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Anxiety and Error Monitoring: Increased Error Sensitivity or Altered Expectations?

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Abstract

This study tested the prediction that the error-related negativity (ERN), a physiological measure of error monitoring, would be enhanced in anxious individuals, particularly in conditions with threatening cues. Participants made gender judgments about faces whose expressions were either happy, angry, or neutral. Replicating prior studies, midline scalp negativities were greater following errors than following correct responses. In addition, state anxiety interacted with facial expression to predict ERN amplitudes. Counter to predictions, participants high in state anxiety displayed smaller ERNs for angry-face blocks and larger ERNs for happy-face blocks, compared to less anxious participants. These results are inconsistent with the simple notion that anxiety enhances error-sensitivity globally. Rather, we interpret the findings within an expectancy violation framework, in which anxious participants have altered expectations for success and failure in the context of happy and angry facial cues, with greater ERN amplitudes when expectations are violated.

A critical cognitive skill is the ability to learn from mistakes and to use that knowledge to guide future behavior. In some arenas of life, such as schoolwork or video games, people receive direct performance feedback that can be used to motivate improvement. In many other situations, however, a person must rely upon internal self-monitoring to determine when behavior is adequate or when adjustments need to be made. Psychologists have examined error monitoring in simplified laboratory settings to understand the mental operations involved in these crucial aspects of self-regulation.

The discovery of a scalp potential linked to the commission of errors has provided a useful tool for studying the neural processes underlying error recognition (Falkenstein, Hohnsbein, Hoormann, & Blanke, 1991; Gehring, Goss, Coles, Meyer, & Donchin, 1993). The error-related negativity, or ERN, is a negative-going event-related potential that appears over midline scalp sites within 150 ms following a person's response in simple choice tasks. Numerous studies have determined that amplitudes are significantly greater following an error compared to following a correct response (for reviews, see Falkenstein, Hoorman, Christ, & Hohnsbein, 2000; Holroyd & Coles, 2002; Nieuwenhuis, Holroyd, Mol, & Coles, 2004). The neural source of the ERN has been localized to the anterior cingulate cortex (e.g., Gehring, Himle, & Nisenson, 2000; Herrmann, Römmler, Ehli, Heidrich, & Fallgatter, 2004; Holroyd, Dien, & Coles, 1998; Mathalon, Whitfield, & Ford, 2003; van Veen & Carter, 2002), a brain region known through other methods to play a crucial role in cognitive control and executive attention (e.g., Botvinick, Cohen, & Carter, 2004; Bush, Luu, & Posner, 2000; Kerns, Cohen,

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MacDonald, Cho, Stenger, & Carter, 2004). The ERN is followed in time by a positive-going potential, dubbed the Pe, which also differentiates between error and correct trials but is more closely tied to conscious awareness of errors (Nieuwenhuis, Ridderinkhof, Blom, Band, & Kok, 2001).

Researchers generally agree that the ERN is an index of performance-monitoring, although there is controversy about precisely which mental operation the ERN reflects. While some argue that the ERN reflects a specific process of error-detection (Coles, Scheffers, & Holroyd, 2001), others posit that it taps a more general process of performance-checking (e.g., Vidal, Hasbroucq, Grapperon, & Bonnet, 2000) or detection of conflict (Gehring & Fencsik, 2001; Yeung, Botvinick, & Cohen, 2004). Alternatively, some researchers propose that the ERN may index emotional distress elicited by mistakes (e.g., Bush et al., 2000). An integrative model proposed by Holroyd and Coles (2002) argues that the ERN is elicited by violations of expectancies, specifically when outcomes are worse than expected. Regardless of specific interpretation, most researchers view the ERN and Pe as part of a broader cognitive control system that monitors behavior and implements necessary adjustments.

