
Trait anxiety and conflict monitoring following threat: An ERP study

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Abstract

Threat-related attentional disruptions in anxiety may relate to changes in cognitive control during task processing. The present study examined this question using the N2 event-related brain potential. It was predicted that threat stimuli will selectively influence the N2 for those showing elevated trait anxiety and that reduced N2 may reflect a compensatory process predicting better attention performance. EEG was recorded while 36 participants completed a cued flanker task with threat or nonthreat distracters. N2 amplitudes were greater to incongruent versus congruent flankers. Following threat, high trait anxious participants showed reduced modulation of the N2 by flanker type and greater N2 amplitudes to congruent flankers. Reduced N2 was associated with better attention performance. This study was among the first documenting the emotional modulation of the N2 related to the threat bias and its links with attention interference in anxiety.

Descriptors: Emotional face processing, Event-related potentials, Conflict monitoring, Trait anxiety

Threat-related stimuli interfere with attention performance, particularly among those showing heightened anxiety (Eastwood, Smilek, & Merikle, 2003; Fox, Russo, Bowles, & Dutton, 2001; Mogg, Mathews, & Eysenck, 1992). In both normative and clinical populations, this bias involves relatively automatic capture of attention by threat stimuli, reflecting attentional alertness, as well as more difficulty disengaging from threat once attention is engaged, reflecting attentional orienting (Derryberry & Reed, 2002; Fox, Russo, & Dutton, 2002; Yiend & Mathews, 2001). In addition, the threat bias has been measured in terms of interference in the top-down cognitive control of attention, such as executive attention tasks like flanker and Stroop tasks (Fenske & Eastwood, 2003; Simpson et al., 2000; Williams, Mathews, & MacLeod, 1996). Thus, the threat bias is detectable in multiple domains of attention.

Threat-related attention interference effects have been primarily attributed to changes in emotional processing: When there is conflict and competition for attention, emotional processing is prioritized over cognitive processing (Easterbrook, 1959; Hanoch & Vitouch, 2004; Leith & Baumeister, 1996; Meinhardt & Pekrun, 2003; Wood, Mathews, & Dalgleish, 2001). For this reason, anxious compared to nonanxious individuals may be more susceptible to disruptions in attention by threat because they devote more

emotional processing resources to threat-relevant information (Mathews & MacLeod, 2002; Mogg, Millar, & Bradley, 2000).

In addition to the role of enhanced emotional processing of threat, recent research further suggests that threat-related distracters reduce the degree to which anxious individuals effectively recruit cognitive control resources to support task-focused processing (Bishop, Duncan, Brett, & Lawrence, 2004; Compton, 2003; Compton et al., 2007). For example, one neuroimaging study showed that when individuals with heightened anxiety viewed threat-related emotional distracters (fearful faces) while performing a simple non-emotional decision-making task, activity of neural regions associated with cognitive control, such as the anterior cingulate cortex and lateral prefrontal cortex, was reduced (Bishop et al., 2004). Although such research suggests reduced top-down cognitive control over threat-related distracters in a nonclinical sample, these neural changes were not associated with decrements in performance. Therefore, among those showing normative levels of anxiety, reduced activity could reflect a compensatory mechanism that protects performance rather than reduces control. In other words, reduced neural activity may signal greater neural efficiency (Gray, 2004) rather than indiscriminant engagement of cognitive control, which may weaken overall attention performance. In addition, in this study by Bishop and colleagues it is difficult to disentangle the impact of threat on emotional processing versus task-focused processing because emotional and non-emotional information was presented simultaneously.

One way to evaluate the impact of threat on the cognitive control of attention is to test how threat-related information influences neural responses related to top-down cognitive control after the emotional distracter is presented and testing whether

This research was supported by National Institutes of Health (NIH) Grants 5T34 GM007823, 5K01 MH075764-02, and 5S06GM060654-04, the latter two awarded to T.D. This publication was also made possible by Grant RR03037 from the National Center for Research Resources (NCRR), a component of the NIH.

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such neural changes predict attention performance. This allows examination of task-focused processing separate from emotional processing of threat and of the implications of neural responses for behavior. Scalp-recorded event-related potentials (ERPs) are uniquely well suited to this question. Techniques such as fMRI rely upon the hemodynamic response, which is tracked second by second. Affective processes, however, occur on the order of milliseconds, and thus neuroimaging data may lack the temporal resolution to capture some of the earliest processes related to the emotional modulation of cognitive control (Banaschewski & Brandeis, 2007; Hajcak, Moser, & Simons, 2006). ERPs, because of their excellent temporal resolution, are able to measure the most rapid affective and cognitive processes. Moreover, those at risk for but not showing clinically elevated anxiety may not show overt disruptions in attention due to the threat bias; in this case, ERPs may represent critical biomarkers for cognitive disruptions underlying the attentional threat bias and risk for anxiety problems.

The N2 scalp-recorded ERP reflects changes in the recruitment of cognitive control (Parasuraman, 1998; Potts, Martin, Burton, & Montague, 2006; Yeung, Holroyd, & Cohen, 2005). The N2 occurs over frontal midline regions 200 to 350 ms following a stimulus and is larger under conditions of conflict, such as incongruent response options (e.g., incongruent flanker displays in a visual flanker task) and during tasks that require inhibition of prepotent responses (Kopp, Rist, & Mattler, 1996; Nieuwenhuis, Yeung, Van Den Wildenberg, & Ridderinkhof, 2003; van Veen & Carter, 2002a). Therefore, the N2 is thought to signal the extent to which higher order cognitive control resources are recruited to resolve current and future conflict and inhibit incorrect responses (Braver, Barch, Gray, Molfese, & Snyder, 2001; Jones, Cho, Nystrom, Cohen, & Braver, 2002).

