismatch model. Specifically, we predict that a mismatch between elevated threat-sensitivity and positive-valenced NoGo-stimuli should be associated with a greater need for cognitive-control, as reflected by greater N2s.

To fully assess the mismatch model, one needs to not only examine the mismatch between negative-temperamental styles and positive-valenced NoGo-stimuli, but also between positive-temperamental styles and negative-valenced NoGo-stimuli. To address this, here we employed self-reported reward-sensitivity and hypomanic personality. Conceptualized as orthogonal to threat-sensitivity, reward-sensitivity relates to the degree of positive/approach-related affect that one experiences toward rewarding/goal-relevant stimuli (Gray, 1987, 1989; Corr and McNaughton, 2008). For example, self-reported reward-sensitivity is positively associated with the number of positive words generated, recognized and recalled (Gomez and Gomez, 2002). Similarly, hypomanic-personality is associated with increased self-reported reward-sensitivity (Johnson *et al.*, 2005; Alloy *et al.*, 2006), elevated reward-related brain function (Nusslock *et al.*, 2012; Chase *et al.*, 2013; Harada *et al.*, 2013) and elevated familial-risk for bipolar-disorder (Kwapil *et al.*, 2000; Meyer and Hautzinger, 2001). According to the mismatch model, both elevated self-reported reward-sensitivity and hypomanic-personality should be associated with a greater need for cognitive-control (more-negative N2s) to negative-NoGo relative to positive-NoGo stimuli.

Early and late attentional-processing

Early (<200 ms) and late (>400 ms) attentional-processing to emotional-stimuli have been studied intensively with ERPs (Olofsson *et al.*, 2008). Early ERPs (including, a midline-central, positive-going component, called the P2) are thought to reflect rapid selective-attention to negative-valenced stimuli, while late ERPs (including, a midline-parietal, positive-going component, called the P3) appear to underlie the subsequent employment of cognitive-resources to stimuli high on arousal (Olofsson *et al.*, 2008). In passive-viewing studies, for instance, fearful faces typically elicit more-positive P2s and P3s than happy faces (Eimer and Holmes, 2002; Schupp *et al.*, 2004; Williams *et al.*, 2006; Smith *et al.*, 2012), consistent with the perspective that mammals are biologically prepared to respond to threatening stimuli (Ohman and Mineka, 2001).

According to the negative attentional-bias model, elevated threat-sensitivity further modulates attentional-processing by enhancing attention toward negative-stimuli and away from positive-stimuli (Gomez and Gomez, 2002; Armstrong and Olatunji, 2012). Accordingly, individuals high on self-reported threat-sensitivity have particularly elevated attentional-processing ERPs (especially P3s) to negative (relative to positive) stimuli (Kayser *et al.*, 2000; Miltner *et al.*, 2005; Krompinger and Simons, 2009). In Krompinger and Simons' (2009) emotional-Go/NoGo study, for instance, individuals with elevated depression-scores displayed more-positive P3s to negative (relative to positive) NoGo-IAPS photos than individuals who were low on depression. Strikingly, this profile of elevated P3s to negative NoGo-IAPS photos among depressed individuals was contrasted by these same depressed-individuals displaying more-negative N2s to positive (relative to negative) NoGo-IAPS photos. This dissociation between profiles of N2 and P3 suggests that attentional-processing and cognitive-control may be independently modulated by temperament. That is, threat-sensitivity may enhance attentional-processing (P3s) toward negative-stimuli and away from positive-stimuli (i.e. the negative attentional-bias model), whereas threat-sensitivity may enhance cognitive-control (N2s) to positive (relative to negative) stimuli (i.e. the mismatch model).

To date, the independent modulation of temperament on cognitive-control *vs* attentional-processing has only been observed for depressive-symptoms (Krompinger and Simons, 2009). This study aimed to extend this work to the examination of temperamental risk-factors for depression (threat-sensitivity) and to an earlier attentional-processing ERP-component (P2). We predicted that elevated threat-sensitivity would modulate attentional-processing and cognitive-control ERPs in a similar manner to depressive symptoms. That is, individuals with elevated threat-sensitivity would have more-positive attentional-processing P2s and P3s to negative (relative to positive) stimuli, while having more-negative cognitive-control N2s to positive (relative to negative) stimuli. Additionally, although studies often show an association between elevated threat-sensitivity and enhanced attentional-processing ERPs to negative (relative to positive) stimuli (Kayser *et al.*, 2000; Miltner *et al.*, 2005; Krompinger and Simons, 2009), the association between elevated reward-sensitivity and enhanced attentional-processing ERPs to positive (relative to negative) stimuli is less consistently observed (e.g. Mardaga and Hansenne, 2009). This asymmetry suggests that the role that temperament plays in modulating attentional-processing ERPs may be specific to threat-sensitivity, and not present for reward-sensitivity. This study examined this temperament-specific hypothesis by assessing the relationship between self reported reward-sensitivity and hypomanic-personality with attentional-processing ERPs to both positive and negative stimuli.

Current study

We examined how temperament modulates cognitive-control and attentional-processing ERPs to emotional cues, using an emotional Go/NoGo task. Regarding cognitive-control, we tested whether a mismatch between participants' temperament and the valence of the NoGo stimulus enhances need for cognitive-control (N2s). We predict that the mismatch effect on N2s would be observed for both threat-sensitivity and reward-sensitivity. Specifically, we predict that individuals with elevated threat-sensitivity will display more-negative N2s to Happy-NoGo (relative to Fearful-NoGo) faces and that individuals with either elevated reward-sensitivity or elevated hypomanic-personality will display more-negative N2s to Fearful-NoGo (relative to Happy-NoGo) faces. Results consistent with these predictions would suggest that the mismatch model of the cognitive-control N2 applies to both negative-(threat-sensitivity) and positive (reward-sensitivity, hypomanic-personality) temperamental-traits. Concerning attentional-processing, we base our predictions on the negative-attentional bias model that links elevated threat-sensitivity with enhanced attentional-biases toward negative stimuli and away from positive stimuli (Gomez and Gomez, 2002; Mardaga and Hansenne, 2009; Armstrong and Olatunji, 2012). Specifically, we predict that both early (P2s) and later (P3s) attentional-processing for individuals with elevated threat-sensitivity would be enhanced for Fearful-NoGo (relative to Happy-NoGo) faces. We further test whether this attentional-bias effect is temperament-specific to threat-sensitivity (Mardaga and Hansenne, 2009) or reflects more general neuro-cognitive processes that are also observed for positive temperamental-traits. If the attentional-bias effect is temperament-specific, we should only observe a relationship between threat-sensitivity and attentional-bias ERPs. In contrast, if the attentional-bias effect is not temperament-specific, then we should also observe that elevated reward-sensitivity/hypomanic-personality is associated with enhanced P2s and P3s to Happy-NoGo (relative to Fearful-NoGo) faces.

METERIALS AND METHODS

Participants

Thirty-six right-handed, native English Northwestern-University undergraduates participated for course credit (21 females, $M_{age} = 18.56$ years).[2] Five additional participants were excluded due to excessive-artifacts (<20 trials of analyzable data per condition). Participants had no history of head-injury and were not taking psychotropic-medications. Participants provided written consent, approved by local IRB.

[2] There was no effect of gender on any of our dependent variables: NoGo-ERP difference-scores (Fearful-NoGo-ERP-minus-Happy-NoGo-ERP), NoGo-ERPs separately for the Fearful-NoGo and Happy-NoGo conditions, behavioral performance indices, and self-report measures (including, threat/reward-sensitivity and hypomanic personality) (P's > 0.05). Additionally, although our sample size ($n = 36$) is larger than many ERP studies of individual-differences in which similar constructs of threat/reward-sensitivity were investigated (e.g. Boksem *et al.*, 2006; Boksem *et al.*, 2008; Huang *et al.*, 2009; Balconi and Crivelli, 2010; Balconi *et al.*, 2012), it still is relatively small and may limit our ability to examine the specificity of our effects. Future replications are needed to determine whether the relationships found here are stable across studies, which will ultimately facilitate meta-analyses of these relationships (Lieberman and Cunningham, 2009).

