The error-related negativity relates to sadness following mood induction among individuals with high neuroticism

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The error-related negativity (ERN) is an event-related potential (ERP) that indexes error monitoring. Research suggests that the ERN is increased in internalizing disorders, such as depression and anxiety. Although studies indicate that the ERN is insensitive to state-related fluctuations in anxiety, few studies have carefully examined the effect of state-related changes in sadness on the ERN. In the current study, we sought to determine whether the ERN would be altered by a sad mood induction using a between-subjects design. Additionally, we explored if this relationship would be moderated by individual differences in neuroticism—a personality trait related to both anxiety and depression. Forty-seven undergraduate participants were randomly assigned to either a sad or neutral mood induction prior to performing an arrow version of the flanker task. Participants reported greater sadness following the sad than neutral mood induction; there were no significant group differences on behavioral or ERP measures. Across the entire sample, however, participants with a larger increase in sad mood from baseline to post-induction had a larger (i.e. more negative) ERN. Furthermore, this effect was larger among individuals reporting higher neuroticism. These data indicate that neuroticism moderates the relationship between the ERN and changes in sad mood.

Keywords: event-related potential; error-related negativity; emotion; affect; sad mood induction

INTRODUCTION
The error-related negativity (ERN) is a negative waveform in the event-related potential (ERP) that occurs \textasciitilde50 ms after an erroneous response (Falkenstein et al., 1991; Gehring et al., 1993). In general, the ERN is thought to represent error monitoring, and contemporary models focus on functions that include reinforcement learning (Holroyd and Coles, 2002) and conflict monitoring (Yeung et al., 2004). Studies also indicate that the ERN is influenced by motivational and affective factors. For example, the ERN is increased when errors are more monetarily valuable or personally significant (Gehring et al., 1993; Hajcak et al., 2005; Kim et al., 2005). The ERN is also larger among individuals with anxiety disorders (Gehring et al., 2000; Johannes et al., 2001; Ruchstow et al., 2005; Ladouceur et al., 2006; Endrass et al., 2008; Hajcak et al., 2008) and individuals endorsing high levels of negative affect and related traits (Luu et al., 2000; Hajcak et al., 2003, 2004; Boksem et al., 2006). In contrast to the impact of trait anxiety, the ERN appears insensitive to changes in state levels of anxiety. For example, one study exposed individuals who were spider phobic to a tarantula while performing a flanker task; the ERN did not change as a result of this rather intense provocation of anxiety (Moser et al., 2005). Other studies have demonstrated that the ERN does not change after successful treatment for anxiety disorders (Ladouceur et al., 2007; Hajcak et al., 2008).

The relationship between the ERN and depression is less straightforward than the relationship between the ERN and anxiety. Some studies have demonstrated an increased ERN among individuals with major depressive disorder (MDD; Chiu and Deldin, 2007; Holmes and Pizzagalli, 2008, 2010). However, other recent studies report that severe depression may result in a reduced ERN (Schrijvers et al., 2008, 2009; Olvet et al., 2010). In light of these findings, it has been suggested that the relationship between the ERN and MDD is non-linear (Schrijvers et al., 2008; Olvet et al., 2010) such that mild to moderate depression is related to an increased ERN, whereas more severe depression is related to a reduced ERN (Olvet et al., 2010).

Two studies have reported changes in the ERN in the context of viewing emotional pictures used to induce short-term changes in emotion (Larson et al., 2006; Wiswede et al., 2009). Larson and colleagues found an increased ERN on trials that included pleasant pictures (Larson et al., 2006), whereas Wiswede and colleagues reported an increased ERN on trials that followed the presentation of unpleasant pictures, but only in the first half of the task (Wiswede et al., 2009). More recently, van Wouwe and colleagues (2010) presented either a positive (i.e. scenes from The Lion King...
or The Little Mermaid) or neutral (i.e. street scenes) film clip to participants prior to performing a continuous performance task and found that the ERN was increased in subjects in the positive condition. Although these studies suggest that the presentation of pleasant and unpleasant pictures can modulate the ERN, quantitative measures of mood were not obtained. Furthermore, the contrary results and variability in methodology in these studies make the results difficult to integrate.

