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# Evidence for specificity of the impact of punishment on error-related brain activity in high versus low trait anxious individuals

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## ABSTRACT

A previous study suggests that when participants were punished with a loud noise after committing errors, the error-related negativity (ERN) was enhanced in high trait anxious individuals. The current study sought to extend these findings by examining the ERN in conditions when punishment was related and unrelated to error commission as a function of individual differences in trait anxiety symptoms; further, the current study utilized an electric shock as an aversive unconditioned stimulus. Results confirmed that the ERN was increased when errors were punished among high trait anxious individuals compared to low anxious individuals; this effect was not observed when punishment was unrelated to errors. Findings suggest that the threat-value of errors may underlie the association between certain anxious traits and punishment-related increases in the ERN.

## 1. Introduction

Detecting errors is fundamental for learning and survival (Hajcak, 2012; Holroyd and Coles, 2002). Indeed, errors increase distress (Spunt et al., 2012) and initiate a cascade of physiological responses that suggest preparation for defensive action, including: skin conductance response and heart rate deceleration (Hajcak et al., 2003), potentiated startle reflex (Hajcak and Foti, 2008; Riesel et al., 2013), pupil dilation (Critchley et al., 2005), and corrugator (i.e. frowning) muscle contraction (Lindström et al., 2013). The detection of errors is also associated with distinct neural activity evident in the event-related potential (ERP) (Falkenstein et al., 1991; Gehring et al., 1993). Specifically, the error-related negativity (ERN) is a response-locked, negative-going, sharp deflection with fronto-central scalp distribution, occurring approximately 50 ms after an incorrect response (Falkenstein et al., 1991; Gehring et al., 1993; Hajcak, 2012).

Many theories regarding the function of the ERN have focused on cognitive processes (Bernstein et al., 1995; Botvinick et al., 2001; Carter et al., 1998; Falkenstein et al., 1991; Holroyd and Coles, 2002), and predict that variation in the ERN should relate to task performance and subsequent behavioral adjustments. However, there are many instances in which variation in the ERN occurs in the absence of behavioral differences (for a review, see: Weinberg et al., 2012). Recent work has sought to address additional sources of variance in the ERN related to affect and motivation. Indeed, source localization analyses, as well as fMRI data suggest that the ERN is generated in the anterior cingulate cortex (ACC) (Agam et al., 2011; Carter et al., 1998; Kiehl et al., 2000; Mathalon et al., 2003), a region of the brain thought to integrate information about negative affect, pain, threat, and punishment is integrated to modulate fear and anxiety-related behaviors, as well as signal the need for control (Cavanagh and Shackman, 2015; Shackman et al., 2011).

Consistent with these theories of ACC function, a growing body of literature suggests that the amplitude of the ERN can be modulated by experimental manipulations that alter error significance. For example, an increased ERN has been observed when instructions emphasize performance accuracy over response speed (Gehring et al., 1993), when participant performance is explicitly evaluated (Hajcak et al., 2005; Kim et al., 2005), by introducing monetary incentives for correct responses (Chiu and Deldin, 2007; Endrass et al., 2010; Hajcak et al., 2005) and when errors are associated with punishment (Riesel et al., 2012). In these cases, the experimental manipulations modulate affect or motivation integral to error commission. However, affective modulations that are incidental to error commission, such as the presence of a spider while a spider phobic completes a flanker task, do not seem to impact the ERN (Moser et al., 2005).

Based on these data, we have argued that the ERN may reflect the relative threat value or significance of errors—and that variation in the amplitude of the ERN reflects individual differences linked to certain anxious phenotypes (Proudfit et al., 2013). For example, the amplitude of the ERN is enhanced in patients with general anxiety disorder (Weinberg et al., 2010; Xiao et al., 2011) and obsessive-compulsive

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disorder (Gehring et al., 2000; Hajcak et al., 2008; Riesel et al., 2011). Additionally, two recent meta-analyses have confirmed the association between the ERN and trait anxiety (Cavanagh and Shackman, 2015; Moser et al., 2013).

Overall then, there are both trait- and state-like effects on the ERN: it is increased among trait anxious individuals and in experimental conditions in which errors are more aversive or valuable. Indeed, these effects may be related: Riesel et al. (2012) found that modulation of the ERN by punishment varied by individual differences in anxiety. In this study, participants were sometimes punished after errors with a loud, unpleasant sound. The ERN was enhanced in blocks where errors could be punished, and this effect was most evident in individuals with higher levels of trait anxiety. These results suggest that punishing errors may potentiate the ERN differentially, as a function of certain traits and dispositions. However, the Riesel et al. study did not include a condition in which punishment was unrelated to performance errors, leaving it unclear whether the "punishment-related" modulation of the ERN was due to a general increase in anxiety induced by the threat of punishment, or was specifically due to punishment following errors.