Source analyses suggest that the N2 is generated by the anterior cingulate cortex, which underlies conflict and action monitoring when two or more incompatible response tendencies are activated at the same time (Banich et al., 2001; Carter et al., 1998; van Veen & Carter, 2002b). The anterior cingulate cortex is also sensitive to emotional and motivational factors, given substantial input from the amygdala and other limbic regions (Bush, Luu, & Posner, 2000; Luu & Tucker, 2004), and has been shown to be more active under conditions of processing conflict that arises from emotionally salient distracters (Bishop et al., 2004; Vuilleumier, Armony, Driver, & Dolan, 2001). Therefore, the anterior cingulate cortex has been focused on as a neural basis for emotion–cognition integration. ERPs generated by the anterior cingulate cortex are thus highly appropriate for studying how threat-related distracters influence the top-down cognitive control of attention.

To our knowledge, no studies have yet examined the threat bias in anxious individuals using the N2. However, research on anxiety and other ERPs generated by the ACC, such as error-related negativity, shows that in the absence of an emotional context anxious individuals (both clinically anxious and within a normative range) evidence enhanced neural responses associated with conflict and action monitoring (Gehring, Himle, & Nisenson, 2000; Hajcak, McDonald, & Simons, 2003; Johannes et al., 2001). Therefore, one possibility is that in threat-relevant contexts, N2 amplitudes will be enhanced among anxious individuals under conditions of increased conflict between response options (e.g., incongruent flanker displays) or even under conditions of low conflict (e.g., congruent flanker displays), the latter suggesting excessive or indiscriminant conflict monitoring. Indeed, research on anxiety and error-related brain activity shows

enhanced brain activity among anxious individuals for both correct and incorrect trials (e.g., Hajcak et al., 2003).

In contrast, however, one of the few studies examining error-related negativity in a threat-relevant context documents *reduced* neural activity among anxious participants within a typical range (Compton et al., 2007). Because anxious individuals are reactive to and potentially distracted by threat, the authors posited that the addition of threat stimuli may have reduced expectations for success and thus reduced the perceived incongruence between success and failure (which dampened error monitoring). Therefore, inferring from this example, a second possibility for the present study is that nondisordered anxious individuals will show reduced N2 amplitudes in threat-related contexts due to changed expectations for success (and reduced motivation to monitor conflict).

The possibility that N2 is reduced for participants showing nonclinical signs of anxiety is also consistent with the notion of neural efficiency. Neural efficiency models suggest that reduced activity related to conflict monitoring may actually reflect more efficient allocation of processing resources and ability to conserve resources for attention performance (Dennis & Chen, 2007; Gray, 2004; Gray, Braver, & Raichle, 2002). Such compensation may have been evident in the study by Bishop and colleagues (2004), which documented reduced neural activity in nondisordered anxious individuals but no performance decrements. Therefore, nondisordered anxiety may be associated with the ability to compensate for the threat bias by reducing neural effort toward task monitoring, thus preserving resources for task performance. This view is also consistent with dual-system models of cognitive control (Botvinick, Braver, Barch, Carter, & Cohen, 2001), which state that attention performance relies upon both action monitoring and successful response initiation and inhibition, and cognitive resources are divided between these two functions. Larger N2 amplitudes may reflect greater resources being devoted to action monitoring at the expense of attention performance. To clarify this, the present study examined associations between modulation of the N2 by threat stimuli and attention performance.

This present study is based on a previously published experiment (Dennis & Chen, 2007). In this study, we found that threat-sensitive individuals showed enhanced processing of distracting emotional faces, but no preferential processing of threat-related faces (fearful). In terms of attention performance, smaller N2 amplitudes to fearful faces were associated with superior attention performance, particularly for those showing low threat sensitivity. This study documented facilitated attention performance with reduced N2 amplitudes, but focused on emotional processing of threat; it did not examine whether the top-down cognitive control of task processing was influenced by the threat stimuli. This latter question was the goal of the present study. It was predicted that for participants varying in trait anxiety, reduced N2 to the target task will be associated with facilitated attention performance.

The Present Study

Although the N2 reflects the recruitment of cognitive control and is likely sensitive to emotional context, to date the N2 has not been systematically examined in relation to anxiety-related threat biases. The present study examined the impact of threat-related (fearful) and threat-unrelated (happy, sad, and neutral) emotional faces on the N2 during congruent and incongruent trials of a cued flanker task. Previous research documents that trait

anxious participants show both decreased neural responses associated with action monitoring (perhaps reflecting resource preservation) and increased neural responses (perhaps reflecting indiscriminant engagement of action monitoring), although few studies have examined the emotional context of these effects. Links with attention performance will clarify whether changes in the N2 reflect resource preservation supporting attention performance or resource allocation reducing performance.

To measure the N2 separately from emotional processing, faces were presented briefly before each trial of the task, but were not present during task performance. Because previous studies suggest that modulation of the N2 by incongruent versus congruent stimuli reflects the degree to which conflict monitoring is engaged (Nieuwenhuis et al., 2003), we will examine both N2 amplitudes and difference scores (incongruent–congruent flankers).

The N2 was measured in relation to individual differences in trait anxiety because we were interested in examining the possibility that reduced N2 amplitudes reflect compensatory resource preservation in nondisordered individuals and because we wished to target more long-term sensitivity to the threat bias: Trait anxiety reflects the more stable dispositional tendency to experience state anxiety, rather than state anxiety, which reflects current level of anxious mood that continuously fluctuate (Rutherford, MacLeod, & Campbell, 2004; Spielberger, 1983).

The task was a cued flanker task, the Attention Network Test (ANT; Fan, McCandliss, Sommer, Raz, & Posner, 2002), which yields reaction times (RTs) and three attention performance scores, alerting, orienting, and executive attention. Incongruent flanker displays provide two competing response options and thus represent the high-conflict condition; congruent flanker displays, in contrast, provide only one response option and represent the low-conflict conditions. This task was modified to present intertrial emotional faces (for more details, see Dennis & Chen, 2007). Fearful faces have been used in multiple studies of the threat bias because they are salient and socially significant (Mathews & MacLeod, 2002). The ANT provides reliable estimates of three distinct attention functions, alerting, orienting, and executive attention (Fan et al., 2002). The ANT generates an executive attention score by comparing reaction times to incongruent versus congruent flankers across all cue types, as in a standard flanker paradigm. Alerting and orienting are calculated by comparing reaction times after specific cueing conditions and averaging across flanker types.