In the current study, we focused specifically on sadness as a discrete emotion linked to depression, and sought to determine if the ERN would be altered by a sad mood induction using a between-subjects design. Based on the literature documenting enhanced ERNs in mild-to-moderate depression (Chiu and Deldin, 2007; Holmes and Pizzagalli, 2008), we hypothesized that the induction of sad mood would lead to an increased (i.e. more negative) ERN. Further, we predicted that those subjects who became sadder would demonstrate the largest increase in ERN magnitude. We also explored whether this effect would be moderated by individual differences in neuroticism. Neuroticism reflects the tendency to experience negative emotions, and is a risk factor for both anxiety and depression (Hettema et al., 2006). Thus, individuals high in neuroticism are at increased risk for internalizing psychopathology, are more emotionally reactive, and might be characterized by a larger increase in the ERN following a sad mood manipulation.

**METHODS**

### Participants

Forty-seven undergraduates (27 males, 20 females) participated in the current study. Participants completed four tasks in a fixed order during the course of this study, including the flanker task and a gambling task. Data from the gambling task has been published elsewhere (Foti and Hajcak, 2010). For the flanker task, data from one participant was lost due to experimenter error and one participant who made less than six errors was excluded (Olvet and Hajcak, 2009); therefore, the final sample consisted of 45 participants (20 females). Reaction time (RT) data from one subject was missing due to experimenter error. Twenty-two participants (11 females; age: mean $= 18.41; \text{standard deviation (s.d.)} = 1.05$ were randomly assigned to the neutral mood induction, and 23 participants (9 females; age: mean $= 18.74; \text{s.d.} = 1.29$) were randomly assigned to the sad mood induction. The two groups were comparable with respect to age ($t(43) = -0.94, P = 0.35$), gender ($\chi^2(1) = 0.54, P = 0.46$), and ethnicity ($\chi^2(4) = 4.29, P = 0.37$). Informed consent was obtained from participants prior to the experiment. This research was formally approved by the Stony Brook University Institutional Review Board. No participants discontinued their participation in the experiment once procedures had begun, and all participants received course credit for their participation.

### Mood induction

The sad and neutral mood induction paradigms were based on the guidelines provided by Rottenberg et al. (2007) for using film clips to elicit discrete emotions. Each mood induction consisted of 2–5 min film clips and a song that was played in the background throughout the entire experiment. In the neutral mood induction, the film clips used were from *Alaska’s Wild Denali*, and the song used was Robert Ronne’s Meditation No. 19. In the sad mood induction, the film clips used were from *The Champ* and *My Girl*, and the song used was Gabriel Faure’s Piano Quintet No. 1 in D Minor (Op. 89). The order of the film clips was counterbalanced across subjects. Upon completing the computer tasks, a pleasant mood was induced in all participants using an amusing film clip of funny cats.

To assess current mood throughout the experiment, the valence scale of the Self-Assessment Manikin was used (Lang, 1980). Participants were asked to rate their current mood ranging from one (happy) to nine (sad). This measure was administered at five points throughout the experiment: before and after each of the two film clips, and again at the conclusion of the experiment. For this study, the ratings of interest were those taken at baseline and immediately following the first film clip (i.e. immediately before the flanker task). At the end of the experiment, individuals filled out the Big Five Inventory (BFI; John and Srivastava, 1999) to assess the personality dimension of neuroticism.

### Task and materials

The present task was administered on a Pentium D class computer, using Presentation software (Neurobehavioral Systems Inc., Albany, CA, USA) to control the presentation and timing of all stimuli. The task was an arrow version of the flanker task (Eriksen and Eriksen, 1974). On each trial, five horizontally aligned arrowheads were presented. Half of all trials were compatible (‘<<<<<’ or ‘>>>’) and half were incompatible (‘<<<’ or ‘>>>’) and the order of compatible and incompatible trials was random. All stimuli were presented for 200 ms followed by an interval that varied randomly from 2300 to 2800 ms.