Equipped with this tool, researchers have begun to examine individual differences in error monitoring, particularly in relationship to affective variables. Because mood disorders such as anxiety and depression are characterized phenomenologically by preoccupation with past, present or future failure, it is not surprising that research has investigated how error monitoring is influenced by affective traits. Such studies provide a window onto processes of cognitive control that may play a critical role in emotional disorders, which are known to involve functional alterations in the cingulate cortex (for review, see Davidson, Abercrombie, Nitschke, & Putnam, 1999). Studies have found increased ERN amplitudes in individuals with clinically diagnosed obsessive-compulsive disorder (Gehring et al., 2000), obsessive college students (Hajcak & Simons, 2002) and worry-prone college students (Hajcak, McDonald, & Simons, 2003a). Anxiolytic drugs reduce ERN amplitudes, further supporting the link between anxiety and error monitoring (Johannes, Wieringa, Nager, Dengler, & Münte, 2001; Riba, Rodriguez-Fornells, Münte, & Barbanj, 2005). Additional studies indicate that increased error monitoring may generalize beyond anxiety per se to characterize the broader dimension of trait negative affect (Hajcak, McDonald, & Simons, 2004; Luu, Collins, & Tucker, 2000). Recent research has also found that personality traits can interact with motivational variables to influence ERN amplitude (Pailing & Segalowitz, 2004b), emphasizing the need to consider situational as well as trait influences on error processing.

Because most prior studies have examined trait-like aspects of emotion, less is currently known about how experimental manipulations of emotion may influence error monitoring. One relevant study found that the presence of overt performance evaluation led to increased ERN responses compared to a non-evaluation condition (Hajcak, Moser, Yeung, & Simons, 2005). Although the increased ERN in the evaluation condition could be due to increased state anxiety, it could also be explained by an increase in motivation that occurs when participants believe they are being evaluated (Hajcak et al., 2005). In a more direct manipulation of state anxiety, Moser, Hajcak, and Simons (2005) tested spider-phobic participants in the presence and absence of a tarantula, and found that the ERN amplitude was not influenced by this manipulation. This finding indicates that changes in state anxiety do not necessarily lead to increased error monitoring as indexed by the ERN.

Two other prior studies examined the influence of affect on the ERN by manipulating the affective content of stimulus materials. One study found increased ERN amplitudes when participants viewed negative emotional pictures just prior to the target stimulus, compared to when they viewed positive or neutral pictures (Wiswede, Rüsseler, Goschke, & Münte, 2006). These results are consistent with the view that state-related negative affect, induced by

the negative pictures, can increase error monitoring. Yet conflicting findings were reported in a similar study that presented target stimuli against a background of positive, negative, or neutral pictures (Larson, Perlstein, Stigge-Kaufman, Kelly, & Dotson, 2006). These researchers found that the ERN was largest when positive pictures were presented, and they interpreted this result as indicating that the ERN is largest when a negative outcome (an error) mismatches with a positive emotional context (Larson et al., 2006). In summary, while prior findings have consistently linked trait-related negative affect with increased ERN amplitudes, mixed results have emerged from studies that experimentally manipulated contextual affective variables.

The present study builds on this existing literature by examining the interactive effects of individual differences in state anxiety and stimulus emotionality. Participants in most prior ERN studies have completed tasks involving target stimuli that are emotionally neutral, such as Stroop-like colored words or directional arrows in a flankers task. In the present study, participants made judgments about faces that varied in their emotional expression. Facial expressions serve as an ecologically valid performance cue, as many people look to the reactions of others to gauge performance adequacy in real-life situations. If negative affect enhances error monitoring, the ERN should be increased when participants make decisions about angry faces compared to happy or neutral faces, because angry faces should prime negative affect and increase the subjective sense of failure. In addition, this study examined the role of individual differences in state anxiety. If state-related negative affect increases error monitoring, then ERN amplitudes should be greater in individuals who report higher levels of anxiety. Finally, because anxious people are typically more attentive to threat-related cues (e.g., Bradley, Mogg, & Millar, 2000; Byrne & Eysenck, 1995; Fox, 2002), we predicted that anxious individuals would show the most sensitivity to errors in blocks of trials involving angry faces, resulting in an interactive effect between stimulus emotionality and anxiety level.

Methods

Participants

Twenty-seven undergraduate students participated in exchange for payment. According to self-report, participants did not regularly use medication or other non-medical substances that could affect the central nervous system and had normal vision (with correction) and no neurological history. Participants were prescreened to be either high ($n=11$) or low ($n=16$) scorers on the Penn State Worry Questionnaire (Meyer, Miller, Metzger, & Borkovec, 1990). PSWQ scores were uncorrelated with ERP variables and only weakly correlated with state anxiety ($r=.32$, $p>.10$), so results presented here focus on the state anxiety measure. State anxiety scores (see below) were missing for one participant, and ERP data were unusable for one participant due to technical problems. The primary analyses were therefore conducted on 25 participants.

