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Fear, Anxiety, and the Error-Related Negativity: A Registered Report of a Multi-Site Replication Study

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Competing Interests:
The authors disclose no conflicts of interest related to this manuscript.

Funding:
#EEGManyLabs is supported by the DFG (PA 4005/1-1) and the UK Biotechnology and Biological Sciences Research Council (BB/X008428/1). The funders had no role in study design or the decision to submit the work for publication.

Abstract

The error-related negativity (ERN), a scalp-recorded neural index of error monitoring, was directly linked to anxiety in a highly influential paper by Hajcak et al. (2003), which found that individuals high in worry symptoms of anxiety show greater ERN amplitude than those low in worry. This research sparked a flurry of further investigations, with subsequent work proposing the ERN to be a putative neural marker for anxiety. However, almost two decades later, the robustness of the relationship between the ERN amplitude and anxiety has been called into question. As part of the #EEGManyLabs international collaborative (Pavlov et al., 2021), the proposed replication involves the collection of data from three highly-powered samples (n = 234 each) across nine collaborating sites in Germany, Norway, The Netherlands, Poland, Russia, and the United States. Participants for the replication will be selected from a larger pool and assigned to the following three groups based on their scores on worry and phobia symptom scales: 1) high worry group, 2) high phobia/low worry group, and 3) low worry/phobia (control) group, with 70-80 participants in each group. All three groups of participants will complete a modified color-word Stroop task, consistent with procedures of Hajcak et al. (2003), while EEG recordings are made. As per Hajcak et al. (2003), we expect a significant main effect of group, with a larger overall ERN in the worry group than in the phobia and control groups, suggesting that enhanced sensitivity to errors is specific to worry vs. phobia. In addition to individual analyses conducted within each replicating lab, we will pool data across study sites and fit a two-stage individual participant data meta-analysis. Replication of this study will help in further characterizing the ERN signal and its link to clinical phenomena.

Keywords: Anxiety, Worry, ERN, Response Monitoring, #EEGManyLabs, replication

Fear, Anxiety, and the Error-Related Negativity: A Registered Report of a Multi-Site Replication Study

In 2003, Hajcak et al. observed that individuals high in worry symptoms of anxiety show larger negative deflections in a scalp-recorded EEG signal related to error monitoring, the Error-Related Negativity (ERN). Since its publication, this study has become one of the most highly-cited studies in the clinical neurosciences literature and inspired almost two decades of research on anxiety and the ERN. Subsequent work by these investigators, and others, has led to the proposal that the ERN could be a potential "neural marker" for anxiety (e.g., Hajcak et al., 2019; Weinberg et al., 2012). Since publication, the original finding has been confirmed by some studies (e.g., Moran et al., 2012; Moser et al., 2013; Weinberg et al., 2015), but there have been several contradictions (e.g., Compton et al., 2007; Härpfer et al., 2020; Xiao et al., 2011). In fact, a recent meta-analysis across 29 clinical samples indicates that after correcting for publication bias, the correlation between anxiety and ERN could be as small as zero (Saunders & Inzlicht, 2020).

Given (i) the potential implications of a biomarker for anxiety for the purposes of treatment; (ii) the current state of the literature; and (iii) the relatively small sample size (N = 67, across three groups of participants) of the original study, we propose a multi-site, large scale direct replication to establish the robustness of the relationship between worry symptoms of anxiety and the ERN. This Registered Report will attempt to follow the original study as closely as possible, with statistical power to detect an effect size that is half of that reported in Hajcak et al. (2003).

Error Monitoring and Anxiety

The monitoring of errors and the adjusting of behavior in response to errors is important for the effective pursuit of goals (Moser et al., 2011). ERP researchers have identified the ERN component as a neural index of response monitoring processes (Bernstein et al., 1995; Dehaene et al., 1994; Falkenstein et al., 1991, 2000; Holroyd et al., 1998; Luu et al., 2000; Van't Ent & Apkarian, 1999). The ERN (also called error negativity, Ne) is a negative-going deflection in the waveform between 0 and 100 ms following the commission of an error, maximal in fronto-central sites (Falkenstein et al., 1991; Gehring et al., 1993). Neuroimaging studies have localized the source of ERN to the posterior medial frontal cortex (Dehaene et al., 1994; Ullsperger & von Cramon, 2001), with the anterior cingulate cortex (ACC) considered important in conflict monitoring theories (Botvinick et al., 1999; Ito et al., 2003; MacDonald et al., 2000). More recent EEG-fMRI studies relate ERN amplitude to activation of the rostral cingulate zone, responsible for outcome prediction and performance adjustment (Debener et al., 2005; Nee et al., 2011). Neurocircuitry involving the basal ganglia connections with midbrain dopamine and the ACC is a salient generator of ERN in reinforcement learning theory (de Bruijn et al., 2004; Holroyd & Coles, 2002; Schultz, 2002).