### Procedure

Following a brief description of the experiment, electroencephalograph sensors were attached. Participants viewed the film clip (with pre- and post-mood ratings) and then performed the flanker task followed by another task, an additional film clip, and two other tasks. In the flanker task, participants were instructed to press the right mouse button if the center arrow was facing to the right and to press the left mouse button if the center arrow was facing to the left. Participants performed a practice block containing 30 trials and were instructed to be both as accurate and fast as possible. The actual task consisted of 10 blocks of 30 trials (300 trials total) with each block initiated by the participant. Feedback was given at the end of each block to
maintain performance between 75% and 90% accuracy. The task lasted for \( \sim 10 \) min. Participants filled out the self-report questionnaire at the end of the experiment.

**Psychophysiological recording, data reduction and analysis**

The continuous EEG activity was recorded using an ActiveTwo head cap and the ActiveTwo BioSem system (BioSemi, Amsterdam, The Netherlands). The EEG was pre-amplified at the electrode with a gain of one; EEG data was digitized at 64-bit resolution with a sampling rate of 512 Hz using a low-pass fifth-order sinc filter with a half-power cutoff of 102.4 Hz using ActiView Software (BioSemi). Recordings were taken from 64 scalp electrodes based on the 10/20 system, as well as two electrodes placed on the left and right mastoids. The electro-oculogram (EOG) generated from blinks and eye movements were recorded from four facial electrodes: two \( \sim 1 \) cm above and below the participant’s right eye (vertical EOG bipolar recording), one \( \sim 1 \) cm to the left of the left eye and one \( \sim 1 \) cm to the right of the right eye (horizontal EOG bipolar recording). As per BioSemi's design, each electrode was measured online with respect to a common mode sense electrode that formed a monopolar channel.

Off-line analysis was performed using Brain Vision Analyzer software (Brain Products, Gilohing, Germany). EEG data were re-referenced to the numeric mean of the mastoids and band-pass filtered with cutoffs of 0.1 and 30 Hz. The EEG was segmented for each trial, beginning 400 ms before each response and continuing for 1000 ms. The EEG was corrected for blinks and eye movements using the method developed by Gratton et al. (1983). Specific intervals for individual channels were rejected in each trial using a semi-automated procedure, with physiological artifacts identified by the following criteria: a voltage step of \( >50.0 \) µV between sample points, a voltage difference of 300.0 µV within a trial, and a maximum voltage difference of \(<0.50\) µV within 100 ms intervals; all segments were also visually inspected for additional artifacts.

Response-locked average ERPs were computed for correct and error trials. The ERN and correct response negativity (CRN) were quantified on error and correct trials, respectively, as the average activity from 200 to 400 ms at Pz following response onset. A 200 ms window from \(-400\) to \(-200\) ms prior to response onset served as the baseline. Behavioral measures included the number of error trials for each subject, average reaction time (RT) on error and correct trials, and post-error slowing.

\( ^{1} \)An area measure of the ERN and the CRN was also scored on error and correct trials, respectively, from response onset to 100 ms (i.e. \(0\) - \(100\) ms) at FCz.

**(PES; RT on correct trials after errors minus RT on correct trials after correct responses).**

**Statistical analysis**

All data was checked for normality prior to analysis. The only measure that resulted in skewness and kurtosis scores that deviated from normality was the \( P_{e} \) (both on error and correct trials), which was due to two subjects with scores that were outliers (i.e. \( \sim 5\) s.d. from the mean in both cases). Removing these data-points resulted in normality statistics that were below 2 with no change in the overall pattern of results.

In all cases, behavioral and ERP data were statistically evaluated using SPSS General Linear Model software (Version 16.0; SPSS Inc., Chicago, IL, USA). For state mood scores, a 2 (group: sad vs neutral mood induction) \( \times 2 \) (time: before vs after induction) mixed model analysis of variance (ANOVA) was used to detect differences between the groups. For the behavioral and ERP measures, a 2 (group: sad vs neutral mood induction) \( \times 2 \) (trial type: correct vs error trial) mixed model ANOVA was used to detect differences between the groups. Independent sample \( t \)-tests were performed for follow-up post-hoc comparisons. Group differences on post-error slowing and neuroticism scores were evaluated with a one-way ANOVA. The Pearson correlation coefficient (\( r \)) was used to examine the relationship between ERPs, neuroticism scores and mood ratings across groups. Fisher’s \( z \)-test was used to examine differences between correlation coefficients.