Faces Task

Stimuli were eighteen black-and-white photographs from the Ekman and Friesen (1976) set. The selected photographs included six posers (three male and three female) each depicting three facial expressions (angry, happy, neutral). Each photograph was cropped to a size of 4×6 degrees of visual angle, and stimuli were presented unilaterally with the medial edge at 3 degrees of eccentricity. Unilateral presentation (to either the left or right of the fixation point) was chosen as part of a larger study intended to address questions about hemispheric specialization that are not relevant to the present report. Error monitoring effects reported here did not interact with visual field of presentation, so all results are collapsed across visual field.

The task consisted of 432 trials, divided into six blocks of 72 trials each. On each trial, the participant indicated by a keypress whether the photograph depicted a male or female. Half of

the participants used the left index finger on the “g” key to indicate female and the right index finger on the “h” key to indicate male, and half of the participants used the reverse mapping. Emotional expression varied across blocks, such that two blocks included only angry faces, two included only happy faces, and two included only neutral faces. Within each block, trials included half male and half female faces. Trial types were fully counterbalanced, such that each photograph appeared 6 times on the left and 6 times on the right in a given block. The computer software randomly determined the sequence of trial types within each block as well as the order of the six blocks. To confirm that block order was not confounded with state anxiety, we calculated for each participant the mean ordinal position for the two angry blocks, the two happy blocks, and the two neutral blocks and found that those ordinal position values were not significantly correlated with STAI scores (r 's = .00, p 's > .98).

Trialwise events began with a 500-ms black fixation point against a gray background. The face stimulus was then presented against the gray background for 14 ms, synchronized with the monitor's 75-Hz refresh cycle. Following the stimulus presentation, a fixation screen remained on until the participant's keypress or for a maximum of 1000 ms. After the keypress, the fixation point remained on the screen for a variable duration of 500-1500 ms prior to the beginning of the next trial. Therefore, considering the variable post-response fixation screen and the 500-ms pre-stimulus fixation screen, the time interval between a keypress and the next stimulus varied from 1000 to 2000 ms. This variable inter-trial interval was intended to reduce anticipatory effects. No explicit feedback was given. At the onset of each stimulus and keypress, a digital trigger coded for trial type was sent via the parallel port to the EEG amplifier for purposes of event marking.

EEG Data Acquisition and Signal Processing

Electrodes were applied using an elastic cap (Quik-Caps) fitted with sintered Ag/AgCl electrodes. Positioning of the cap was confirmed by measurements from nasion and inion, and left-right alignment of the cap was confirmed by ensuring that midline electrodes were positioned halfway between the two ears. Data were recorded continuously from 15 scalp sites: Fz, FCz, Cz, C3/C4, CP3/CP4, P3/P4, PO1/PO2, O1/O2, and T5/T6. Data reported here focus on the fronto-central midline sites (Fz, FCz, Cz) where error-related potentials are typically observed. Signals were amplified by a NuAmps amplifier controlled by Neuroscan software, with a sampling rate of 1000 Hz and a bandpass of 0.1-70 Hz (−3 dB). Data were referenced on-line to the right mastoid and digitally re-referenced off-line to the average of left and right mastoids. Eye movements were monitored by electrodes placed above and below the left eye and at the outer canthus of each eye. Recordings from these four sites were used to compute bipolar horizontal and vertical EOG channels off-line.

Artifacts were addressed off-line in three steps. First, upon visual inspection, portions of the EEG record with large non-blink artifacts were manually excluded. Second, the effect of blinks was reduced using the Neuroscan software's regression-based algorithm for ocular artifact reduction. Finally, remaining artifacts in the EEG were identified using a $\pm 150 \mu\text{V}$ threshold, and corresponding epochs were rejected.

Epochs were baseline-corrected with the baseline defined by values in the interval 200 -100 ms prior to the keypress response. Signal averaging was carried out separately for correct and incorrect trials for each type of emotional expression and encompassed a window from −200 to 600 ms surrounding the keypress.

State Anxiety Questionnaire

At the end of the testing session, participants completed the state version of the State-Trait Anxiety Inventory (STAI; Spielberger, 1968). Questionnaire instructions specified that the

participant should use the rating form to describe his or her mood during the testing session. The mean STAI score for the sample was 37.6 ($SD=7.97$, range 26-60).