Given the links between ERN and conflict monitoring, research has examined the role of the ERN in anxiety and stress-related disorders, which are characterized by heightened vigilance and disrupted cognitive control (Newman et al., 2013). Early clinical studies on the ERN (e.g., Gehring et al., 2000) observed enhancements of ERN associated with obsessive compulsive disorder (OCD), a diagnosis formerly categorized as an anxiety disorder in earlier versions of the Diagnostic and Statistical Manual of Mental Disorders (American Psychiatric Association, 2000). Clinical neuroscience studies have reported increased ACC activity, implicated in the ERN, among participants with OCD, panic disorder, and post-traumatic stress disorder when

experiencing state increases in fear and anxiety (Boshuisen et al., 2002; Breiter et al., 1996; Rauch et al., 1996).

Drawing on this prior work on OCD and evidence that enhanced ERN may more generally characterize persons high on negative affect (Luu et al., 2000), Hajcak et al. (2003) hypothesized that larger ERN would be associated with generalized anxiety or worry, not just OCD. This hypothesis was consistent with evidence that worry symptoms are associated with altered activation of neurocircuitry implicated in emotion and behavioral regulation, including the ACC. Importantly, Hajcak et al. (2003) expected enhanced ERN among individuals high on worry but not those high on phobic fear, consistent with long-standing conceptualizations and neuroscience evidence differentiating "anxiety" and "fear" (Davis et al., 1988; Heller et al., 1997; LeDoux & Pine, 2016). Fear refers to states that manage immediate or acute threat of harm, whereas anxiety is a state that is enhanced by either ambiguous or temporally or spatially diffuse threat of harm (Grillon, 2002; Öhman, 1993). Enhanced self-monitoring was expected to covary with anxiety/worry and not fear/phobia, since worry was considered by Hajcak et al. (2003) to be a trait-like (i.e., not context-specific) indicator of negative affect that triggers sensitivity to errors. Recent theories concur with the focus on worry vs. phobia. The Attention Control Theory implicates an overactive attentional system, which becomes overwhelmed in attending to internal and external stimuli, as a characteristic of anxious apprehension (worry) in particular (Eysenck et al., 2007). Moser et al. (2013) proposed that higher ERN in anxiety reflects a compensatory mechanism where increased monitoring and cognitive control is necessary to inhibit the interference of task irrelevant worry to maintain goal-directed behavior.

In the original study, Hajcak et al. (2003) recruited three groups of college students. The first group represented those who scored high on a measure of worry (what they referred to as "trait anxiety") meant to capture persistent experiences of diffuse anxiety as measured by the Penn State Worry Questionnaire (PSWQ; Meyer et al., 1990). The second group represented participants scoring low on worry but high on phobia symptoms (what they referred to as "state anxiety", or context-specific anxiety), based on a combined spider and snake phobia questionnaire, meant to assess experiences of acute fear. A third, low-anxious control group scored low on both measures. Results indicated that the worry group showed larger amplitudes of the ERN in response to the commission of errors in the Stroop task relative to the other two groups. It is worth noting that increased performance monitoring in the worry group was not specific to error processing but was also observed in response to correct behavior, as indexed by the correct-related negativity (CRN). The CRN is a negative deflection that occurs in the same time window as the ERN, but shortly after correct response execution (Vidal et al., 2000, 2003). Larger CRN amplitudes have been linked to higher uncertainty about the correctness of the actual response (Pailing & Segalowitz, 2004; Scheffers & Coles, 2000), overactive response checking (Falkenstein et al., 2000; Vidal et al., 2000) or increased post-response implementation of cognitive control (Bartholow et al., 2005). Further, Hajcak et al. (2003) found no group differences on behavioral performance on the Stroop task (i.e., RT, errors, percent correct, post-error slowing).