A moderated multiple regression (MMR) analysis (Aiken and West, 1991) was used to test whether neuroticism moderated the relationship between the change in mood and the ERN minus the CRN (\( \Delta \)ERN) in the entire sample. First, continuous independent variables (i.e. change in mood score and neuroticism) were centered by subtracting the mean from each of the individual datapoints. Second, an interaction term was created by multiplying the centered values of change in mood score by neuroticism scores. Finally, for the MMR, mood condition (i.e. sad vs neutral condition), change in mood scores and neuroticism were entered in step 1, and mood condition, change in mood score, neuroticism and the interaction term were entered in step 2.

**RESULTS**

**Self-report ratings**

Mean neuroticism scores, and mood scores before and after the presentation of the film clips are presented in Table 1. The neutral and sad mood groups did not differ on neuroticism scores \( F(1,43) < 1 \). Participants reported being sadder following both films \( F(1,43) = 22.41, P < 0.001 \), and those assigned to the sad film had higher sadness ratings overall \( F(1,43) = 27.78, P < 0.001 \); importantly, there was an interaction between the two factors \( F(1,43) = 18.18, P < 0.001 \) such that change in mood scores (i.e. post-induction mood
Table 1 Trait neuroticism, mood ratings, performance and ERP data means (and s.d.’s)

<table>
<thead>
<tr>
<th>Trait neuroticism scores</th>
<th>Sad condition</th>
<th>Neutral condition</th>
</tr>
</thead>
<tbody>
<tr>
<td>(N = 23)</td>
<td>(N = 22)</td>
<td></td>
</tr>
<tr>
<td>Neuroticism</td>
<td>23.53 (5.97)</td>
<td>22.36 (6.99)</td>
</tr>
<tr>
<td>Mood ratings</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pre-induction</td>
<td>3.87 (1.36)</td>
<td>3.14 (0.99)</td>
</tr>
<tr>
<td>Post-induction</td>
<td>5.61 (1.34)</td>
<td>3.23 (0.97)</td>
</tr>
<tr>
<td>Performance</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Error reaction time (ms)</td>
<td>329 (34)</td>
<td>337 (36)</td>
</tr>
<tr>
<td>Correct reaction time (ms)</td>
<td>392 (32)</td>
<td>398 (37)</td>
</tr>
<tr>
<td>Post-error slowing (ms)</td>
<td>19 (28)</td>
<td>14 (34)</td>
</tr>
<tr>
<td>No. of errors</td>
<td>32 (13)</td>
<td>36 (15)</td>
</tr>
<tr>
<td>ERPs</td>
<td></td>
<td></td>
</tr>
<tr>
<td>ERN Peak (µV)</td>
<td>-3.90 (9.24)</td>
<td>-1.12 (6.84)</td>
</tr>
<tr>
<td>CRN Peak (µV)</td>
<td>7.41 (8.30)</td>
<td>9.07 (6.42)</td>
</tr>
<tr>
<td>ΔERN Peak (µV)</td>
<td>-13.35 (7.61)</td>
<td>-11.55 (4.73)</td>
</tr>
<tr>
<td>Pc Area (µV)</td>
<td>16.24 (8.97)</td>
<td>19.24 (14.38)</td>
</tr>
<tr>
<td>Pc Area (µV)</td>
<td>3.83 (7.28)</td>
<td>4.45 (5.60)</td>
</tr>
</tbody>
</table>

scores minus baseline mood scores) were larger among individuals who watched the sad film \( t(43) = -4.32, P < 0.001 \). Correlations between neuroticism and change in mood scores did not reach significance in the entire sample \( r = -0.11, P = 0.49 \), nor in the neutral \( r = 0.07, P = 0.77 \) and sad mood groups separately \( r = -0.39, P = 0.07 \).