[3] One possible limitation involves using fearful and happy faces that inevitably confounds valence with arousal. This is especially because early attentional-processing ERPs are sensitive to valence-information, whereas later attentional-processing ERPs are sensitive to arousal-information (Olofsson *et al.*, 2008). One possible study to separate arousal from valence is comparing high-arousal *vs* low-arousal negative-NoGo stimuli (e.g. fearful *vs* sad faces) and high-arousal *vs* low-arousal positive-NoGo stimuli (e.g. extra-happy *vs* calm faces).

Facial stimuli

We used NIMSTIM facial stimuli (Tottenham *et al.*, 2009), recently validated in ERP studies (Blau, *et al.*, 2007; Smith *et al.*, 2012). We selected 10-Caucasian faces for each valence (Fearful, Happy and Neutral)[3], with an equal number of faces for each gender, that were scored as most intensely expressing each emotion (Tottenham *et al.*, 2009). Faces were converted to gray-scale, controlled for illumination and contrast with Photoshop. A gray oval-shaped frame masked hair and other non-facial features (Figure 1).

Emotional Go/No-Go task

Adapting previous Go/No-Go tasks (Amodio *et al.*, 2008), we instructed participants to monitor facial stimuli presented on a gray-screen (Figure 1). Each trial began with a white fixation-crosshair (500 ms). Facial stimuli were presented next (300 ms), followed by a blank-screen. Participants were instructed to press a designated 'Go' button with their right-index finger when seeing a Neutral face and to refrain from responding to Fearful and Happy faces (NoGo stimuli).[4] If participants made an accurate and fast response (within 800 ms of stimulus-onset) to the Neutral-Go faces, the trial would be terminated (random inter-trial-interval between 850 and 1150 ms). To maintain task-engagement, if participants' responses to Neutral-Go faces exceeded 800 ms, or no-response was provided to neutral faces, the feedback 'Too Slow!' was shown in red font one-second following the Neutral-Go stimuli offset. Similarly, participants were presented with the feedback 'Incorrect!' if making a Go-response to emotional faces. There were 640 trials in total, separated into eight blocks of 80 trials with 60 Neutral-Go, 10 Fearful- and 10 Happy-NoGo faces per block. There were brief intra-block breaks, and 50 practice-trials before the task.

Individual-difference questionnaires

Self-reported threat/reward-sensitivity were measured using the behavioral inhibition and activation scales (BIS/BAS; Carver and White, 1994) and the Sensitivity to Punishment and Sensitivity to Reward Questionnaire (SPSRQ; Torrubia *et al.*, 2001). The BIS/BAS scale consists of 20 Likert-scale items. The 13-item BAS-total subscale assesses self-reported reward-sensitivity and the 7-item BIS scale

[4] We used neutral-valence faces as Go stimuli and emotional-valence faces as NoGo stimuli, as opposed to alternating the valence of the Go and NoGo facial stimuli across blocks (Krompinger and Simons, 2009), for the following reasons. First, assigning faces as Go and NoGo stimuli may alter emotional evalution and cognitive-control of the faces. In a previous Go/NoGo study (Kiss *et al.*, 2008), neutral-Go faces were rated more positively than neutral-NoGo faces. Moreover, positively rated faces were associated with less-negative NoGo-N2s than negatively rated faces. Thus, in our study, responding mostly to fearful-Go stimuli that are mismatched with their temperament may reduce N2s for participants when they inhibit their response to the same stimuli in the subsequent block (and vice versa). Second, varying the valence of the Go and NoGo stimuli across blocks would impose an additional cognitive-load onto participants associated with task-switching (i.e. participants withholding their response to positive-stimuli in one block and to negative-stimuli in another). Task-switching between blocks may inadvertently enhance overall cognitive-control processes (Miyake and Friedman, 2012; Schroder *et al.*, 2012). Despite the advantages of using neutral-Go stimuli and emotional-NoGo stimuli of both positive and negative valence, this approach did have a limitation. Specifically, any difference observed in ERPs between emotional *vs* neutral stimuli were inseparable from those observed between NoGo *vs* Go stimuli. That is, it is difficult to disentangle the effect of emotion from cognitive-control. However, this limitation is minimized by the fact that the primary goal of this article was to examine whether individual-differences in temperament (threat/reward-sensitivity, hypomanic-personality) modulate cognitive-control and attentional-processing to the valence of the NoGo stimuli. Given this paper's focus on individual-differences to the valence of the NoGo stimuli, we wanted to maximize our power by placing all of the emotional-valence stimuli as NoGo stimuli. Moreover, we argue that the N2 difference-score correlations were likely not influenced by either emotional valence or cognitive-control alone, but rather the two combined. This is because previous research using passive-viewing paradigms of emotional stimuli did not typically elicit N2s (Eimer and Holmes, 2002; Ashley *et al.*, 2004; Schupp et al., 2004), and studies using non-emotional Go/NoGo tasks only found correlations with threat-, but not reward-, sensitivity (Amodio *et al.*, 2008). By using emotional stimuli in a cognitive-control task, we were able to demonstrate correlations between N2s and both threat- and reward-sensitivity. Likewise for P2s, previous research using an emotional odd-ball paradigm, a less demanding cognitive-control task in terms of inhibition, failed to demonstrate that threat-sensitivity modulates P2s, reporting instead modulation at P3s (Huang *et al.*, 2009). Altogether these findings suggest that the combination of emotional-valence and cognitive-control influenced our N2 and P2 results.

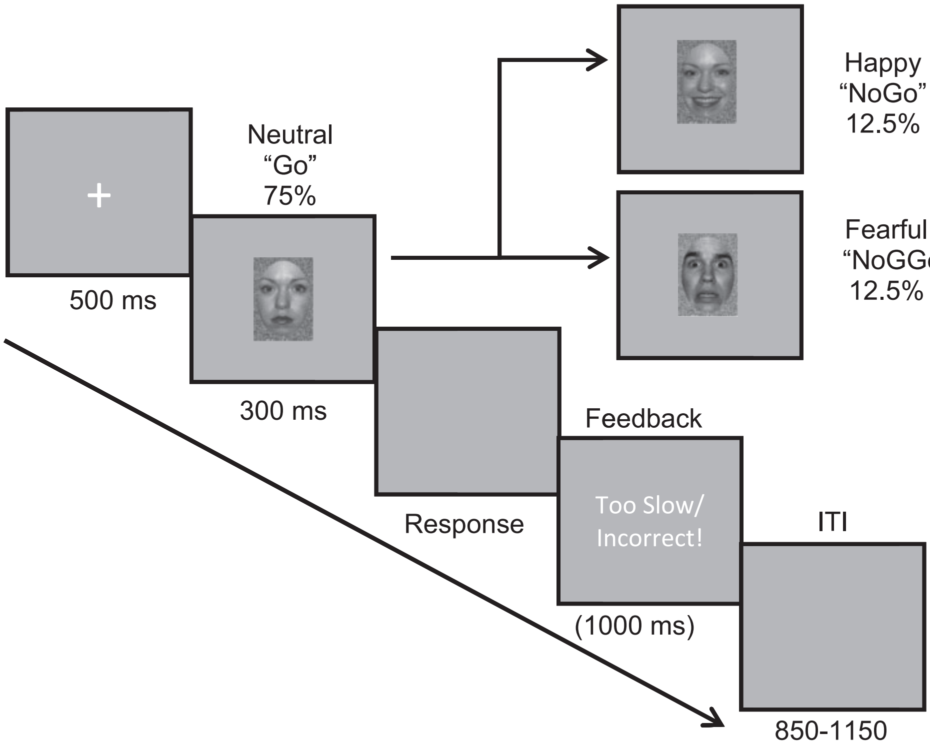

Fig. 1 Emotional Go/NoGo task.

assesses sensitivity to threat/punishment. Forty-eight true-false SPSRQ questions are divided into sensitivity-to-punishment (SPSRQ-Punishment, 24 items) and sensitivity-to-reward (SPSRQ-Reward, 24 items) subscales. The SPSRQ-Reward items were designed to assess impulsivity as it relates to rewarding-stimuli (a construct not directly assessed by BAS), and thus it is correlated with self-reported impulsivity (Torrubia *et al.*, 2001). Including both the BAS-Total and SPSRQ-Reward allowed investigation of reward-sensitivity varying in impulsivity.