Results

Performance data

Accuracy—The dependent variable in this analysis was the proportion of keypresses that were correct. Non-responses, in which the participant did not press either button within the allotted time, were excluded from consideration. The number of non-responses did not differ significantly for angry ($M=14.1$), happy ($M=12.3$) or neutral faces ($M=14.0$; $F < 1$). Further, STAI scores were not significantly correlated with either the total number of non-responses or the number of non-responses for any of the three expression categories considered separately (p 's $> .35$).

A one-way ANOVA on proportion correct with Emotion (angry, happy, neutral) as the repeated measures factor found that the main effect was significant ($F(2,52)=3.95$, $p < .05$). The proportion correct was higher (p 's $< .05$, Bonferroni-corrected t -test) for neutral faces ($M=0.86$) compared to angry faces ($M=0.81$) and happy faces ($M=0.82$), which did not differ significantly from one another.

When STAI scores were entered as a covariate, the Emotion $\times$ STAI interaction was significant ($F(2,48)=4.40$, $p < .04$). This interaction appeared to reflect a trend towards worse accuracy for angry faces as STAI level increased. However, subsequent analyses revealed that this interaction disappeared when an outlying participant (with STAI = 60) was excluded. Without this outlier, the Emotion $\times$ STAI interaction became non-significant ($F(2,46)=1.27$, $p > .25$), and zero-order correlations among STAI and accuracy for the three emotion types were all non-significant ($0.12 > r$'s $> -.15$, p 's $> .50$). Therefore, the accuracy data yielded no reliable evidence that STAI scores were correlated with overall performance or with performance for any of the three expression types.

Reaction Time (RT)—RT data were submitted to a repeated-measures ANOVA with Accuracy (correct, incorrect) and Emotion as factors. The ANOVA revealed a main effect of Accuracy ($F(1,26) = 10.03$, $p < .005$), due to faster responses on correct trials ($M=607$ ms) compared to incorrect trials ($M=633$ ms). No other effects were significant, and entering STAI scores as a covariate produced no additional significant effects (F 's < 1).

ERN

Grand-average response-locked waveforms are illustrated in Figure 1 for the three emotion types at the Cz site. As seen in the figure, ERN-like responses were observed on both correct and incorrect trials, an issue that we will return to in the discussion section. The ERN peak was defined as the most negative point within a window -50 to 150 ms surrounding the response. Peak amplitudes were submitted to an ANOVA with Accuracy (correct, error), Site (Fz, FCz, Cz) and Emotion (angry, happy, neutral) as repeated-measures factors. P -values were corrected by the Greenhouse-Geisser adjustment where appropriate.

As expected, the main effect of Accuracy ($F(1,25)=13.79$, $p < .001$) reflected higher (more negative) amplitudes on error trials ($M=-8.41 \mu\text{v}$) compared to correct trials ($M=-6.70 \mu\text{v}$). Means for the main effect of Site ($F(2,50)=5.14$, $p < .02$) and the Accuracy $\times$ Site interaction ($F(2,50) = 4.26$, $p < .03$) are represented in Table 1. Amplitudes tended to be highest overall at the FCz site, whereas the Cz site was the most sensitive to differences in amplitude for correct versus incorrect trials. Neither the main effect of Emotion nor the Accuracy $\times$ Emotion

interaction was significant, indicating that facial expression did not have a consistent overall effect on error monitoring processes tapped by the ERN.

However, subsequent analyses demonstrated that state anxiety interacted with emotion type to predict ERN amplitudes. When STAI scores were entered into the analysis as a covariate (with Accuracy, Emotion, and Site as factors), the Accuracy $\times$ Emotion $\times$ STAI interaction was significant ($F(2,46)=3.91, p<.04$). This effect was also significant when STAI was considered as a dichotomous factor, with high/low groups defined by a median split ($F(2,46)=3.80, p<.04$). Means for the interaction from the median-split ANOVA are illustrated in Figure 2. As seen in the figure, low anxiety participants tended to better differentiate between correct and incorrect trials on the angry-face blocks, compared to the happy- and neutral-face blocks. Conversely, high anxiety participants tended to better differentiate between correct and incorrect trials on the happy- and neutral-face blocks, compared to the angry-face blocks. Sample error-trial ERPs separated by expression type and anxiety group are displayed in Figure 3.