### Behavioral performance

Accuracy, RT and PES data are presented in Table 1. Participants were faster on error than correct trials \( F(1,42) = 184.31, P < 0.001 \), however, the groups did not differ in RT \( F(1,42) < 1 \), nor was there a significant interaction between trial type and group \( F(1,42) < 1 \). Participants in the neutral and sad mood groups did not differ on PES \( F(1,42) < 1 \) or number of errors \( t(43) = 1.03, P = 0.31 \). Correlations between neuroticism and performance measures did not reach significance in the entire sample (error reaction time: \( r = 0.06, P = 0.72 \); correct reaction time: \( r = 0.08, P = 0.62 \); PES: \( r = 0.15, P = 0.32 \); number of errors: \( r = -0.01, P = 0.94 \)), nor in the neutral (error reaction time: \( r = 0.13, P = 0.58 \); correct reaction time: \( r = 0.12, P = 0.59 \); PES: \( r = 0.27, P = 0.23 \); number of errors: \( r = 0.06, P = 0.79 \)) and sad mood groups separately (error reaction time: \( r = 0.00, P = 0.99 \); correct reaction time: \( r = -0.32, P = 0.14 \); PES: \( r = -0.03, P = 0.91 \); number of errors: \( r = -0.06, P = 0.79 \)).

### ERPs

Grand average response-locked ERPs at FCz and scalp topographies of the ERN are presented in Figure 1, and the average ERP values are presented in Table 1. The ERN was significantly more negative than the CRN \( F(1,43) = 129.19, P < 0.001 \), and individuals in the neutral and sad mood condition did not differ from one another on ERN/CRN amplitudes \( F(1,43) = 1.09, P = 0.30 \); the trial type \( \times \) group interaction was not significant \( F(1,43) < 1 \).² The \( P_c \) was significantly more positive than the \( P_c \) \( F(1,43) = 109.93, P < 0.001 \), and neither the main effect of group \( F(1,43) < 1 \) nor the trial type \( \times \) group interaction \( F(1,43) < 1 \) was significant.

Across the entire sample, there was a significant correlation between the change in mood scores (i.e. post-induction mood scores minus baseline mood scores) and the ERN minus the CRN (i.e. \( \Delta \)ERN; \( r = -0.40, P < 0.01 \)), such that a larger change in mood score (i.e. a greater increase in sadness) related to a larger \( \Delta \)ERN (see Figure 2).³ The correlation between the \( \Delta \)ERN and change in mood score was significant in the sad mood condition \( r = -0.42, P < 0.05 \) and there was a trend toward a similar relationship in the neutral mood condition \( r = -0.30, P = 0.17 \) as well. Using a Fisher’s z-test, the difference between the correlation coefficients was non-significant \( z = 0.41, P = 0.68 \). Thus, across both groups, those participants who became sadder following the mood induction were characterized by larger (i.e. more negative) error-related brain activity. This finding was driven by the relationship between the post-induction mood scores and the ERN \( r = -0.31, P < 0.05 \), not the pre-induction mood scores and the ERN \( r = -0.07, P = 0.64 \). There was also a trend towards a significant relationship between the ERN and the change in mood scores \( r = -0.28, P = 0.07 \). Neither the pre- nor post-induction mood scores correlated with the CRN (pre-induction: \( r = -0.14, P = 0.37 \); post-induction: \( r = -0.13, P = 0.40 \)). Correlations between neuroticism and ERP measures did not reach significance in the entire sample (ERN: \( r = 0.15, P = 0.32 \); CRN: \( r = 0.13, P = 0.41 \); \( \Delta \)ERN: \( r = 0.11, P = 0.49 \); \( P_c \): \( r = -0.11, P = 0.47 \); \( P_c \): \( r = -0.09, P = 0.58 \); in the neutral (ERN: \( r = 0.18, P = 0.43 \); CRN: \( r = 0.12, P = 0.60 \); \( \Delta \)ERN: \( r = 0.21, P = 0.35 \); \( P_c \): \( r = -0.17, P = 0.45 \); \( P_c \): \( r = -0.23, P = 0.30 \)) or sad mood groups separately (ERN: \( r = 0.18, P = 0.42 \); CRN: \( r = 0.17, P = 0.45 \); \( \Delta \)ERN: \( r = 0.08, P = 0.73 \); \( P_c \): \( r = 0.03, P = 0.89 \); \( P_c \): \( r = 0.05, P = 0.83 \)).