Individual-differences in hypomanic-personality were measured using the 48 true-false-item hypomanic personality scale (HPS; Eckblad and Chapman, 1986). HPS was developed to identify individuals at risk for bipolar-disorder. Previously used among undergraduate populations, elevated HPS scores prospectively predict bipolar-disorder onset and related conditions over 10 years (Kwapil *et al.*, 2000), and was previously used to examine hypomanic-personality neurophysiology (Harmon-Jones *et al.*, 2002).

Electrophysiological recording

Continuous EEG data were sampled at 500 Hz (DC to 100 Hz on-line filter) from seventeen scalp-electrodes (F3/F4/F7/F8/FZ/FCz, C3/C4/CZ/CPz, T3/T4/T5/T6 and P3/P4/PZ). Recordings (impedances $<5\,k\Omega$) were referenced on-line to the left mastoid and re-referenced offline to linked mastoids.

During offline analyses, eye blinks were first corrected in EDIT 4.5 (Neuroscan Inc.) with PCA algorithms. Saccades and movement-related artifacts were removed manually. EEG data were then high-pass filtered at 1 Hz (24 dB), a setting conventionally used in Go/NoGo studies (e.g. Van Veen and Carter, 2002; Nieuwenhuis *et al.*, 2003; Amodio *et al.*, 2008). Data were epoched from −100 to 1000 ms relative to stimuli onset and baseline corrected using a 100-ms pre-stimulus window. Epochs with remaining artifacts ($\pm 75\,\mu V$) were rejected, and remaining clean trials were low-pass filtered (30 Hz, 12 dB). Only epochs associated with correct trials were averaged (Amodio *et al.*, 2008).

Data analysis

Reaction time (RT) was log-transformed to minimize outlier influence. Accuracy was divided into hit rate for Go (correctly-pressing 'Go' for Neutral-faces) and false-alarm rate for NoGo (incorrectly-pressing 'Go' for Happy/Fearful-faces) conditions. A sensitivity index, or d′, was calculated [Z(hit rate) − Z(false-alarm rate)]. False-alarm rate was also calculated separately for each emotional-NoGo condition.

ERPs were averaged for each stimulus-condition: Fearful-NoGo, Happy-NoGo and Neutral-Go. A pre-defined time window based on previous studies (e.g. Eimer and Holmes, 2002; Amodio *et al.*, 2008; Smith *et al.*, 2012) was used to identify each component. Cognitive-control N2s were defined as the most-negative trough between 200 and 400 ms post-facial stimuli-onset, while attentional-processing P2s and P3s were defined as the most-positive peak between 150–200 and 400–700 ms, respectively.

Separate statistical analyses were conducted for N2s, P2s and P3s. Analysis of variance (ANOVA) tests were computed first to analyze differences in ERP magnitude between Stimulus Conditions.[5] Specifically, a 3 (Stimulus Conditions: Fearful-NoGo, Happy-NoGo and Neutral-Go) × 5 (Midline Sites: Fz/FCz/Cz/CPz/Pz) repeated measures ANOVA was used. The Greenhouse-Geisser (G-G)

[5] Although correlational analyses with threat/reward-sensitivity, hypomanic personality and cognitive control (N2) and attentional (P2, P3) ERPs were the primary focus of the current study, the ANOVA analyses comparing Emotional-NoGo and Neutral-Go conditions were important for two reasons. First, they allowed us to confirm the presence of each ERP component, thus serving as a manipulation check. For instance, N2s reflecting the need for cognitive-control should be more-negative for NoGo than Go stimuli, whereas P2s and P3s reflecting an attentional-bias to negative-valence stimuli should be more-positive for Fearful-NoGo than Happy-NoGo stimuli. Second, they helped identify electrode sites for the subsequent correlational analyses.

correction was used for ANOVA analyses when sphericity was violated. The Sidak method was applied to control for multiple comparisons to follow-up a significant omnibus ANOVA. These ANOVA analyses were followed by separate correlational analyses for each component to examine the relationship between individual-differences in threat/reward-sensitivity, hypomanic-personality and Happy-NoGo and Fearful-NoGo ERP amplitude.[6] For components where Fearful-NoGo ERPs were significantly different from Happy-NoGo ERPs, we selected the midline electrode where this difference in amplitude was maximal. If Fear-NoGo ERPs were not significantly different from Happy-NoGo ERPs, we used the midline electrode with the maximal ERP amplitude collapsed across stimulus conditions.

Given that N2s are negatively deflected ERPs, larger values for these difference-scores indicate more-negative amplitudes to Happy- relative to Fearful-NoGo stimuli. Conversely, given that P2s and P3s are positively deflected components, larger values for these difference-scores at P2s and P3s indicate more-positive amplitudes to Fearful-, relative to, Happy-NoGo stimuli. The follow-up correlational analyses with the separate NoGo-ERPs allowed us to determine whether observed correlations with the Fearful-NoGo-minus-Happy-NoGo ERP difference-scores were driven by the relative relationship between the Fearful-NoGo and Happy-NoGo waveform, or the Fearful-NoGo and Happy-NoGo waveforms separately. Additionally, if more than one individual-difference variable was significantly correlated with any of the ERPs, and these individual-difference variables were not correlated with each other (to avoid multicollinearity), then multiple-regression analyses were employed to examine unique and shared effects of these variables.

RESULTS

See Table 1 for descriptive-statistics of self-report measures and task-performance. See Supplementary Page S1 for a summary of the correlations between self-report indices of threat/reward-sensitivity and hypomanic-personality. See Supplementary Table S1 for complete listing of the correlations between self-report indices of threat/reward-sensitivity, hypomanic-personality, behavioral indices and ERP components.

[6] Two strategies were employed to minimize the risk of Type I error for correlational analyses. First, we restricted correlational analyses to one channel per ERP component, thus greatly reducing the number of possible correlational analyses conducted. Second, we required a significant correlation with the Fearful NoGo-minus-Happy-NoGo ERP difference-scores (separately for each component) to proceed with analyses for the separate waveforms. Focusing on the difference-scores allowed us to examine the relationship between individual-difference variables and the relative relationship between the Fearful-NoGo and Happy-NoGo ERPs. If the correlation between a particular self-report measure and the Fearful-NoGo-minus-Happy-NoGo ERP difference-scores was significant, follow-up analyses were conducted examining the relationship between the self-report measures and the Fearful-NoGo and Happy-NoGo ERP components separately.