Since the study by Hajcak et al. (2003), conceptual replications and quantitative reviews of the literature (Moser et al., 2012, 2013; Pasion & Barbosa, 2019; Weinberg et al., 2016) have corroborated expected associations between performance monitoring components (ERN and/or CRN) and anxiety symptoms. Nonetheless, results regarding ERN links to distinct forms of

anxiety are far from conclusive. First, many of the studies that show higher ERN amplitude in anxiety have not directly compared phobia (fear) vs. worry (anxiety) symptoms (Meyer et al., 2013; Weinberg et al., 2015; Zambrano-Vazquez & Allen, 2014). A broad definition of anxiety can lead to high degrees of freedom in the selection of psychometric tools. For example, some measures directly capture worry symptoms or anxious apprehension; in contrast, others are non-specific measures of anxiety-related constructs, including both worry and phobia/fear symptoms (Moser et al., 2013). Second, some studies that have compared worry and phobia dimensions have failed to detect a difference in ERN (Härpfer et al., 2020), found the opposite effect (i.e., higher amplitude ERN in phobia than in worry; Gorka et al., 2017), or found sex-specific effects (i.e., worry associated with ERN in women but not men; Moran et al., 2012). Kujawa et al. (2016) reported enhanced ERN among social anxiety patients but found no difference in ERN amplitude between generalized anxiety disorder (worry) and healthy controls. These mixed results suggest that the link between ERN and anxiety dimensions is not as robust as initially assumed, and the specific conditions under which it can be observed are yet to be determined.

Current Study

As part of the #EEGManyLabs project (Pavlov et al., 2021), the current Registered Report proposes a close replication of Hajcak et al. (2003), involving the collection of data from nine sites across Germany, Norway, The Netherlands, Poland, Russia, and the United States. The focus on replicating highly cited ERP studies is motivated by the field's reliance on typically smaller sample sizes and the complex stream of data reduction methods that allow for a multitude of researcher degrees of freedom (Baldwin, 2017; Clayson et al., 2019; Garrett-Ruffin et al., 2021; Luck & Gaspelin, 2017; Paul et al., 2021). The focus on a close replication of Hajcak et al. (2003) in particular is warranted given its high citation count and influence on the

field of anxiety and ERN. Further, the many examinations of the ERN-anxiety link following Hajcak et al. (2003) show inconsistent results, and a recent meta-analysis suggests a much smaller effect size than reported in the original study (Saunders & Inzlicht, 2020). Mixed findings may be due to the varied operationalizations of anxiety and qualitatively different participant characteristics (e.g., clinical vs. non-clinical) across studies. Finally, advances in the literature also motivate a close replication of Hajcak et al. (2003), so that results from a highly-powered replication can be interpreted in light of new discoveries. For example, Hajcak et al. (2003) presaged the expansion of shifts away from nominal disorder categories to a focus on common variance and symptom dimensions, as exemplified by the recently proposed HiTOP model (Kotov et al., 2017). In this model, the larger internalizing disorder dimension can be subdivided into two subdimensions: the first characterized by loadings of generalized anxiety/worry and depression symptoms, and the second characterized by the "fear" disorders like panic and phobia symptoms (Brown et al., 1998; Eaton et al., 2013). The co-occurrence of depression and worry in the first subdimension suggests that measures of worry may be capturing generalized distress or "misery" in humans instead of something specific to anxiety (Judd et al., 1998). Results from a close replication of Hajcak et al. (2003) can be interpreted in this context.

In Hajcak and colleagues (2003), overall ERN activity was larger in the worry group than in the non-anxious control group and the individuals in the phobia group. The present study seeks to replicate this main effect of group, and we predict we will observe the same pattern of effects.

Method

The present manuscript is a Stage 1 Registered Report and follows recommendations for open science practices in psychophysiological research (Garrett-Ruffin et al., 2021). A project repository is hosted on Open Science Framework (OSF; https://osf.io/6suf8/) and contains all study materials and preliminary code for data processing. The OSF repository will serve as a project hub that links to raw EEG data which will be posted on OpenNeuro (https://openneuro.org/), and data processing and analysis code which will be posted on GitHub (https://github.com/).