This task allowed us to examine specific associations between changes in the N2 due to threat and attention performance in three domains. This is a critical goal, because changes in the recruitment of cognitive control may differentially influence these separable attention capacities (Fan et al., 2002; Posner & Petersen, 1990). For example, these three systems vary in the degree to which they are driven by relatively automatic or voluntary attentional mechanisms (Derryberry & Reed, 2002; Posner & Petersen, 1990): Alerting and orienting are supported by the more automatic posterior attention system and executive attention by the more voluntary anterior attention system, including the anterior cingulate cortex. Therefore, because the N2 is also associated with activity of the anterior cingulate cortex, emotional modulation of the N2 may have more of an impact on executive attention performance compared to other attention systems. Previous research has not examined this possibility.

There were two hypotheses: (a) Threat-relevant fearful faces compared to other emotional faces will selectively influence the N2 among participants showing elevated trait anxiety; we will

explore whether this is due to increases or decreases in N2 amplitudes to congruent and incongruent flanker displays; and (b) reduced N2 following threat stimuli may reflect a compensatory process such as resource preservation that correlates with better attention performance.

Method

Participants

Participants were 36 adults, aged 18 to 40 ($M = 21.42$, $SD = 5.25$; 26 women) recruited through the psychology participant research pool at a university in New York City and screened for identified psychological or neurological impairments via open-ended self-report. Self-reported race and ethnicity was as follows: 16 Caucasian, 2 African American, 10 Hispanic, 7 Asian, 1 “Other.”

Procedures and Measures

Participants spent approximately 2 h in the laboratory. They completed a series of questionnaires immediately after consent procedures and before electrophysiological recording. Participants completed the State Trait Anxiety Inventory (Spielberger, 1983) to assess trait anxiety and were categorized into low and high groups based on a median split (50th percentile = 44). Average trait anxiety scores were $M = 52.05$, $SD = 7.39$, range 44–66 in the high-anxiety group and $M = 35.71$, $SD = 5.08$, range 28–43 in the low-anxiety group. All scores were consistent with those reported for a normative sample of adults and college students (Spielberger, 1983). Low and high trait anxiety groups did not differ on any demographic variables and did not differ in the likelihood of being excluded from analyses due to computer failure, excessive EEG artifacts, or performance errors.

After the questionnaire period, EEG was recorded while subjects were administered a modified version of the ANT (Fan et al., 2002). The ANT was presented via E-Prime software (Psychological Software Tools, Pittsburgh, PA) on an IBM personal computer running Window XP, presenting to a 14-in. IBM monitor. Participants viewed the screen from a distance of 65 cm, and responses were collected via two buttons on the mouse. The ANT combines a cued reaction time and flanker task (Eriksen & Eriksen, 1974). It quantifies the efficiency of three attention systems by measuring how response times to the target flanker task are influenced by alerting and spatial cues and flankers. Following presentation of the intertrial faces over a fixation cross, a valid cue is presented, followed by the target arrow, which randomly appears either above or below the fixation cross and is surrounded on the left and right by four “flanker” stimuli. Participants indicate with one of two alternative button presses whether the central target arrow points left or right.

Figure 1a shows the intertrial face stimuli and Figure 1b shows the cue conditions. Cues modulate whether subjects are alerted to the impending stimulus and whether subjects are oriented ahead of time to the location of the target. Cues are no cues, double cues (asterisk appears above and below the fixation), center cues (asterisk appears superimposed over the fixation), and spatial cues (asterisk appears above or below the fixation to indicate the location of the subsequent target). Figure 1c shows the flanker stimuli: Congruent flankers point in the same direction as the central target arrow, incongruent flankers point in the opposite direction, and neutral flankers have no directional information. For the purposes of the present study, only incongruent and congruent flanker trials were examined (representing two thirds of trials).