[7] The finding of higher false-alarm rates for Fearful-NoGo than Happy-NoGo stimuli was unexpected. One possible explanation for this pattern is that Fearful-NoGo faces may impair the ability to monitor responses, and this may lead to inadvertently pressing toward these faces. Given such responses to Fearful-NoGo faces can be considered approached-related, this reasoning is consistent with the observed main-effect of Feaful-NoGo faces. That is, by enhancing attentional-processing at the P2 and P3 time windows, Feaful-NoGo faces may facilitate approached-related responses. Although this is possible, our individual-difference analyses did not provide evidence to support this explanation. We indeed found no significant correlations between false-alarm rates and either P2s or P3s to NoGo stimuli (Supplementary Table 1). It is important to note, however, that regardless of what a higher false-alarm rate for Fearful-NoGo than Happy-NoGo stimuli indicates, it should not influence the primary analyses for the present study, which focus on whether individual-differences in temperament modulate ERPs. In fact, there were no significant relationships between false-alarm rates, any ERPs, or any of the temperament variables Supplementary Table 1). Furthermore, our ability to interpret this enhanced false-alarms for Fearful-NoGo (than Happy-NoGo) stimuli is limited by our design. Given that only correct trials (not responding to the NoGo stimuli) were included in analyses (e.g. Van Veen and Carter, 2002; Nieuwenhuis *et al.*, 2003; Amodio *et al.*, 2008), our NoGo-ERPs (the P2, N2 and P3) may not be suitable for analyzing cognitive processes underlying false-alarms. An ERP index that more closely indexes false-alarm is the error-related negativity (ERN) since the ERN is calculated by averaging false-alarm trials (Falkenstein *et al.*, 2000). The present study did not provide enough trials for analyzing ERNs separately for each NoGo condition. Further research is needed to understand this effect.

Table 1 Means and standard deviations (in parentheses) of self-report measures (items 1–5) and task performance (items 6–10)

	M (s.d.)
BIS	20.11 (3.57)
BAS	38.95 (3.81)
SPSRQ-Punishment	10.64 (5.41)
SPSRQ-Reward	12.53 (4.54)
HPS	16.93 (7.85)
RT	417.10 ms (52.26)
Hit rate	92.47% (1.26)
Fear false alarm	16.72% (11.17)
Happy false alarm	13.03% (9.41)
d′	3.45 (0.77)

Note. BIS and BAS, behavioral inhibition system and behavioral approach system from behavioral inhibition and activation scales, respectively; SPSRQ-Punishment and SPSRQ-Reward, Sensitivity to Punishment and Sensitivity to Reward from Sensitivity to Punishment and Sensitivity to Reward Questionnaire, respectively. d′ was calculated by [Z(hit rate) − Z(false-alarm rate)], collapsing across the two NoGo conditions.

Behavioral results

Participants mistakenly responded (false-alarm) to Fearful-Nogo faces significantly more often than to Happy-NoGo faces, $t(35) = 2.70$, $P = 0.01$, Cohen's $d = 0.45$.[7] Additionally, there was a negative relationship between log-transformed RT to Neutral-Go faces and false-alarm to Fearful-NoGo, $r(34) = -0.62$, $P < 0.001$, and Happy-NoGo, $r(34) = -0.42$, $P = 0.011$, faces. This suggests a trade-off between RT and false-alarm rates, such that the slower participants responded to Neutral-Go faces, the fewer mistakes they made in inhibiting their responses to NoGo faces.

ERP results

See Table 2 for descriptive statistics of each ERP component at the midline electrodes. See Table 3 for correlations between self-report measures and the Fearful-NoGo-minus-Happy-NoGo ERP difference-scores and Table 4 for correlations between self-report measures and the Fearful-NoGo and Happy-NoGo ERP waveforms separately.

Cognitive-control ERP

N2s: there was a significant main effect of Stimulus Condition on N2s, $F\ (2, 70) = 23.12$, $P < 0.001$, $\eta_p^2 = 0.40$ (Figure 3a). Pairwise-comparisons indicated that both Fearful-NoGo and Happy-NoGo faces elicited more-negative N2s than Neutral-Go faces (P's < 0.001). Fearful-NoGo and Happy-NoGo N2s did not significantly differ ($P = 0.92$). A main effect of site on N2s, $F_{G\text{-}G}\ (1.44, 50.45) = 5.97$, $P = 0.01$, $\eta_p^2 = 0.15$, indicated that N2s were most-negative over the frontal-central sites (Figures 2 and 3a). Pairwise-comparisons indicated that N2s were maximal at Cz, and that N2s at Cz were significantly more-negative than N2s at Pz ($P = 0.003$). Lastly, there was a significant Stimulus Condition × Site interaction ($F_{G\text{-}G}\ (2.56, 89.70) = 9.42$, $P < 0.001$, $\eta_p^2 = 0.21$). Simple-effect analyses revealed that both NoGo faces elicited more-negative N2s than Neutral-Go faces across midline sites (P's < 0.02), but that the difference was more pronounced at frontal-central ($Ms > 2.24\ \mu V$) than posterior ($Ms < 1.5\ \mu V$) sites.

Given that Fearful-NoGo N2s were not significantly different from Happy-NoGo N2s, we used Cz as the maximal site across stimulus conditions for correlation analyses, similar to previous work (Amodio *et al.*, 2008; Leue *et al.*, 2009). Consistent with prediction, there was a significant relationship between the N2 difference-score (Fearful-NoGo-N2-minus-Happy-NoGo-N2) and BIS, such that individuals with elevated BIS showed more-negative N2s for Happy-NoGo relative to Fearful-NoGo faces (Figure 4a). In examining the

Table 2 Means and standard deviations (in parentheses) of ERP amplitudes (in μV) for midline electrodes to different face stimuli for each component

	Fz	FCz	Cz	CPz	Pz
Cognitive-control ERP (N2s)					
1. Fearful-NoGo N2s	−5.13 (3.29)	−5.81 (3.4)	−5.61 (3.19)	−4.69 (3.02)	−3.87 (3.12)
2. Happy-NoGo N2s	−5.2 (3.03)	−5.91 (3.34)	−5.76 (3.53)	−4.96 (3.32)	−4.2 (3.28)
3. Neutral-Go N2s	−2.45 (2.47)	−2.89 (2.89)	−3.37 (3.09)	−3.43 (3.27)	−3.02 (3.28)
Attentional-processing ERPs (P2s and P3s)					
1. Fearful-NoGo P2s	6.33 (3.65)	6.34 (3.94)	5.67 (4.23)	5.34 (4.28)	5.07 (4.2)
2. Happy-NoGo P2s	5.15 (3.63)	4.97 (3.97)	4.27 (4.37)	3.86 (4.49)	3.71 (4.58)
3. Neutral-Go P2s	5.62 (3.64)	5.76 (3.91)	5.13 (4.12)	4.56 (4.03)	4.35 (4.03)
4. Fearful-NoGo P3s	8.6 (2.79)	10.6 (3.51)	11.29 (3.29)	10.85 (3.19)	10.46 (2.99)
5. Happy-NoGo P3s	8.14 (3.03)	9.88 (3.54)	10.44 (3.6)	9.98 (3.42)	9.58 (3.25)
6. Neutral-Go P3s	3.77 (1.45)	4.6 (2)	5.57 (2.09)	6.33 (2.01)	6.86 (2.06)

Table 3 Correlations between self-report measures and NoGo-ERP difference-scores (Fearful-NoGo-ERP-minus-Happy-NoGo-ERP)

	BIS	BAS	SPSRQ-Punishment	SPSRQ-Reward	HPS
Cognitive-control ERP (N2s)					
Fearful-Happy N2s	0.34*	−0.24	0.20	−0.34*	−0.64**
Attentional-processing ERPs (P2s and P3s)					
Fearful-Happy P2s	0.34*	0.25	0.08	0.26	−0.03
Fearful-Happy P3s	0.42*	0.21	0.34*	0.26	−0.02

Note. More negative scores for N2s indicate greater ERP amplitudes since N2s represent negative-going waveforms. BIS and BAS, behavioral inhibition system and behavioral approach system from behavioral inhibition and activation Scales, respectively; SPSRQ-Punishment and SPSRQ-Reward, Sensitivity to Punishment and Sensitivity to Reward from Sensitivity to Punishment and Sensitivity to Reward Questionnaire, respectively; $*P \leq 0.05$, $**P \leq 0.01$.