This replication attempt is an international effort with "replicating labs" comprising multiple study sites that are independent and geographically separated. As of the first submission of the Stage 1 report, there are three groups of replicating lab "collaboratives", with separate sites represented within each of these collaboratives. That is, each replicating lab collaborative comprises several study sites that use the same model of amplifier and electrodes for recording EEG, and each lab collaborative will pool the data across participants for a total of three highly-powered replication databases. Full information on each site, including equipment and electrode specs, site-specific language, and participant recruitment procedures is included in table format and posted on the OSF repository (https://osf.io/6suf8/). The first collaborative comprises four study sites that use BioSemi amplifier systems (BioSemi, Amsterdam, Netherlands) and are located across Germany, Norway, The Netherlands, and Poland. The second collaborative comprises two study sites that use Electrical Geodesics, Inc. (Magstim EGI, Eugene, OR, USA) amplifier systems located in the United States and Germany. The third collaborative comprises three study sites that use ActiCHamp amplifier systems (Brain Products GmbH, Gilching, Germany) across Russia and the United States. Each study site will obtain approval from their local institutional review board/ ethics committee to conduct the study and share de-identified

data. Each replicating lab collaborative is expected to collect EEG data from at least 234 participants (pooled across study sites), or about 70-80 participants in each group (high worry, high phobia, and control groups), for a minimum of 702 participants across all replicating labs (see Power Analysis section).

Participants

Participants will be recruited from undergraduate courses or the community and provide written informed consent prior to participation and to the posting of anonymized raw data. The only inclusion criterion[1] is that participants are over 18 years of age. Participants recruited from undergraduate courses will be compensated for their time with course credit, and those from the community will be financially compensated for their time according to local policies for the remuneration of participants.

In the original study, 393 participants completed the Penn State Worry Questionnaire (PSWQ; Meyer et al., 1990) and modified versions of the Snake (SNAQ) and Spider (SPQ) Anxiety Questionnaires (Klorman et al., 1974). Subsequently, 17% of these participants (n = 67) completed the EEG portion of the study. The 67 participants were divided into one of the three groups (worry group: n = 24; phobic group: n = 20; control group: n = 23). In the present study[2], study sites will pretest participants from a larger pool, who complete questionnaires in their native language: an assessment of worry and assessments of snake phobia and spider phobia (see Self-Report Measures). Participants will then be assigned to one of three groups, depending on the scores on these measures. The three groups include 1) a high worry group (i.e., worry group), 2) a low worry and high phobia group (i.e., phobia group), and 3) a low worry/low phobia group

[1] The original study included undergraduate student participants that could consent to the experiment. Therefore, only adults (> 18 years of age) will be allowed to participate in the study. No inclusion/exclusion criteria were explicitly stated in the original study, and therefore the present study has no additional inclusion/exclusion criteria.
[2] Some study sites might include additional measures during pretest for other research purposes unrelated to the current study.

(i.e., control group). To make assignments, participants' scores on the measure of worry and measures of snake and spider phobia will be rank-ordered separately. Participants ranked at the top of the distribution of the worry measure will be assigned to the worry group[3]. Participants ranked at the top of the distribution of the combined phobia measures who also rank at the bottom of the distribution of the worry measure will be assigned to the phobia group. Participants who score at the bottom of both distributions will be assigned to the control group. Participants who do not meet these requirements will be excluded from further participation. We expect to recruit about 20% of the surveyed participants within each site to maintain a similar ratio of EEG completers to total sample as the original study.

Self-Report Measures

The original study was conducted in an English-speaking sample and used the PSWQ for measuring worry and a modified version of SNAQ and SPQ to assess phobia of snakes and spiders. Unfortunately, the modified 25-item version of the SPQ/SNAQ used in Hajcak et al. (2003) is unavailable[4]. Therefore, the present replication study will use the full 31-item SPQ and 30-item SNAQ and combine these scores for selecting participants for the phobia group.

For study sites recruiting non-English speaking participants, adaptations of the PSWQ, SPQ, and SNAQ in the local languages will be used. When necessary, these questionnaires will be translated by the investigating team at each non-English speaking study site following guidelines for translating and adapting tests (International Test Commission, 2018; Meyer et al., 1990). The psychometric internal consistency of all questionnaires from each study site will be separately reported at Stage 2.

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[3] The original study did not specify a cut-off or percentile for assigning participants at the top or bottom range of scores. The replication will follow these procedures and assign participants according to score rankings until the sample sizes are reached, with 20% of surveyed participants assigned to the groups, as in the original study.

[4] The authors of the original study no longer had the modified versions of the questionnaire and could not recall which items from each measure were used in their study.

Additional self-report measures will be administered following the completion of a resting state EEG recording, and these measures will take approximately 10 minutes to complete. The resting state EEG and additional measures are included as part of the resting state #EEGManyLabs Resting State project (https://osf.io/sp3ck/), and these data will be reported elsewhere.