A moderated multiple regression (MMR) analysis was used (Aiken and West, 1991) to test whether neuroticism moderated the relationship between the change in mood and the \( \Delta \)ERN in the entire sample. Data from the MMR analysis is presented in Table 2. The MMR analysis revealed that neuroticism scores significantly moderated the relationship between change in mood scores and the \( \Delta \)ERN [Figure 3; \( F(4,40) = 3.48, P < 0.05 \)]. Among individuals

²Using an area measure of the ERN and the CRN, the ANOVA results are consistent with the peak data. The ERN is significantly more negative than the CRN \( F(1,43) = 126.07, P < 0.001 \), with no effect of group \( F(1,43) < 1 \), nor a trial type \( \times \) group interaction \( F(1,43) < 1 \).

³Using an area measure, correlations were significant between the change in mood score and the \( \Delta \)ERN \( r = -0.31, P < 0.05 \), but only reached a trend significance between post-induction mood scores and the \( \Delta \)ERN \( r = -0.23, P = 0.13 \). For the MMR analysis, there was a similar trend that neuroticism scores moderated the relationship between change in mood scores and the \( \Delta \)ERN \( F(4,40) = 1.84, P = 0.14 \).
who scored low in neuroticism, the ΔERN was not related to change in mood. However, among individuals who scored high in neuroticism, those reporting a greater increase in sadness had a larger ΔERN than those who reported a smaller increase in sadness. The unstandardized simple slope for high neuroticism (+1 s.d.) was –3.68 (r = –0.88) and the unstandardized simple slope for low neuroticism (–1 s.d.) was –0.38 (r = –0.09). There was no significant effect of condition in the model.

### DISCUSSION

The sad mood induction appeared successful: those individuals who viewed a sad film and listened to sad music reported increased sadness compared to participants who viewed a neutral film and listened to neutral music. Although errors elicited an ERN, error-related brain activity did not differ between subjects in the sad and neutral mood.
induction conditions. There was, however, a significant correlation between self-reported change in sadness and the ΔERN across the entire sample: greater change in sadness from pre- to post-mood induction was related to increased error-related brain activity.

In the sad condition, 18 out of 23 (78%) individuals reported an increase in sadness, and in the neutral condition, 4 out of 22 (18%) individuals reported an increase in sadness. Thus, not all participants assigned to the sad mood condition became sadder, whereas some of the participants assigned to the neutral mood induction became sadder. It is important to note that the relationship between sadness and ΔERN was specific to the change in mood—ΔERN was not related to baseline mood. Thus, increased error-related brain activity predicted changes in mood. One possibility is that the ΔERN may relate to individual differences in the propensity to become sad following exposure to both neutral and sad stimuli. For example, the neutral film clip could have had the effect of reducing a more pleasant mood to a more neutral one, which is possibly equivalent to an increase in sad mood if you assume this bipolar dimension. The existing literature suggests that both mildly and moderately depressed individuals are characterized by increased error-related brain activity (Chiu and Deldin, 2007; Holmes and Pizzagalli, 2008, 2010). The current study is in line with these data: changes in mood were related to increased error-related brain activity both before and after a sad mood induction to determine whether there are transient changes in the ERN based on neuroticism and the experience of sadness—or whether the ERN is stable across variation in sadness and instead can be used to predict sadness in response to emotional challenge as a function of neuroticism. In addition, future studies might obtain separate ratings of negative and positive affect, so that the impact of each dimension on the ERN can be examined separately. Finally, this study was conducted in a non-clinical sample, and therefore we cannot determine whether a sad mood manipulation in individuals with MDD or their offspring might produce different results. These are promising avenues for future work on the ERN.

### REFERENCES