To confirm this pattern while considering STAI more appropriately as a continuous variable, we calculated correct-incorrect difference scores for each emotion condition and site. Difference scores were calculated as correct-trial amplitude minus incorrect-trial amplitude, such that a positive score indicates a larger amplitude on incorrect than correct trials (that is, better differentiation of incorrect versus correct trials in the predicted direction). Pearson's correlations confirmed that STAI scores were inversely correlated with amplitude difference scores on angry-face trials, particularly at the central site. Correlations between STAI scores and angry-face amplitude difference scores were significant for the Cz site ($r=-0.48, p<.05$), marginal at the FCz site ($r=-0.37, p<.07$), and nonsignificant but in the same direction at the Fz site ($r=-0.31, p<.14$). For all three sites, the pattern of correlation indicated a smaller correct-incorrect difference score for angry faces as state anxiety increased. Analyses indicated the opposite pattern for happy-face trials; correct-incorrect difference scores tended to be greater as state anxiety increased, especially at the central site (Cz, $r=0.43, p<.03$; FCz, $r=0.29, p<.17$; Fz, $r=0.35, p<.09$). No correlations involving neutral trials were significant. Thus, as state anxiety increased, participants showed worse correct-incorrect trial differentiation for angry faces but better correct-incorrect trial differentiation for happy faces.

Figure 4 illustrates the scatterplot of STAI scores versus amplitude difference scores at the Cz site for angry faces (top panel) and happy faces (bottom panel). As seen in the scatterplots, an outlying case with the highest STAI score appears to depart from the overall trend for angry faces while possibly contributing unduly to the correlation for happy faces. To confirm that the significant relationships between STAI and error-related processing were not disproportionately influenced by this participant, we reran the original ANCOVA without this suspect participant. The results still yielded a significant Accuracy $\times$ Emotion $\times$ STAI interaction ($F(2,44)=4.81, p<.02$) as well as an Accuracy $\times$ Emotion $\times$ Site $\times$ STAI interaction ($F(4,88)=4.76, p<.008$), reflecting the fact that the influence of state anxiety on correct-incorrect differences was most pronounced at the central site. Removal of this suspect participant, then, did not affect the overall pattern of results except to make the results somewhat more robust and focused on the Cz site.

Because correlations between STAI and correct-incorrect difference scores could be driven primarily by amplitudes on either correct or incorrect trials, we carried out a multiple regression that predicted STAI scores from four predictor variables, amplitudes on correct and incorrect trials for happy and angry faces, all measured at the Cz site. The overall model was significant ($F(4,24)=4.45, p<.02, r^2=0.47$), and partial correlations indicated that only incorrect-trial amplitudes were significant predictors of STAI. Once the influence of the other variables was partialled out, amplitudes on incorrect angry trials (partial $r=0.58, p<.005$) and incorrect happy

trials (partial $r = -0.60$, $p < .004$) predicted STAI, whereas correct-trial amplitudes were not significant predictors for either angry or happy faces (p 's $> .25$). These results were essentially unchanged when the outlying participant was removed from the analyses (overall model, $F(4,23) = 4.57$, $p < .01$, $r^2 = 0.49$; partial r 's, angry-incorrect $r = 0.64$, happy-incorrect $r = -0.47$).

In sum, the ERN analyses yielded the expected overall effect of accuracy on amplitudes. In addition, results revealed that state anxiety interacted with facial expression type to predict ERN amplitudes. Increasing state anxiety was associated with relatively decreased ERN amplitudes following angry-face errors and increased ERN amplitudes following happy-face errors.

Pe

The Pe was defined as the most positive point within a window 200–400 ms after the response. Pe peak amplitudes were submitted to an ANOVA with Accuracy, Emotion, and Site as repeated-measures factors. Similar results were obtained when the Pe was defined instead by a mean amplitude within the 200–400 ms window post-response, so only peak results are reported here. Greenhouse-Geisser adjustments were applied where appropriate.

Significant effects included main effects of Accuracy ($F(1,25) = 53.68$, $p < .0001$) and Site ($F(2,50) = 8.20$, $p < .004$) and the Accuracy $\times$ Site interaction ($F(2,50) = 5.53$, $p < .02$). As expected, amplitudes were higher (more positive) on incorrect trials ($M = 3.20 \mu\text{v}$) than on correct trials ($M = -1.77 \mu\text{v}$). Means for the Site and Site $\times$ Accuracy effects are listed in Table 1. As seen in the table, while overall voltages tended to be most positive at the Fz site, the Cz site was most sensitive to differences between correct and incorrect trials.