Experimental Paradigm

After resting state EEG recording and completion of self-report measures, participants will complete a modified version of the Stroop task (Stroop, 1935), and the task will be modeled on the original study (see Figure 1 schematic)[5]. The experimental paradigm will be presented using E-Prime (Psychology Software Tools, USA), Presentation (Neurobehavioral Systems Inc., 2021), or PsychoPy (Peirce et al., 2019). Each study site will use a task adapted to the local language, and the English version is described here. On each trial, one of three color words will be shown ('red', 'green', or 'blue'), presented in either red or green font. Half of the participants will be instructed to click the left mouse button if a word is presented in red font and click the right mouse button if a word is presented in green font. The color-to-key mapping will be switched for the other half of participants. Color-to-key mapping will be counterbalanced across participants. Participants will be instructed to respond as quickly and accurately as possible.

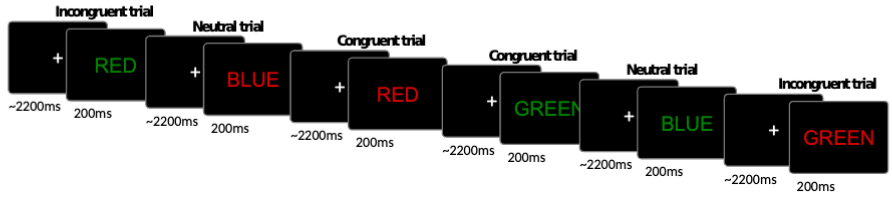

Figure 1. Stroop Task

[5] Authors of the original study provided additional details beyond what was reported in the original manuscript to inform the setup of the experimental paradigm. Those details are provided here.

The task will begin with two blocks of 24 practice trials. Trial blocks will consist of 1/3 congruent trials (e.g., the color word and font color require the same response), 1/3 incongruent trials (e.g., the color word and font color require different responses), and 1/3 neutral trials (e.g., the word 'blue' in red or green font). At a viewing distance of 50 cm, each word will occupy approximately 3° of visual angle. Following the practice task, participants will complete 24 blocks, with 48 trials per block, resulting in 1152 total trials. The order of trials will be randomly determined within each block. Word stimuli will be presented for 200 ms, on a black background, followed by a jittered inter-trial interval (ITI) that consists of a fixation cross (+) lasting between 2000 and 2400 ms. The planned duration of EEG recording is about 50 minutes.

Electrophysiological Data Recording and Reduction

EEG will be recorded using BioSemi, Magstim EGI, and ActiCHamp amplifier systems. Specific information about each system and its online recording parameters are provided in the online supplementary material. All EEG will be digitized continuously at a sampling rate of at least 500 Hz.

All EEG data will be imported into EEGLab (Delorme & Makeig, 2004) and processed using two pipelines: a pipeline that follows the original study as closely as possible (see Hajcak et al., 2003), and a recent pipeline optimized for measuring ERN (Clayson et al., 2021b). Determination of replication will focus on findings from the pipeline of the original study. The alternative pipeline will simply function as a robustness check to evaluate how dependent findings are on the approach to analyzing the data. As such, the pipeline for the original study is described here, and an alternative pipeline is described in Table 1. The final code necessary for data processing at each of the sites will be posted online at the submission of the Stage 2 report.

Table 1. Details on the replication (similar to Hajcak et al.) and alternative pipelines

Offline Processing Step	**Hajcak et al.**	**#EEGManyLabs (similar to Hajcak et al.)**	**#EEGManyLabs (alternative pipeline)**
Offline Filter[1]	Bandpass: .05 to 35 Hz [1]Note that an online filter was used	Fourth-order IIR Butterworth bandpass filter Half-amplitude cutoffs: .05 – 35 Hz	Fourth-order IIR Butterworth bandpass filter Half-amplitude cutoffs: .01 – 30 Hz
Segmentation[2]	Stimulus-locked 0 to 1500 ms	Response-locked -400 to 800 ms	Response-locked -400 to 800 ms
Ocular Artifact Correction	Regression	Regression	ICA[3]
Movement Correction[4]	-	-	Temporal PCA
Bad Channel Identification[5]	-	-	Automatic procedure
Artifact Rejection	Excessive physiological artifact (out of range A/D conversion or 'flat' analog signal > 25 ms in duration)	Excessive physiological artifact (out of range A/D conversion or 'flat' analog signal > 25 ms in duration)	Epochs with > 10% channels marked bad
Bad Channel Interpolation	-	-	Spherical Splines[6]
Epochs Rejected based on RT	RT < 200 or RT > 800	RT < 200 or RT > 800	RT < 200
Baseline adjustment[7]	-100 – 0 ms	-100 – 0 ms	-400 – -200 ms
ERN Scoring	Peak Negative Amplitude 0 – 150ms at Fz, Cz, Pz	Peak Negative Amplitude 0 – 150ms at Fz, Cz, Pz	Time-Window Mean Amplitude 0 – 100 ms at Fz, Cz, Pz