To further investigate this possibility, in the current study, participants were punished after error commission with an electrical shock in one condition; however, participants were punished *randomly* (i.e., unrelated to error commission) in another condition; in a final control condition, no punishment was administered. By introducing a block with random punishment, the current study aimed to investigate whether the relationship between anxiety and punishment-related increases in the ERN is related specifically to the threat-value of errors, or to anxiety elicited by potential punishment more generally. Rather than employing a loud sound, the current study used electrical shock as the aversive punishment to be more consistent with the fear conditioning literature (Lissek et al., 2005). Based on previous findings, we hypothesized that the ERN would be increased only in blocks in which errors were followed by punishment, and that this effect would be larger among individuals characterized by high trait anxiety.

## 2. Methods

### 2.1. Participants

Fifty-seven undergraduate students (30 female) participated in this study. Data from six subjects were excluded from analysis due to excessive electroencephalogram (EEG) artifacts. Three of the participants committed fewer than six errors in at least one condition (Olvet and Hajcak, 2009b) and were therefore excluded from further analysis. Two of the participants did not complete the STAI due to experimenter error. The final sample consisted of 46 participants (27 female). The mean age was 20.08 (*SD* = 4.68) and 37% of the sample reported being Caucasian, 4.3% Hispanic, 6.5% African-American, 47.8% Asian, and 4.3% as "other". All participants were given verbal and written information about the procedure of the study, and written consent was obtained. Participants received course credit for participation in the study.

### 2.2. Measures

Individual differences in trait anxiety were measured with the trait version of the State-Trait Anxiety Inventory (STAI) (Speilberger et al., 1983). The STAI scores of the participants ranged from 28 to 54 (*M* = 41.44, *SD* = 6.55); higher scores indicate more anxiety.

### 2.3. Stimuli

An arrowhead version of the flanker task (Eriksen and Eriksen, 1974) was used with Presentation software (Neurobehavioral Systems, Inc., Albany, CA). During each trial, five horizontally aligned arrowheads (white font on a black background) were presented for 200 ms and participants were told to respond with the left or right mouse button according to what direction the center arrow was pointing. The inter-stimulus interval varied between 2500 and 3000 ms on trials that participants did not receive a shock, and between 3000 and 5500 ms on trials in which participants received a shock. Half of the trials were compatible (" > > > > > " or " < < < < < ") and half were incompatible (" < < > < < " or " > > < > > "); the order of trials was randomly determined. Each set of arrowheads occupied approximately 0.9° of visual angle vertically and 7.5° horizontally. Throughout the experiment, participants were encouraged to be both fast and accurate: performance-based feedback was presented at the end of each block. If performance accuracy was below 75%, the message "Please try to be more accurate" was displayed; if performance was above 90%, the message "Please try to respond faster" was displayed; otherwise the message "You're doing a great job" was displayed.

### 2.4. Procedure

Electrical shocks were administered to the participants' left triceps using an electrical stimulator and PSYLAB hardware and software (Contact Precision Instruments), producing 60 Hz constant AC stimulation between 0 and 5 mA for 500 ms. Shock intensity was determined on an individual basis. Participants initially received a mild shock, which was increased incrementally until participants reported they were at a level of shock that was uncomfortable but manageable. After participants' shock level was individually determined, it was kept constant throughout the rest of the task.

The flanker task consisted of three conditions (4 blocks of each), administered quasi-randomly block-wise, such that no block was repeated sequentially (e.g., ACBABACBCACB). Each block consisted of 64 trials (768 total in the entire task). In the *punishment after errors condition*, participants were instructed they could only be shocked after committing an error; at the beginning of these blocks, a screen was presented that read, "In the next block, shocks will only follow some of your errors". In this condition, participants were randomly shocked after 50% of their errors, 600 ms after response commission. In the *random punishment condition*, participants were instructed they would be randomly shocked throughout the block, regardless of error commission; prior to these blocks, a screen was presented that read, "In the next block, shocks will be completely random". In the random punishment condition, participants were shocked 600 ms after response commission on exactly 4 of the 64 trials, randomly determined and independent of trial accuracy. Finally, in the *no punishment condition*, participants were instructed they would never be shocked; these blocks were preceded with the following screen: "In the next block, there will be NO shocks".

After completing the flanker task, participants completed the STAI and a self-report rating of discomfort/anxiety (on a 1–7 scale) for each condition (i.e., punishment after errors, random punishment, and no punishment). The questions were phrased in the following way: "How uncomfortable or anxious did you feel during the blocks in the experiment where you were shocked randomly (1 = not anxious, 7 = extremely anxious)?", "How uncomfortable or anxious did you feel during the blocks in the experiment where you did not receive any shocks (1 = not anxious, 7 = extremely anxious)?", "How uncomfortable or anxious did you feel during the blocks in the experiment where you were sometimes shocked for making errors (1 = not anxious, 7 = extremely anxious)?".

### 2.5. Psychophysiological recording, data reduction, and analysis

The continuous EEG was recorded using an elastic cap and the ActiveTwo BioSemi system (BioSemi, Amsterdam, The Netherlands). Thirty-four electrode sites were used, as well as two electrodes on the right and left mastoids. The electrooculogram (EOG) was recorded using four additional facial electrodes: two electrodes placed approximately 1 cm outside of the right and left eyes and two electrodes placed