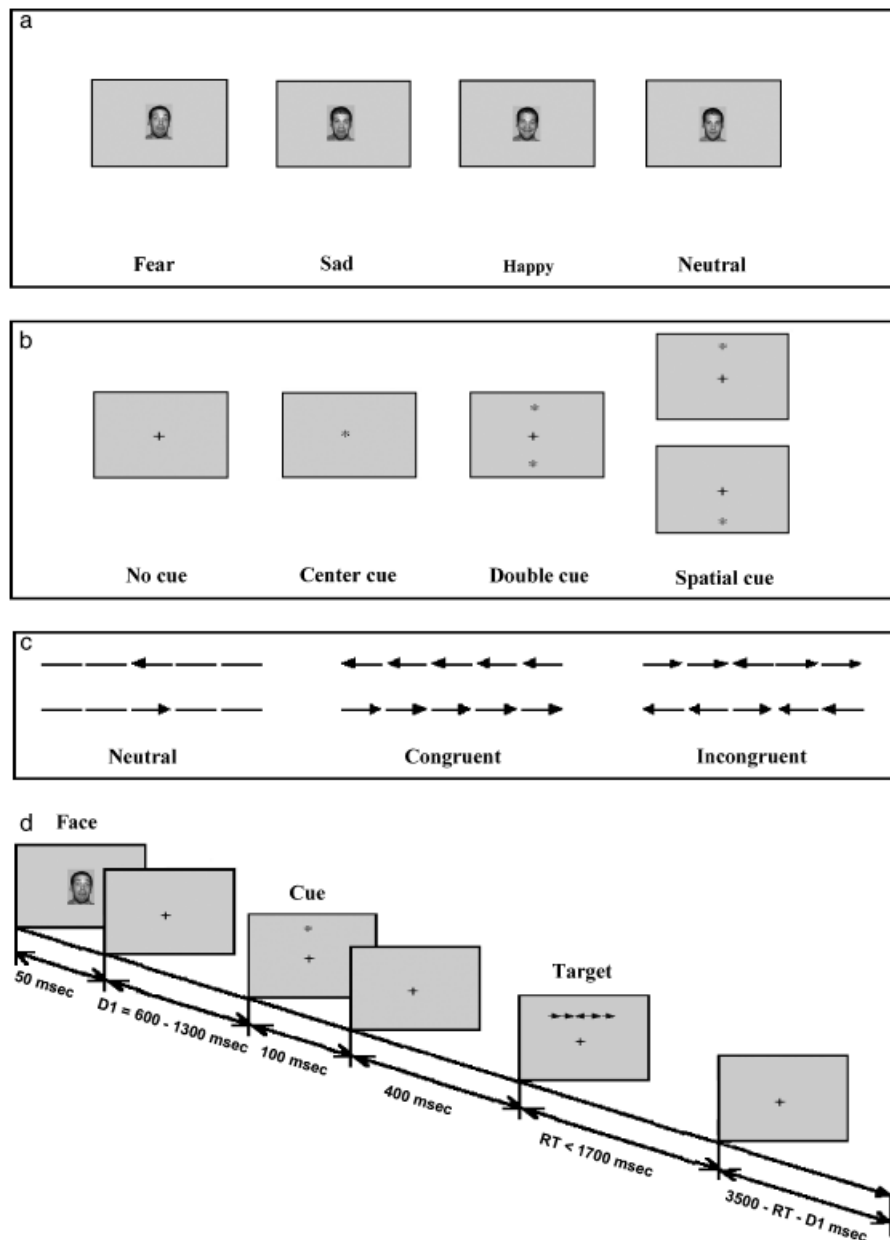


Figure 1. Diagram of the experimental task. a: Face types. b: Cue conditions. c: Flanker types. d: Trial events.

The experiment consisted of a 24-trial full-feedback practice block (reaction time, whether answer was correct, and cumulative success rate) followed by four blocks of feedback-free trials (96 trials per block). Block order was counterbalanced across subjects. The ANT was modified in this study by presenting fearful, sad, happy, or neutral faces over the central fixation cross at the beginning of each trial, one face type per block. Emotional faces were taken from a battery developed by the Research Network on Early Experience and Brain Development (Tottenham, Borscheid, Ellertsen, Marcus, & Nelson, 2002). The faces used in this study were selected based on normative ratings of the faces for emotional facial expressions and obtaining equal representation of gender and ethnicity. Faces were randomly presented within each block of trials, thus minimizing the potential for effects of face gender and ethnicity. Participants were informed that there would be faces presented at the beginning of each trial of the task, but were not instructed to attend or not attend.

Because faces were completely unrelated and uninformative for performance of the primary ANT task, this design provides a simple but effective way to examine processing of task-irrelevant emotional stimuli and its effects on conflict monitoring and attention performance.

Figure 1d shows that each trial consisted of six events: (1) face (fearful, sad, happy, or neutral; 50 ms), (2) fixation period (variable 600–1300 ms), (3) cue condition (no cue, center cue, double cue, spatial cue; 100 ms), (4) fixation period (400 ms), (5) simultaneously presented target and flanker stimuli (terminated at response up to 1700 ms), and (6) posttarget fixation period (varied, based on the first fixation and reaction time for that trial). Each trial lasted for 4050 ms.

Efficiency of the three attention networks, alerting, orienting, and executive attention, is determined by measuring how response times to the flanker displays are influenced by alerting cues, spatial cues, and flanker type (see Fan et al., 2002, for

additional details). Using correct trials only and those in which RTs were within 3 *SD* of the sample mean, the efficiency of *alerting* is calculated as RT following no cue–RT double cue. The double cue was used because it diffuses attention between the two potential target locations while alerting the participant to the arrival of the target. Higher scores indicate greater alerting efficiency due to presence of cues. The efficiency of *orienting* is calculated as RT following center cue–RT spatial cue. Higher scores indicate greater orienting efficiency due to presence of spatially predictive information of one cue while controlling for alerting effects in the other. The efficiency of *executive attention* is calculated in terms of *conflict* interference–RT to incongruent flankers–RT to congruent flankers. Higher scores indicate greater conflict interference or *less* efficient executive attention.

Valence and Arousal Ratings for Faces

At the completion of the attention task, participants rated each face using the Self-Assessment Mannequin technique (Lang, Bradley, & Cuthbert, 1998). Faces were rated on a 1–5 scale for arousal, with 5 indicating low arousal, and a 1–5 scale for valence, with 1 being very positive and 5 being very negative. Sad faces were rated as less arousing than fearful, $t(35) = 4.75$, $p < .001$, and happy faces, $t(35) = 3.33$, $p < .01$ (sad $M = 3.66$, $SD = 0.80$; fearful $M = 3.33$, $SD = 0.87$; happy $M = 3.18$, $SD = 0.97$), but did not significantly differ from neutral faces ($M = 3.71$, $SD = 0.77$). Happy faces were rated as more positive than fearful, $t(35) = -8.18$, $p < .001$, sad, $t(35) = -9.54$, $p < .001$, and neutral faces, $t(35) = -11.54$, $p < .001$, and sad faces were rated as more negative than fearful, $t(35) = 6.00$, $p < .001$, and neutral faces, $t(35) = 5.24$, $p < .001$ (sad $M = 3.59$, $SD = 0.59$; fearful $M = 3.20$, $SD = 0.52$; neutral $M = 3.12$, $SD = 0.15$; happy $M = 2.00$, $SD = 0.54$). Thus, overall, sad faces were perceived as more negative but less arousing than other faces.

Psychophysiological Recording and Data Analysis

EEG activity was recorded continuously via 64 Ag/AgCl active scalp electrodes embedded in an elasticized nylon ECI cap and from two electrodes placed on the right and left mastoids. Eye movements were monitored by electro-oculogram (EOG) signals from electrodes placed approximately 1 cm above and below the left eye and from electrodes 1 cm lateral to each eye. As per BioSemi system design, the ground electrode during acquisition was formed by the Common Mode Sense active electrode and the Driven Right Leg passive electrode.