Table 4 Correlations between self-report measures and NoGo-ERPs separately for the Fearful-NoGo and Happy-NoGo conditions

	BIS	BAS	SPSRQ-Punishment	SPSRQ-Reward	HPS
Cognitive-control ERP (N2s)					
Fearful-NoGo N2s	−0.16	0.01	−0.12	−0.21	−0.30
Happy-NoGo N2s	−0.36*	0.17	−0.24	0.02	0.13
Attentional-processing ERPs (P2s and P3s)					
Fearful-NoGo P2s	−0.09	0.01	−0.30	0.17	0.13
Happy-NoGo P2s	−0.27	−0.12	−0.32	0.03	0.14
Fearful-NoGo P3s	−0.09	−0.05	0.08	−0.10	0.04
Happy-NoGo P3s	−0.32	−0.16	−0.12	−0.24	0.05

Note. More negative scores for N2s indicate greater ERP amplitudes since N2s represent negative-going waveforms. BIS and BAS, behavioral inhibition system and behavioral approach system from behavioral inhibition and activation scales, respectively; SPSRQ-Punishment and SPSRQ-Reward, Sensitivity to Punishment and Sensitivity to Reward from Sensitivity to Punishment and Sensitivity to Reward Questionnaire, respectively; $*P \leq 0.05$

relationship between BIS and N2s for each NoGo condition separately (Happy *vs* Fearful), we found elevated BIS was associated with more-negative Happy-NoGo N2s (Figure 4b), but was unrelated to Fearful-NoGo N2s. This suggests that the relationship between BIS and the N2 difference-scores was driven by the association between BIS and Happy-NoGo N2s.

Also consistent with prediction, there was a significant, albeit opposite, relationship between the N2 difference-score (Fearful-NoGo-N2-minus-Happy-NoGo-N2) and SPSRQ-Reward and HPS. Specifically, both individuals with elevated reward-sensitivity (Figure 5a) and elevated hypomanic-personality (Figure 5b) exhibited more-negative N2s for Fearful-NoGo relative to Happy-NoGo faces. However, unlike threat sensitivity, neither SPSRQ-Reward nor HPS were significantly correlated with N2s for each NoGo condition separately (Happy *vs* Fearful), except that elevated HPS was marginally associated with more-negative Fear-NoGo N2s ($P = 0.076$). Thus, contrary to a negative temperamental-trait [threat-sensitivity (BIS)], correlations between the N2 difference-scores and positive temperamental-traits [reward sensitivity (SPSRQ-Reward); HPS] were driven by the relative relationship between the Fearful-NoGo and Happy-NoGo waveform.

Because BIS, SPSRQ-Reward and HPS were all correlated with the N2 difference-scores, a hierarchical-multiple-regression analysis was used to assess for combined *vs* unique effects of these individual-difference variables (Table 5). Since SPSRQ-Reward was significantly correlated with HPS, $r(34) = 0.52$, $P < 0.001$, we conducted two multiple-regression models, separating SPSRQ-Reward from HPS, to avoid multicollinearity. We entered BIS in the first-step[8]. Either adding SPSRQ-Reward or HPS in the second-step improved the models substantially. Specifically, having both BIS and SPSRQ-Reward in the model explained 28.1% of the variance, and having both BIS and HPS explained 48.4 % of the variance (P's ≤ 0.004), respectively. Furthermore, both SPSRQ-Reward and HPS uniquely predicted the N2 difference-scores as did BIS in this second step.

Attentional-processing ERPs:

P2s: there was a significant main effect of stimulus condition on P2s, $F_{G\text{-}G}$ (1.58, 55.24) = 12.42, $P < 0.001$, $\eta_p^2 = 0.26$ (Figure 3a). Pairwise-comparisons indicated that Fearful-NoGo faces elicited more-positive P2s than Neutral-Go ($P = 0.021$) and Happy-NoGo ($P < 0.001$) faces. Neutral-Go faces, in turn, elicited more-positive P2s than Happy-NoGo faces ($P = 0.018$). A main effect of site on P2s, $F_{G\text{-}G}$ (1.36, 47.64) = 10.11, $P < 0.001$, $\eta_p^2 = 0.22$, revealed that P2s were maximal over the frontal-central sites (Figures 2 and 3a). Pairwise-comparisons indicated that P2s at Fz and FCz were more positive than those at CPz (P's < 0.05) and Pz (P's < 0.05). There was no significant Stimulus Condition × Site interaction.

Because the Fearful-NoGo and Happy-NoGo P2 difference was maximal at CPz ($M = 1.48\,\mu$V, Figure 3a), this electrode was selected for correlational analyses, similar to other studies (Delplanque *et al.*, 2004; González-Roldan *et al.*, 2011; Smith *et al.*, 2012). Consistent with prediction, there was a significant relationship between the P2 difference-score (Fearful-NoGo-P2-minus-Happy-NoGo-P2) and BIS, such that elevated BIS was associated with more-positive P2s for Fearful-NoGo relative to Happy-NoGo faces (Figure 6a). There were no other significant relationships between threat/reward-sensitivity, hypomanic-personality and P2s, including with the separate Fearful-NoGo or Happy-NoGo P2 waveforms. Thus, the relationship between the P2 difference-score and BIS was driven by the relative relationship between the Fearful-NoGo and Happy-NoGo waveform.

P3s: there was a main effect of Stimulus Condition on P3s, $F_{G\text{-}G}$ (1.46, 51.22) = 96.01, $P < 0.001$, $\eta_p^2 = 0.73$ (Figure 3c). Pairwise-comparisons revealed that Fearful-NoGo faces elicited more positive P3s than Happy-NoGo faces ($P = 0.011$), both of which were more positive than Neutral-Go faces ($P < 0.001$). A main effect of Site on P3s, $F_{G\text{-}G}$ (1.92, 67.17) = 44.87, $P < 0.001$, $\eta_p^2 = 0.56$, indicated that P3s were maximal over central-parietal sites (Figures 2 and 3c). Pairwise-comparisons indicated no difference in P3s between Cz, CPz and Pz

[8] BIS was entered in the first step of both models (Model 1: BIS and SPSRQ-Reward as predictors; Model 2: BIS and HPS as predictors) because a) previous research found a relationship between depression and NoGo-N2 to emotional stimuli (Krompinger and Simons, 2009) and b) BIS is a risk-factor for depression (Johnson *et al.*, 2003). BIS explained 12% of the variance ($P = 0.04$) in the first step.