When STAI scores were entered as a covariate in the analysis with Accuracy, Emotion, and Site as factors, no effects involving the covariate reached statistical significance.

Stimulus-locked potentials

Other researchers have cautioned that stimulus-locked potentials may contaminate response-locked waveforms (Coles et al., 2001; Hajcak, Vidal, & Simons, 2004), so we examined stimulus-locked waveforms for effects related to STAI and emotional expression variables. There was no evidence in the stimulus-locked waveforms of differential responses to happy, angry, and neutral expressions as a function of state anxiety.

Discussion

This study investigated the influence of state anxiety and stimulus emotionality on error monitoring processes indexed by the ERN. The main results demonstrated an interactive effect between state anxiety and facial expression type, but not in the predicted direction. A hypothesis based on prior findings predicted that anxious participants would have larger ERN responses, especially on angry-face trials. Instead, we found that participants with higher levels of state anxiety showed smaller ERN amplitudes following errors on angry-face trials and larger ERN amplitudes on happy-face trials, compared to participants lower in state anxiety. While this pattern was unpredicted, it was statistically robust, with ERN amplitudes on angry-face and happy-face trials together predicting nearly half of the variance in state anxiety.

Main effects of trial accuracy on ERN and Pe amplitudes were highly significant, replicating numerous prior studies (see Falkenstein et al., 2000) and demonstrating that in the group as a whole, these potentials were sensitive to performance accuracy in the expected way. However, waveforms for correct and incorrect trials were more similar to one another in the present study than in many previous studies, due primarily to a substantial post-response negativity on correct trials. The phenomenon of ERN-like activity on correct trials has been dubbed the “correct-

response negativity”, or CRN, by other researchers (e.g., Pailing & Segalowitz, 2004a; see also Ford, 1999). The CRN was most likely large in this study because of the difficulty of the task. Because faces were presented in peripheral vision for a very brief duration, it may have been especially difficult for participants to obtain an accurate perceptual representation of the face. This increased difficulty could produce large CRNs for two reasons. First, if the post-response negativity reflects the process of self-monitoring (“checking” one’s own performance) rather than error detection per se, as some have argued (e.g., Vidal et al., 2000), a perceptually difficult task could logically lead to increased self-monitoring and therefore a large post-response negativity on correct trials. Alternatively, if the post-response negativity reflects error detection per se, as others have argued (Coles et al., 2001), the increased task difficulty may produce ERN-like activity on correct trials because participants sometimes think they have erred on those trials even when they haven’t. Prior research has demonstrated that uncertainty about the correctness of one’s own responses is associated with greater CRN activity on correct trials and reduced ERN activity on error trials, together leading to greater similarity in waveforms for correct and incorrect responses (Pailing & Segalowitz, 2004a; see also Scheffers & Coles, 2000). It is likely that in the present study as well, uncertainty about response correctness contributed to similarity between ERN amplitudes on correct and incorrect trials in the group as a whole.

The findings from this study do not fit with a simple idea that anxiety leads to greater error monitoring activity. If that were true, the results should have yielded a main effect of state anxiety (or an anxiety $\times$ accuracy interaction), with greater ERN amplitudes overall for anxious participants. Likewise, if emotionally threatening stimuli led to an increase in error monitoring, we should have found a main effect of emotional expression (or an emotion $\times$ accuracy interaction), with greater amplitudes following errors in the angry-face blocks. Finally, the results directly contradict the hypothesis that anxious participants have especially heightened error responsiveness in the presence of threat-related stimuli, because we found instead that ERN amplitudes were especially small for anxious people during angry-face blocks.

One possible, though unlikely, explanation for the present findings is that threat-related stimuli such as angry faces disrupt cognitive control systems in anxious people, leading to decreased error sensitivity. This explanation has the appeal that it fits with the commonsense notion that threatening situations can disrupt performance in people prone to anxiety. While this explanation cannot be completely ruled out on the basis of the present data, one crucial aspect of the data argues against it. If the effect of angry faces were to disrupt important processes of cognitive control in anxious people, we would expect to see corresponding performance declines in those blocks of trials. Yet there was no reliable evidence that anxious individuals performed more poorly in the angry-face blocks (or better in the happy-face blocks) compared to less anxious people. It is difficult to make the case for disrupted cognitive control when there is no apparent consequence for performance. In addition, there was no evidence in stimulus-locked potentials that perceptual and cognitive processes leading up to the response differed for angry versus happy faces as a function of state anxiety. This latter point argues against the possibility that anxious people may have extracted less information from angry faces, for example, which might have led to decreased ability to distinguish between errors and correct responses.