For each trial, EEG recording began at stimulus onset (the flanker display) and continued until a response was made. EEG and EOG signals were sampled at 512 Hz and amplified with a bandpass of 0.16–100 Hz by the ActiveTwo amplifier (BioSemi, Amsterdam, the Netherlands). All data were re-referenced off-line to an average reference and filtered with a high-pass frequency of 0.2 Hz and a low-pass frequency of 30 Hz. Stimulus-locked data were segmented into epochs from 200 ms before to 500 ms after stimulus onset; the baseline of 200 ms was used for baseline correction. The raw EEG epochs were passed through a computerized artifact scan batch to correct artifacts using Brain Electrical Source Analysis version 5.1 (BESA; MEGIS Software GmbH, Munich, Germany). If, after artifact correction, trials still included EEG or EOG activity with a voltage step of more than 50 μ V between sampling points or trials with voltages remaining above ± 100 μ V, these trials were excluded from further analysis. Given these criteria, trial acceptance rates were $M = 0.87$, $SD = 0.10$, ranging from 0.56 to 1.00.

The N2 was quantified separately for congruent and incongruent flanker displays as the most negative peak occurring in a window from 320 to 380 ms poststimulus. Visual inspection of individual subject averages showed that peak amplitudes for all participants occurred within this time window. Results reported below did not differ when analyses were conducted with mean amplitude, and thus peak amplitudes were used throughout. Four electrodes were targeted for analysis (from anterior to posterior): Fz, FCz, Cz, and Pz.

Results

Behavioral Data

Table 1 presents attention scores and RTs for trials with congruent or incongruent flankers, separately for high and low trait anxiety groups. Error rates were $M = 3\%$, $SD = 4\%$, ranging from 0% to 24%. RTs were significantly greater for trials with incongruent versus congruent flankers, $t(35) = 14.22$, $p < .001$. Trait anxiety was not significantly correlated with attention.

N2 Amplitude and Difference Score: Analysis of Variance (ANOVA)

The first hypothesis was that N2 amplitudes will be reduced following fearful faces among high trait anxious participants. To test this, we conducted a 4 (Electrode: Fz, FCz, Cz, Pz) \times 4 (Emotional Face: fearful, sad, happy, neutral) \times 2 (Flanker: incongruent or congruent) \times 2 (Trait Anxiety Group: low or

Table 1. Descriptive Statistics for Attention Performance Scores

	Fear <i>M</i> (<i>SD</i>)		Sad <i>M</i> (<i>SD</i>)		Happy <i>M</i> (<i>SD</i>)		Neutral <i>M</i> (<i>SD</i>)	
	Low trait anxiety	High trait anxiety	Low trait anxiety	High trait anxiety	Low trait anxiety	High trait anxiety	Low trait anxiety	High trait anxiety
Alerting	23.85 (25.63)	26.15 (32.34)	33.12 (20.58)	34.26 (45.40)	28.61 (44.74)	24.92 (24.04)	25.16 (27.48)	23.36 (32.82)
Orienting	37.57 (26.75)	46.10 (39.42)	44.90 (26.66)	42.25 (35.12)	51.79 (30.97)	35.67 (39.15)	34.45 (29.90)	26.59 (34.72)
Executive attention	97.62 (49.46)	104.02 (45.44)	93.41 (42.42)	84.07 (52.62)	100.79 (50.40)	103.10 (46.78)	95.44 (42.97)	100.42 (45.79)
Congruent flanker RT	479.00 (57.42)	501.29 (73.59)	481.62 (54.82)	519.53 (84.69)	475.90 (52.61)	498.94 (64.52)	479.59 (69.01)	501.48 (75.42)
Incongruent flanker RT	576.62 (81.41)	605.31 (92.89)	575.03 (73.90)	603.60 (108.19)	576.69 (76.01)	602.04 (92.49)	575.03 (81.18)	601.91 (104.16)

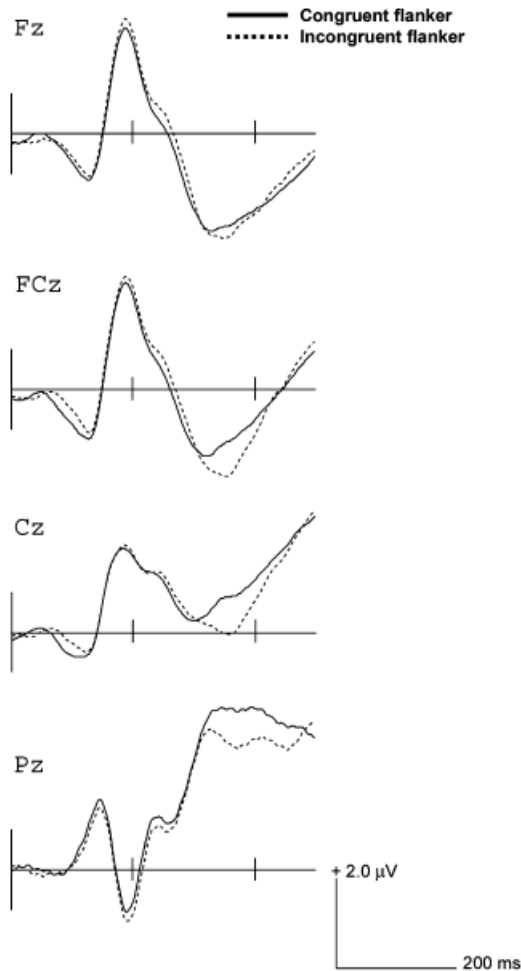


Figure 2. Grand-averaged waveforms for N2 amplitudes (maximal between 320 to 380 ms) were greater following incongruent versus congruent flanker displays.

high based on a median split) repeated measures ANOVA. N2 amplitudes were the dependent variable. Greenhouse–Geisser corrections were inspected, but did not differ from uncorrected values. This analysis will also yield information about the amplitude and topography of the N2 in relation to task characteristics, such as flanker type.