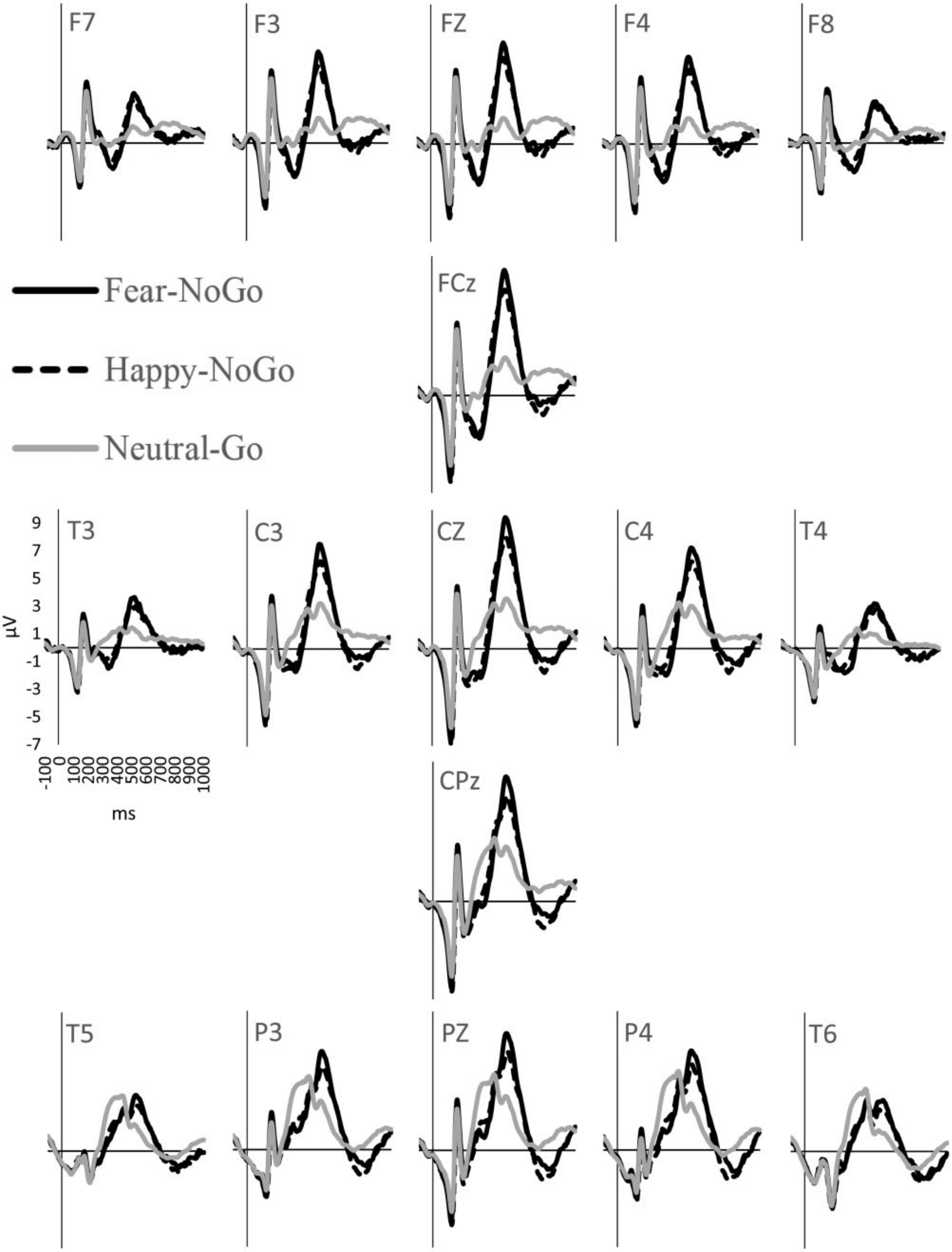

Fig. 2 Fearful-NoGo (solid black line), Happy-NoGo (dotted line) and Neutral-Go (gray line) ERPs at all electrodes.

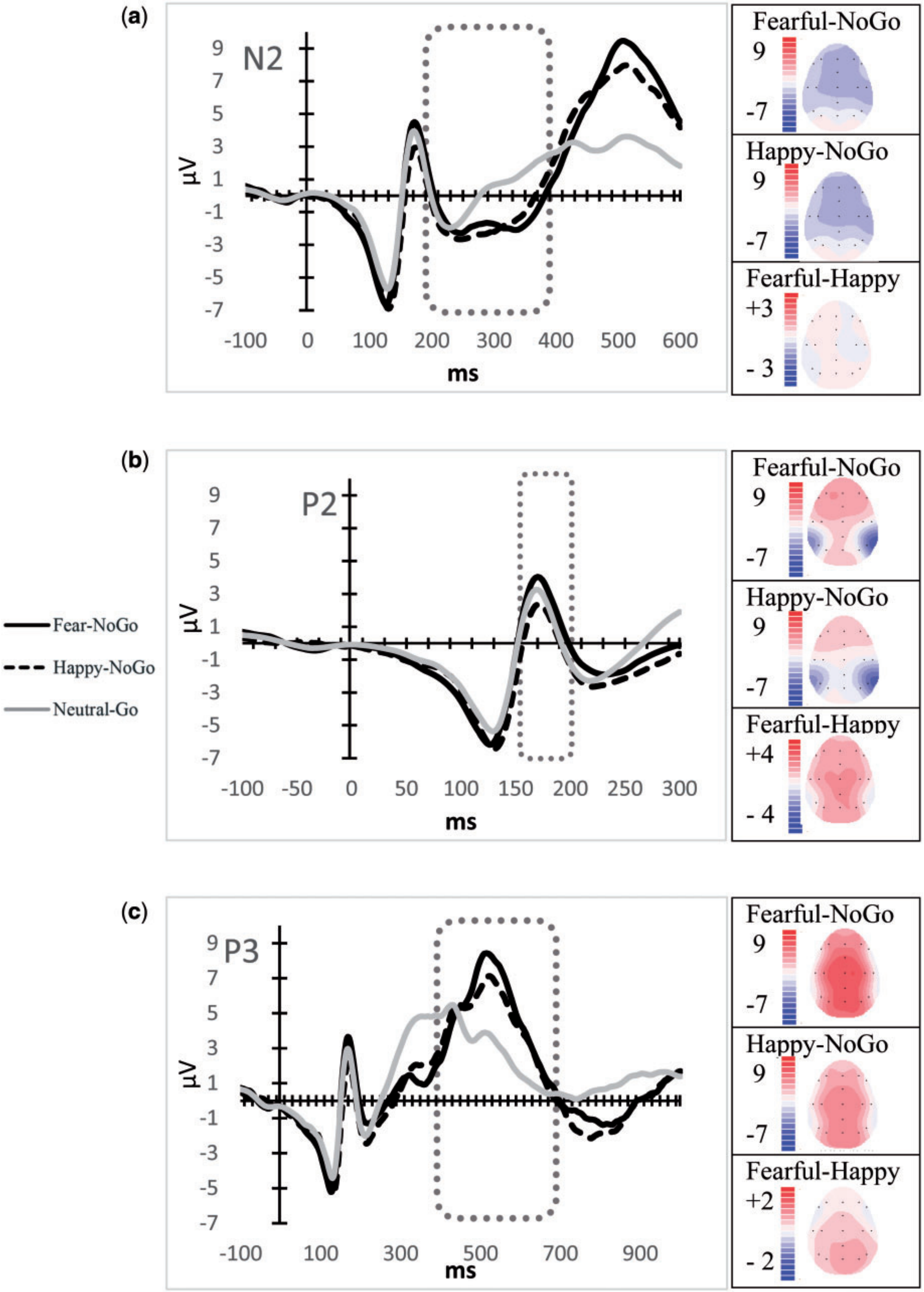

Fig. 3 Fearful-NoGo (solid black line), Happy-NoGo (dotted line) and Neutral-Go (gray line) ERP waveforms and topographical maps for each component. N2s, P2s and P3s were plotted at Cz, CPz and Pz, respectively. The time windows used to measure each component are indicated by a dotted box. The Fearful–Happy topographical map was computed by subtracting Happy-NoGo ERPs from Fearful-NoGo ERPs.

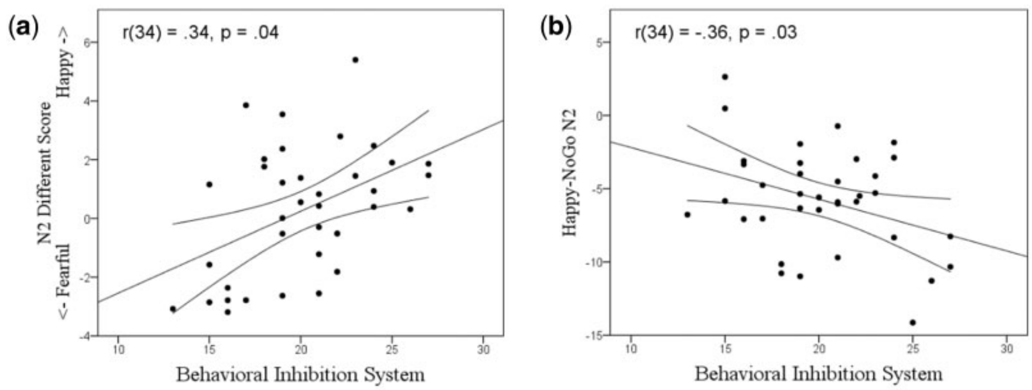

Fig. 4 Scatterplots of the correlations between behavioral inhibition system (BIS) scores, the N2 difference-score (Fearful-NoGo N2s minus Happy-NoGo N2s), and the Happy-NoGo N2s.