The present results may be more fruitfully interpreted within a framework that considers the ERN as a marker of expectancy violation. In a theoretical formulation, Holroyd and Coles (2002) argue that the ERN reflects a process in which actual outcomes are compared to expected outcomes. In particular, the theory holds that the ERN is a “reward prediction error signal”; when an outcome is worse than predicted, the ERN is generated. According to the theory, this signal of discrepancy is used to modify behavior accordingly. Because people generally expect to perform accurately on simple choice tasks, an error represents a deviation from this

expectation and is marked by the ERN. Indirect evidence for this view is the finding that more accurate people tend to have larger ERNs, presumably because an error is more unexpected for highly accurate individuals than for those who commit more frequent mistakes (Hajcak, McDonald, & Simons, 2003b; see also Pailing, Segalowitz, Dywan, & Davies, 2002). More directly supporting the central claims of the expectancy theory, researchers have found that unfavorable feedback elicited smaller ERN activity when it was expected rather than unexpected (Holroyd, Nieuwenhuis, Yeung, & Cohen, 2003; though see also Hajcak, Holroyd, Moser, & Simons, 2005). Likewise, in a study in which performance-based monetary gains and losses were manipulated, the ERN amplitude was sensitive to the relative value of the outcome in relation to the range of possible outcomes, rather than being sensitive to the absolute value of the outcome (Holroyd, Larsen, & Cohen, 2004). In other words, in these studies the participants' expectancies determined when an ERN was elicited, with larger ERNs when outcomes were more discrepant from expected values.

This expectancy violation theory can be applied to the present data by considering the expectations of anxious and non-anxious individuals in different blocks of trials. When confronted with trials involving angry facial cues, anxious individuals may expect to fail. That is, anxious individuals may implicitly interpret the task-irrelevant angry expression as a cue for failure and may adjust expectations downward accordingly. Therefore, an error in these blocks of trials may not elicit a large ERN because an error is actually consistent with the expectations of an anxious person. Less anxious individuals do not necessarily expect to fail on the angry-trial blocks, so errors mismatch with expectations of a positive outcome and an ERN is elicited. This interpretation applies and extends the Holroyd and Coles (2002) model by assuming that expectancy violations generate the ERN, as Holroyd and Coles proposed, and by arguing further that expectancies can themselves be influenced by emotional factors such as the anxiety level of the participant and contextual emotional cues (cf. Larson et al., 2006). The notion that expectancies can be influenced by emotional variables is consistent with a large body of cognitive research on emotion and decision-making (e.g., Loewenstein, Weber, Hsee, & Welch, 2001).

Results from the happy-face trials fit less intuitively within this expectancy framework, but may be consistent when viewed in a certain way. Significant trends indicated that errors on happy-face trials provoked larger ERNs as state anxiety increased. This result does not fit with the idea that anxious participants always expect to fail; if that were so, under the expectancy violation theory, anxious participants should exhibit smaller ERNs across all emotional conditions. Rather, the expectancy explanation could account for the happy-face results by positing that anxious individuals are more influenced by the emotionality of the stimuli when forming expectations about success and failure. That is, when completing a trial block involving happy faces, anxious participants increase their expectations of a positive outcome, and therefore an error violates that expectancy and elicits an ERN. Conversely, when completing a trial block involving angry faces, anxious participants decrease their expectations of a positive outcome, and therefore an error elicits a smaller ERN. In a series of behavioral experiments, Blanchette and Richards (2003) demonstrated that anxious participants are more likely to rely on contextual cues, whether positive or negative, to guide their interpretation of ambiguous situations. By extension, then, anxious individuals in the present study may have relied more upon the facial expressions to guide expectations about success or failure, which then influenced the ERN amplitude accordingly.