As seen in Figure 2, the multivariate effect of Electrode × Flanker, $F(3,32) = 4.91, p < .01, \eta^2 = .32$, showed that N2 amplitudes at FCz were greater following incongruent compared to congruent flanker displays, $t(35) = -3.38, p < .01$. Flanker comparisons for the other electrodes did not reach significance. Emotional Face and Trait Anxiety were not significantly associated with N2 amplitudes. However, when only frontal electrodes (FCz and Fz), where N2 amplitudes were maximal, were included in the ANOVA, a significant Emotional Face × Flanker × Trait Anxiety effect emerged, $F(3,32) = 3.32, p < .05, \eta^2 = .24$. Between-group differences in N2 amplitudes did not reach significance; instead, the difference between incongruent and congruent flankers was only significant for the low trait anxiety group, FCz $t(16) = -6.07, p < .001$ and Fz $t(16) = -4.48, p < .001$, whereas these differences did not reach significance in the high trait anxiety group (both $ps > .50$). Thus, as predicted, modulation of the N2 by flanker type was influenced (reduced) by threat stimuli only in the high anxious group.

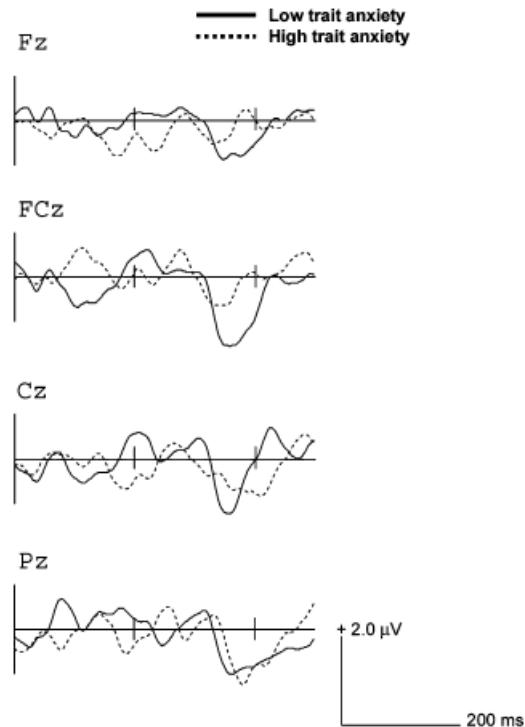


Figure 3. Grand-averaged difference waveforms for N2 following fearful faces was reduced for participants reporting high versus low trait anxiety.

This effect was mirrored in the significant three-way interaction from the Emotional Face × Electrode × Trait Anxiety ANOVA with N2 differences scores at Fz and FCz as the dependent variables (N2 to incongruent flankers minus N2 to congruent flankers), $F(3,32) = 3.32, p < .05, \eta^2 = .24$. Difference waveforms following fearful faces are depicted in Figure 3. N2 differences were significantly smaller in the high versus low trait anxiety group at electrodes FCz and Fz following fearful faces, $t(34) = 3.76, p < .001$ and $t(34) = 3.24, p < .01$, respectively. Trait anxiety group differences on N2 difference scores following other faces and electrodes (sad, happy, or neutral) did not reach significance.

N2: Regression Analyses

Findings thus far show previously documented flanker effects on the N2, which were maximal at electrode FCz, and that this modulation of the N2 by incongruent versus congruent flankers is reduced following fearful faces among those showing high trait anxiety. Because dividing individuals into dichotomous trait anxiety groups fails to represent potentially important variability within and between groups, we reexamined the first hypothesis using regressions informed by the ANOVAs above. To examine trait anxiety as a continuous variable, we conducted four regressions in which trait anxiety was the predictor and N2 difference scores at FCz following fearful, sad, neutral, or happy faces were the dependent variable. Results showed that only the regression with N2 difference scores following fearful faces reached significance, $R^2 = .31, F_{change} = F(1,34) = 15.18, p < .001, B = .10, \beta = .56$. As trait anxiety increased, difference scores decreased (see Figure 4).

Next, rather than using differences scores, we conducted these same regressions using N2 amplitudes at FCz for incongruent or congruent flankers as the dependent variables. Only the regression on N2 amplitudes for congruent flankers following fearful faces was significant, $R^2 = .31, F_{change} = F(1,34) = 15.18, p < .001, B = -.09, \beta = -.40$: As trait anxiety increased, N2

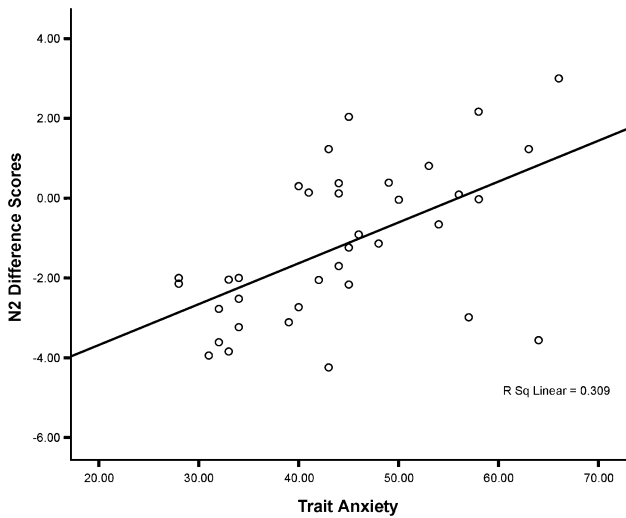


Figure 4. Scatter plot of the association between trait anxiety and N2 difference scores at FCz following fearful faces. As trait anxiety increased, difference scores decreased. Note that negative numbers indicate greater N2 difference scores.

amplitudes increased. This suggests that following fearful faces, N2 was enhanced in the low conflict (congruent flanker) condition and that increased N2 amplitudes for congruent flankers may in part explain the reduced N2 difference scores among those showing higher trait anxiety.