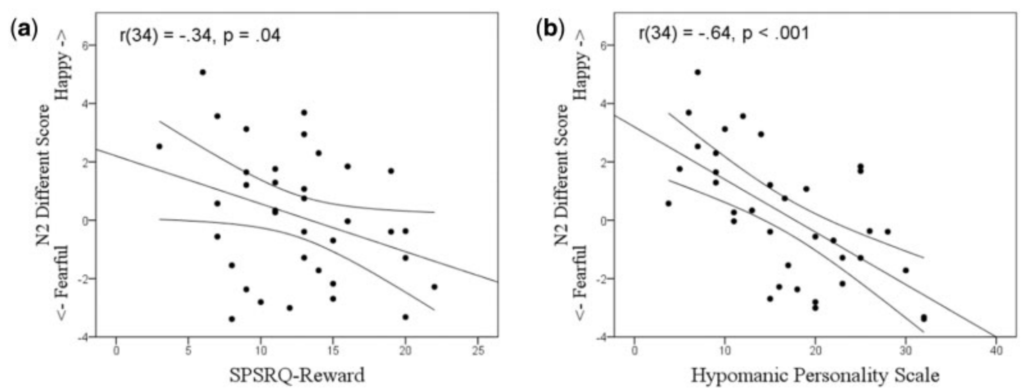

Fig. 5 Scatterplots of the correlations between the N2 difference-score (Fearful-NoGo N2s minus Happy-NoGo N2s) and Sensitivity to Punishment and Sensitivity to Reward Questionnaire-Reward subscale (SPSRQ-Reward) scores and HPS scores.

Table 5 Hierarchical Multiple Regression Analysis of the N2-Difference-scores (Fearful-NoGo N2s minus Happy-NoGo N2s)

	b	SE B	β	P
Model 1and 2, Step 1				
Constant	−4.13	2.04		0.051
BIS	0.21	0.100	0.34	0.04
Model 1, Step 2				
Constant	−2.53	1.95		0.21
BIS	0.26	0.09	0.42	0.009
SPSRQ-Reward	−0.20	0.07	−0.41	0.01
Model 2, Step 2				
Constant	−0.37	1.76		0.84
BIS	0.17	0.08	0.27	0.037
HPS	−0.17	0.04	−0.61	<0.001

Note. $R^2 = 0.12$ ($P = 0.04$) for Step 1; $\Delta R^2 = 0.16$ for Model 1 (Step 2) ($P = 0.01$); $\Delta R^2 = 0.36$ for Model 2 (Step 2) ($P < 0.001$); BIS, behavioral inhibition system; SPSRQ-Reward, Sensitivity to Reward from Sensitivity to Punishment and Sensitivity to Reward Questionnaire.

(P's = .99), but P3s at these sites were significantly more positive than P3s at Fz ($P < 0.001$). The Stimulus Condition × Site interaction was significant, $F_{G\text{-}G}$ (3.18, 111.11) = 24.09, $P < 0.001$, $\eta_p^2 = 0.41$. Simple-effect analyses revealed that both NoGo faces elicited more-positive P3s than Neutral-Go faces across midline sites (P's < 0.001). Moreover, the difference between Fearful-NoGo and Happy-NoGo P3s was significant at all midline sites (P's < 0.04), except for Fz ($P = 0.15$).

We selected Pz for P3 correlational analyses given the maximal difference between Fearful-NoGo and Happy-NoGo P3s at this site ($M = 0.88$ μV, Figure 3c) and its relevance to late attentional-processing P3s at posterior sites (Polich, 2007; Krompinger and Simons, 2009) [see the Supplementary Section for correlational analyses with P3s at frontal-central sites which correspond more with motor-response inhibition (Enriquez-Geppert *et al.*, 2010)]. The P3 difference-score (Fearful-NoGo-P3-minus-Happy-NoGo-P3) was significantly correlated with both BIS (Figure 6b) and SPSRQ-Punishment, such that individuals with elevated threat-sensitivity showed more-positive P3s for Fearful-NoGo relative to Happy-NoGo, faces. There were no significant correlations between BIS and P3s for each NoGo condition separately, although elevated BIS was marginally associated with less-positive Happy-NoGo P3s ($P = 0.058$). Thus, similar to P2s, the relationship between the P3 difference-score and threat-sensitivity (i.e. elevated BIS and SPSRQ-Punishment) was largely driven by the relative relationship between the Fearful-NoGo and Happy-NoGo waveform.

DISCUSSION

We examined the interaction between temperament and emotional-stimuli in modulating cognitive-control and attentional-processing. Concerning cognitive-control, the mismatch model was supported. Specifically, individuals with elevated threat-sensitivity (i.e. BIS) showed more-negative N2s to Happy- relative to Fearful-NoGo faces. Accordingly, the need for cognitive-control was enhanced when one's temperament was mismatched from the NoGo-stimulus

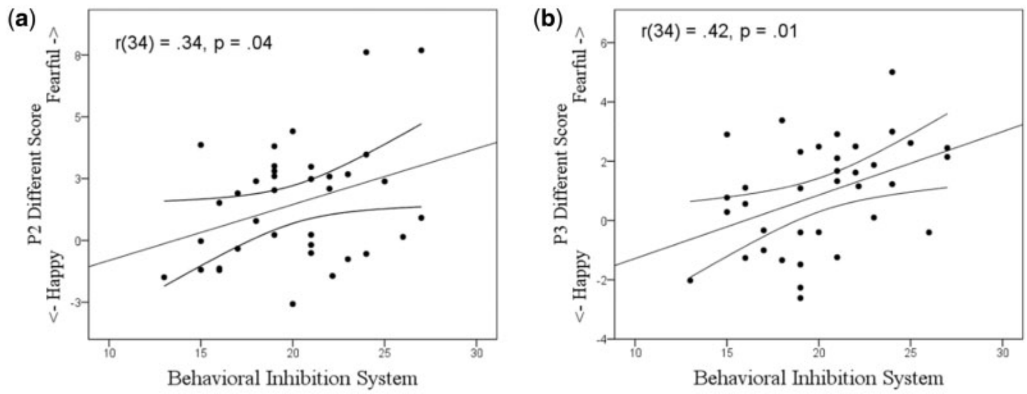

Fig. 6 Scatterplots of the correlations between behavioral inhibition system (BIS) scores and the P2 and P3 difference-scores (Fearful-NoGo ERPs minus Happy-NoGo ERPs).

valence. This is consistent with previous research reporting larger N2s for positive (than negative) IAPS-NoGo photos among people with elevated depression-scores (Krompinger and Simons, 2009). Thus, both depression, and a temperamental risk-factor for depression, elevated threat-sensitivity (Campbell-Sills *et al.*, 2004), are characterized by enhanced cognitive-control to positive-valenced NoGo stimuli.

Importantly, the need for cognitive control is also enhanced (more-negative N2s) when the NoGo-stimulus valence is mismatched with positive-temperamental styles. Consistent with prediction, individuals with elevated reward-sensitivity (SPSRQ-Reward) and hypomanic-personality (HPS) showed more-negative N2s to Fearful- relative to Happy-NoGo faces. Furthermore, both SPSRQ-Reward and hypomanic-personality scores uniquely predicted the N2 difference-score over and above BIS scores alone. Accordingly, this mismatch effect appears to reflect a general neuro-cognitive process that is present across both negative (threat-sensitivity, depression) and positive (reward-sensitivity, hypomanic-personality) temperamental-styles. Specifically, when emotional stimuli are involved in situations that demand high cognitive-control, people generate templates for the valence of the stimuli based on their temperament. This temperament-based mismatch enhances the need for cognitive-control in a manner similar to perception-based (e.g. seeing novel, unique shapes in a train of other standard stimuli) or expectation-based (e.g. seeing a third stimulus that is different from the first-two stimuli in a slot-machine task) (Donkers and van Boxtel, 2005; Folstein and Van Petten, 2008; Cavanagh *et al.*, 2012) mismatches.