Although the expectancy theory can account for the unpredicted interaction between state anxiety and stimulus emotionality, several caveats limit this explanation of the present results. First, the task was not specifically designed to manipulate participants' expectancies, so we can only speculate about what expectations anxious and non-anxious individuals were likely to possess in the different trial blocks. Future studies should test more directly the notion that

anxiety interacts with external cues to alter expectations for success. For example, future studies could manipulate expectancies directly, as some prior studies have done through fixing probabilities of positive or negative outcomes (e.g., Holroyd et al., 2003,2004), and could then determine whether anxious participants are especially sensitive to those manipulations. Alternatively, future studies could assess participants' self-reported expectancies for success or failure under various conditions to determine whether those perceived expectancies are correlated with anxiety level and ERN amplitudes.

Another caveat in interpreting the present study is that it differs from prior error monitoring studies in the difficulty of the task. That is, participants may have been less certain about the correctness of their responses in the present study compared to prior studies that have used easier tasks. Of course, this factor does not invalidate the present findings; real life presents many situations in which we are never completely sure whether we've behaved correctly. It may be in just those situations of uncertainty that anxiety motivates a reliance on external cues, such as the facial expressions in this study, to guide expectations about probable success or failure (see Blanchette & Richards, 2003). Indeed, cognitive studies motivated by the "affect infusion model" (Forgas, 2000) have demonstrated that emotion is most likely to influence cognitive processing under demanding conditions in which simple strategies do not provide clear answers. The possibility that the present study was especially sensitive to "affect infusion" due to the difficulty of the task could be tested in future experiments that manipulate task difficulty directly.

In summary, the present findings demonstrate that individual differences in anxiety are associated with altered error processing, but not in the simple way suggested by prior studies. Results did not support the prediction that ERN amplitudes, a covert marker of error monitoring, were generally greater with increased state anxiety or during conditions involving threatening facial cues. Rather, when confronted with angry stimuli, anxious participants were less responsive to their own errors, yet when confronted with happy stimuli, anxious participants were more responsive to their own errors. These unpredicted findings seem best explained by an expectancy-based theory, in which anxiety differentially influences expectations for success and failure in response to external cues. Because the results were unpredicted, they require confirmation in future studies more directly designed to address individual differences in expectancies. Further, future studies should examine the interaction of trait affect and state-related emotional variables, as the present study's significant results involved state variables. Nevertheless, the results add to the existing literature by demonstrating limitations on the simple idea that anxiety leads to increased error-responsiveness. More generally, the results do not support the conceptualization of ERN amplitude as a direct index of emotional distress (e.g., Bush et al., 2000). Rather, they indicate that the relationship between emotional variables and error monitoring will be best understood by considering cognitive alterations that accompany emotional states and traits.

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Figure 1.

Grand-average waveforms from the Cz site for correct and incorrect responses during angry, happy, and neutral trial blocks. Time 0 is the time of the keypress. Waveforms are filtered with a lowpass of 30 Hz.

Figure 2. Mean ERN peak amplitude at the Cz site as a function of state anxiety (STAI) group, facial expression, and trial accuracy. Low and high STAI groups were determined by a median split. Error bars represent one SEM.

Figure 3. Grand-average waveforms at the Cz site for incorrect responses separated by anxiety group and facial expression type. Time 0 is the time of the keypress. Waveforms are filtered with a lowpass of 30 Hz.

Figure 4.

Correlation between state anxiety (STAI) scores and amplitude difference scores for angry faces (top panel) and happy faces (bottom panel). Difference scores were calculated as correct-trial amplitude minus incorrect-trial amplitude, such that a positive score indicates a greater amplitude (more negativity) for incorrect than correct trials.

Table 1Mean (SEM) amplitudes (in μV) for correct and incorrect trials at three scalp sites.

Site	Trial Type		Mean	Correct-Incorrect Difference
	Correct	Incorrect		
		<i>ERN</i>		
Fz	-6.76 (0.97)	-7.99 (1.03)	-7.38	1.23
FCz	-7.35 (0.96)	-9.17 (0.98)	-8.26	1.82
Cz	-6.00 (1.05)	-8.08 (0.95)	-7.04	2.08
		<i>Pe</i>		
Fz	-0.19 (0.76)	3.89 (0.78)	1.85	4.08
FCz	-1.79 (1.08)	3.40 (0.93)	0.81	5.19
Cz	-3.31 (1.18)	2.30 (1.14)	-0.51	5.61