N2 and Attention Performance

To explore the functional significance of the modulation of the N2 by threat, we next examined associations between N2

amplitudes or difference scores and attention performance. To do so, we conducted a series of hierarchical multiple regressions in which the N2 amplitudes or difference scores at FCz following fearful faces were entered in the first step, trait anxiety was entered in the second step, and the interaction between N2 and trait anxiety was entered in the third step. There were six dependent variables: three attention scores (alerting, orienting, and executive attention), incongruent flanker RT, congruent flanker RT, and error rates. If the interaction term’s contribution to R^2 was significant ($p < .05$), moderation effects were plotted using simple regression equations (Aiken & West, 1991; Finney, Mitchell, Cronkite, & Moos, 1984). These analyses recast the significant interactions as the regression of one criterion on one predictor. The criterion on the y-axis was plotted against two levels of the predictor (N2 difference score), 1 SD below the mean (low) and 1 SD above the mean (high). Plotted regression lines represent two levels of the moderator variable (high and low trait anxiety). Predictor variables were centered to reduce problems of lack of invariance of regression coefficients and multicollinearity (Aiken & West, 1991).

N2 amplitudes. Although there were no significant main effects of N2 or trait anxiety on attention, the interaction between N2 amplitudes-incongruent flankers and trait anxiety reached significance for the regression with alerting, $R^2 = .20$, $\Delta F(1,32) = 8.43$, $p < .01$, $B = 0.75$, $\beta = 2.64$; and the interaction between N2 amplitudes-congruent flankers and trait anxiety also reached significance for the regression with alerting, $R^2 = .13$, $\Delta F(1,32) = 4.95$, $p < .05$, $B = 0.50$, $\beta = 1.75$. The regression equations accounted for 22% and 15% of variance in alerting, respectively. As seen in the top left and right panels of Figure 5, as N2 amplitudes increased, alerting efficiency was reduced. The rate of change for these associations was reduced among participants reporting high trait

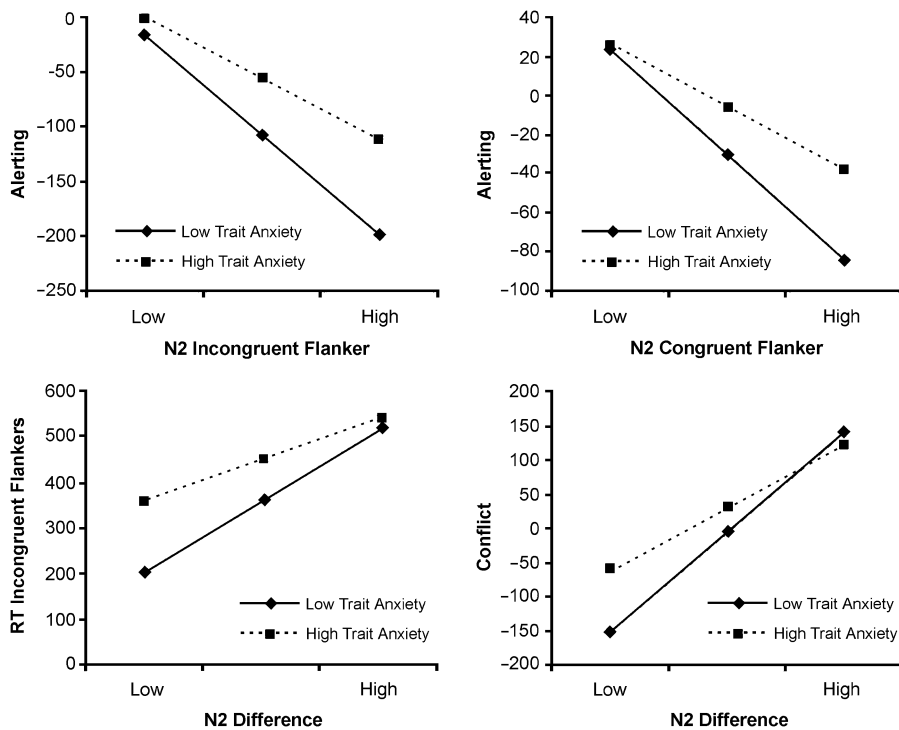


Figure 5. Significant interactions between N2 and trait anxiety predict attention performance. As N2 amplitudes at FCz following incongruent and congruent flankers increased, alerting efficiency was reduced (top left and right panels). As N2 difference scores increased, RTs were slower following incongruent flankers (bottom left panel) and executive conflict interference was greater (bottom right panel).

anxiety. Differences between the slopes were significant at $t(32) = 11.21$ and $t(32) = 9.96$, respectively, both $ps < .001$.

N2 difference scores. Although there were no significant main effects of N2 or trait anxiety, the interaction between N2 difference scores and trait anxiety reached significance for the regression with incongruent flanker RTs, $R^2 = .11$, $\Delta F(1,32) = 4.33$, $p < .05$, $B = 1.53$, $\beta = 1.46$, and for executive conflict interference, $R^2 = .16$, $\Delta F(1,32) = 6.28$, $p < .05$, $B = 1.46$, $\beta = 2.48$. The regression equations accounted for 16% and 17% of variance, respectively. As seen in the bottom left panel of Figure 5, as N2 difference scores increased, RTs were slower and thus attention performance compromised. The rate of change for this association was reduced among participants showing high trait anxiety; difference between the slopes was significant at $t(32) = 2.84$, $p < .01$. This effect may have driven the interaction effect on conflict interference, which is calculated as the difference in RTs between incongruent and congruent flankers. As seen in the bottom right panel of Figure 5, as N2 difference scores increased, conflict interference increased. The rate of change for this association was reduced among those showing high trait anxiety; difference between the slopes was significant at $t(32) = 4.31$, $p < .001$.

Discussion

This study was among the first to investigate whether trait anxiety was associated with modulation of the N2 by threat stimuli and its implications for threat interference effects on attention. Participants reporting heightened trait anxiety showed reduced modulation of the N2 by flanker type (incongruent–congruent flankers) following threat-relevant fearful faces. This effect did not emerge in the context of other face types, even negatively valenced sad faces. In addition, when trait anxiety was treated as a continuous variable, higher trait anxiety was associated with greater N2 amplitudes following congruent flankers in the fearful face context. This increase in conflict monitoring under low-conflict conditions may have in part been driving reductions in the N2 difference scores among high trait anxious participants. Although trait anxiety alone did not predict attention performance, changes in the N2 following threat predicted attention: As N2 amplitudes increased, alerting efficiency was reduced, and as N2 difference scores increased, executive attention was compromised. Therefore, reduced N2 may reflect a compensatory mechanism among some anxious individuals in response to potential attention interference by threat. These findings are potentially important because they suggest that individuals with heightened trait anxiety in a typical range show changes in conflict monitoring in threat contexts that might support or compromise attention. This study is among the first showing that the N2 is sensitive to emotional context and that larger N2 amplitudes during conflict monitoring may reflect resource depletion that is a mechanism in attention interference related to the threat bias in anxiety. Therefore, the N2 could be a useful neural marker for individual differences in the threat bias and attention interference related to anxiety, especially when attention interference effects are not observable.