Besides modulating cognitive-control, threat-sensitivity (BIS) also modulated attentional-processing. Consistent with prediction, elevated BIS was associated with enhanced early (P2s) and late (P3s) attentional-processing for Fearful-NoGo relative to Happy-NoGo faces. Unlike cognitive-control, however, the modulation of attentional-processing by one's temperament was temperament-specific to threat-sensitivity (BIS), and was not observed for reward-sensitivity (SPSRQ-Reward and hypomanic-personality), consistent with earlier ERP research (e.g. Mardaga and Hansenne, 2009). This asymmetry suggests that the modulation of temperament on attentional-processing ERPs does not reflect a general neuro-cognitive process, as in the case of cognitive-control. Rather, more-positive P2s and P3s to Fearful-NoGo (relative to Happy-NoGo) stimuli among people with elevated BIS supports the negative attentional-bias model that emphasizes attentional-biases toward negative-stimuli and away from positive-stimuli among elevated threat-sensitivity (Armstrong and Olatunji, 2012). Our P3 finding extends previous research showing the modulation of depressive-symptoms on emotional-NoGo P3s (Krompinger and Simons, 2009). First, beside depressive-symptoms, elevated threat-sensitivity, a tempermental risk-factor for depression (Campbell-Sills *et al.*, 2004), is also associated with enhanced attentional-biases to Fearful-NoGo (relative to Happy-NoGo) stimuli. Second, we demonstrate that these attentional-processing biases were not limited to late-employment of cognitive-resources (P3s), but also to early, rapid selective-attention (P2s; Olofsson *et al.*, 2008).

Our correlational results imply that cognitive-control (N2s) and attentional-processing (P2s and P3s) may be independently modulated by temperament. First, while elevated reward-sensitivity was associated with enhanced cognitive-control to Fearful-NoGo (relative to Happy-NoGo) stimuli, reward-sensitivity had no relationship with attentional-processing. Second, while elevated threat-sensitivity was associated with enhanced cognitive-control to Happy-NoGo (relative to Fearful-NoGo) stimuli, it was correlated with enhanced attentional-processing to Fearful-NoGo (relative to Happy-NoGo) stimuli for both early (P2s) and late (P3s) attentional-processing.[9] This reversed modulation of threat-sensitivity on cognitive-control and attentional-processing ERPs is consistent with an earlier emotional-Go/NoGo study with depressive-symptoms (Krompinger and Simons, 2009). This suggests that different temperament-related mechanisms modulate cognitive-control (e.g. via mismatch) and attentional-processing (e.g. via negative attentional-biases). Such independent-modulation of temperament on cognitive-control and attentional-processing is consistent with studies focusing on each process independently. For instance, cognitive-control studies employing neutral, non-emotional stimuli usually show the modulation of threat-sensitivity on cognitive-control N2s (but not attentional-processing ERPs; Amodio *et al.*, 2008; Cavanagh and Shackman, 2014). Conversely, attentional-processing studies employing emotional-stimuli in non-cognitive-control tasks (e.g. passive-viewing) show the modulation of threat-sensitivity on attentional-processing P3s (but not cognitive-control ERPs; Kayser *et al.*, 2000; Miltner *et al.*, 2005).

While there were strong, significant relationships for some scales (BIS and SPSRQ-Reward) with ERPs, there were mixed (SPSRQ-Punishment) and non-significant (BAS) relationships for others.

[9] One possible confound of our correlational analyses is component overlap involving ERP components that are close to each other in time (P2s, N2s and P3s). For instance, more-positive P2s are more likely to be followed by less-negative N2s than more-negative N2s. Likewise, less-negative N2s are more likely to be followed by more-positive P3s than less-positive P3s. Thus, a significant correlation at P2 should be followed by reversed correlations at N2, and so on. Component-overlap is a very common problem in ERP literature (Luck, 2005). However, we argue that it is unlikely to explain our present findings given that our correlational results did not fully conform to the pattern one would expect if they were driven by component overlap. For instance, the strongest correlation between a self-report measure and a NoGo-ERP difference-score (Fearful-NoGo-ERP-minus-Happy-NoGo-ERP) is between HPS and the N2 difference-score ($r(34) = -0.64$, $P < 0.001$). However, the correlations between HPS and the difference-scores for the preceding P2 component and the following P2 component were among the weakest [P2s; $r(34) = -0.03$, $P = 0.87$; P3s; $r(34) = -0.02$, $P = 0.92$].

Although the SPSRQ and BAS scales were developed from the same theory (Gray, 1987, 1989), there are differences between them that may help explain these discrepant results. For instance, SPSRQ-Reward was designed to measure impulsivity associated with reward-sensitivity (compared to BAS; Torrubia *et al.*, 2001). This impulsivity component may have facilitated the association between SPSRQ-Reward and N2s, given that impulsivity is associated with cognitive-control in both behavioral and ERP studies (Enticott *et al.*, 2006; Stahl and Gibbons, 2007; Ruchsow *et al.*, 2008). To test this possibility, future studies may employ distinct scales for impulsivity.

This study has potential implications for understanding the pathophysiology of mood/anxiety disorders. For instance, given the link between threat-sensitivity and depression and social-anxiety (Campbell-Sills *et al.*, 2004), our N2 finding may help explain why depressed individuals tend to avoid activities associated with positive-mood (Lewinsohn and Amenson, 1978) and why socially-anxious individuals avoid positive social-situations (Kashdan and Steger, 2006). That is, in situations demanding individuals with depression/social-anxiety to monitor their responses closely, such as social-interactions, positive-stimuli may signal a mismatch. This mismatch may eventually precipitate behavioral-adjustment and avoidance-behaviors.[10] Moreover, enhanced early (P2) and late (P3) attentional-biases to Fearful-NoGo (relative to Happy-NoGo) stimuli in individuals with elevated threat-sensitivity may help explain attentional-biases toward negative-stimuli and away from positive-stimuli in depression/anxiety (Bradley *et al.*, 1998; Mathews and MacLeod, 2005; Chen *et al.*, 2012). Likewise, a reduced need for cognitive-control (N2s) to Happy-NoGo, relative to Fearful-NoGo, stimuli among individuals with elevated reward-sensitivity and hypomanic-personality may help understand deficits in impulse-control and behavioral-regulation to rewarding-stimuli observed in bipolar-disorder (Swann *et al.*, 2001). That is, positive/rewarding-stimuli may not signal a strong mismatch in cognitive-control situations for them, increasing their likelihood of engaging in high-risk behaviors. Though future research is needed to examine cognitive-control deficits and risk-taking behaviors more generally.

SUPPLEMENTARY DATA

Supplementary data are available at *SCAN* online.

Conflict of Interest

The authors report no conflict of interest in the reporting of this research.

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[10] Drawing from our present findings with BIS and previous research with depressive-symptoms (Krompinger and Simons, 2009), we propose that the temperamental-induced mismatch with positive-stimuli among individuals with elevated threat-sensitivity may trigger the perception of the need for cognitive-control (as reflected by elevated N2s). This pattern may extend to disorders that are related to elevated threat-sensitivity, such as depression and social-anxiety (Campbell-Sills *et al.*, 2004). Specifically, this perceived need for cognitive-control may be especially likely in situations that require one to monitor their responses closely, such as social-interactions. This enhanced need for cognitive-control may, in turn, make individuals with depression and/or social-anxiety more cautious about their behavior, given the association between enhanced need for cognitive-control (i.e. elevated N2s) and behavioral-adjustment (e.g. slowing RT and increasing accuracy) (Cavanagh and Shackman, 2014). This enhanced caution, especially during social-interactions, may cause individuals with depression and/or social-anxiety to avoid social-interactions altogether. Our study provides preliminary support for this model, but further research is needed to investigate this possible explanation more systematically (e.g. by using real social-interactions).

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