As previously documented (Gehring & Willoughby, 2002; Kopp et al., 1996; Luu, Flaisch, & Tucker, 2000; Nieuwenhuis et al., 2003; van Veen & Carter, 2002a), the N2 was enhanced following incongruent versus congruent flanker trials. This is consistent with the interpretation that the N2 reflects processing of the competition between the execution and the inhibition of a

single response. A more novel finding of the present study was that emotional factors also influenced the processing of conflict, suggesting that the N2 is sensitive to affective evaluation (Luu & Tucker, 2004): N2 difference scores were reduced following fearful faces among those showing relatively high trait anxiety. However, this effect may have been due in part to the increase in N2 amplitudes for congruent flankers among those showing heightened anxiety. Therefore, it is possible that high trait anxiety is associated with increased monitoring of congruent visual information under conditions of threat. In other words, reduced N2 difference scores could reflect broader engagement of conflict monitoring and less discrimination between incongruent and congruent contexts. If this is the case, then conflict-driven modulation of the N2 (greater N2 for incongruence compared to congruence) may be disrupted in normative trait anxiety. An important possibility for future research is to examine whether elevated or indiscriminate monitoring of conflict plays a role in attention interference effects; results of the present study suggest that this may be the case.

Trait anxiety alone did not predict attention, whereas modulation of the N2 by fearful faces predicted executive attention and alerting: Greater N2 difference scores and amplitudes were associated with reduced attention performance (slower reaction times to incongruent flankers, increased conflict, and inferior alerting efficiency). Resource allocation models of attention interference in anxiety typically argue threat-related disruptions in the recruitment of cognitive control interfere with attention regulation (Easterbrook, 1959; Mathews & MacLeod, 2002); from this perspective, increased conflict monitoring should be adaptive because it allows us to notice conflict and change behavior accordingly to improve attention performance. Results of the present study instead suggest that decreased conflict monitoring may serve a compensatory function, and that enhanced N2 may reflect resource depletion that is a mechanism in attention interference related to the threat bias in anxiety. One possible explanation for this is that threat-relevant information provides a cue to avoid and withdraw from a potentially unsuccessful task, thus leading to reduced monitoring of conflict (Compton et al., 2007), although this would not necessarily lead to better attention performance. To assess this possibility, future research could provide explicit information about probabilities for success. Another and perhaps more likely explanation is that those who recruit relatively few neural resources under conditions of threat are better regulated and show greater “neural efficiency.” Thus, reductions in the N2 following threat stimuli may be best thought of as an individual difference indicating efficient cognitive control (Dennis & Chen, 2007; Gray, 2004).

Interestingly, the strength of the association between N2 and attention was significantly reduced among those with heightened anxiety. This implies that the N2 as a marker for the modulation of attention to threat is sensitive to anxiety in a typical range. To further examine the impact of increased N2 during task processing on attention, it will be important to compare clinical and nonclinical samples. Perhaps individuals with clinical levels of anxiety require enhanced conflict monitoring to offset elevated threat processing, whereas reduced conflict monitoring may be more characteristic of an adaptive response for those showing typical variations in anxiety.

N2 amplitudes and difference scores had implications for distinct aspects of attention. Previous studies suggest that modulation of the N2 by incongruent versus congruent stimuli reflects the degree to which the top-down executive control of

attention is engaged (Nieuwenhuis et al., 2003). Consistent with this, in the present study, reduced N2 difference scores were associated with improvements in executive attention performance (conflict interference and RTs to incongruent flankers). On the other hand, smaller N2 amplitudes in response to both incongruent and congruent flankers were associated with greater alerting efficiency. This may parallel previous research showing that anxiety is characterized by increased vigilance and alertness in threat contexts (Mathews & MacLeod, 2002). Counter to previous studies, however, the N2 was not associated with error rates (Kopp et al., 1996), but this may have been due to the restricted range of errors in the present study. In addition, the lack of associations between anxiety and orienting may be due to the nature of the task, which did not require disengagement of attention from threat, a characteristic sign of the threat bias (Derryberry & Reed, 2002). These attention-system-specific findings underscore the importance of delineating neural mechanisms in the attentional threat bias across multiple domains of attention and examining the threat bias using multiple experimental paradigms.

Findings are also interesting in light of the fact that face stimuli, although socially and emotionally salient, were a subtle

emotional context: They were of short duration and irrelevant to performing the target task. This highlights the degree to which cognitive control systems are finely tuned to motivationally significant information, consistent with interpretation of the ACC as an important neural basis for cognition–emotion integration and for effective emotional and behavioral self-regulation (Bush et al., 2000; Gehring & Willoughby, 2002; Luu et al., 2000; Luu, Tucker, Derryberry, Reed, & Poulsen, 2003; van Veen & Carter, 2002a, 2002b). Additional manipulations of emotional context, including mood inductions and more salient or task-relevant emotional stimuli (e.g., targets of the task), are important goals for future studies.

In conclusion, this was among the first studies using the N2 to examine the modulation of conflict monitoring by threat stimuli and its implications for anxiety-related attentional biases. Findings suggest that the N2 is sensitive to threat-related information and that enhanced N2 following threat may be a neural marker for attentional interference related to the threat bias in those varying in trait anxiety. Results provide a basis for future research examining the neural bases for the threat bias, cognitive mechanisms in anxiety, and early risk detection.

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(RECEIVED January 16, 2008; ACCEPTED May 23, 2008)