[1] The .05 to 35 Hz bandpass was used as an online filter in the Hajcak et al. (2003) study. Each study site uses online filtering specifications consistent with their own hardware. Therefore, the bandpass filter will be applied offline.

[2] The Hajcak et al. (2003) study used a Grass Model 7D polygraph and EEG recording was turned on and off around trials. The #EEGManyLabs project will continuously record EEG throughout the task and will analyze response-locked epochs.

[3] In the alternative pipeline, eye blinks and horizontal and vertical saccadic eye movement will be removed from the segmented waveforms using independent components analysis (ICA) implemented in the ERP PCA Toolkit v2.95 (Dien, 2010). Epoched EEG data from all channels will be processed through a binary version of EEGLab's *runica* function called *binica* (Delorme & Makeig, 2004). Any ICA components that correlate at .9 or above with the scalp topography of a blink template and at .8 or above with the scalp topography of vertical and horizontal saccade templates will be removed from the data. The templates that will be used for artifact correction will include those automatically generated by the ERP PCA Toolkit and those created by the present authors (Dien, 2010).

[4] In the alternative pipeline, movement artifacts will be removed using temporal principal component analysis (PCA) with a promax rotation that will identify factors accounting for amplitude differences greater than 200 μV within a trial (Dien, 2010).

[5] In the alternative pipeline, channels with an absolute correlation with the nearest six neighboring channels that fall below .4 will be marked as globally bad. On a trial wise basis, channels with a voltage difference of 100 μV through the duration of the epoch, channels that are flat, and channels with more than a 30 μV difference with the nearest six neighbors will be marked as bad for the epoch. Channels that are marked as bad for more than 20% of epochs will be considered globally bad.

[6] Bad channels will be interpolated using spherical splines (Perrin et al., 1989), but if more than 10% of channels are marked bad for an epoch, the entire epoch will be rejected.

[7] These numbers are response-locked (0ms is the onset of participant response).

Continuous EEG will be downsampled to 200 Hz and filtered offline using a fourth-order (24 dB/oct) infinite impulse response (IIR) Butterworth filter with half-amplitude cutoffs at .05 and 35 Hz implemented in ERPLab v8.02 (Lopez-Calderon & Luck, 2014). Response-locked epochs will be extracted separately for each participant using a temporal window from 400 ms prior to the participant's button press to 800 ms following a button press[6]. Eye blinks and horizontal and vertical saccadic eye movements will be removed using regression-based ocular artifact correction (Gratton et al., 1983; Miller et al., 1988). Continuous EEG will be rereferenced to an algebraic link of two near-mastoid channels (i.e., linked mastoids). Trials will be rejected when out of range of A/D conversion, if there is a 'flat' analog signal longer than 25 ms, or if the response time for the trial was below 200 ms or above 800 ms, consistent with procedures used in the to-be-replicated study. Response-locked ERPs will be baseline adjusted using a 100-ms window immediately preceding participant response (-100 to 0 ms). ERN activity will be scored as the absolute peak amplitude of the most negative-going peak occurring between 0 and 150 ms following participant response at three electrode sites: Fz, Cz, and Pz.

Data Analysis

Psychometric Internal Consistency/Data Quality. The original study did not exclude outliers based on ERP scores. Therefore, the present study will not do so either. Nonetheless, estimates of group- and subject-level psychometric internal consistency and data quality (standardized measurement error [SME]) will be reported for the sake of characterizing the collected data. Psychometric internal consistency estimates will use generalizability theory equations to coefficients of dependability (φ) (see Baldwin et al., 2015; Brennan, 2001; Clayson

[6] In the original study, EEG recordings began with the presentation of the stimulus and continued for 1500 ms. Then, EEG was time-locked to participant response. In the present replication, EEG will be recorded throughout the task, and then response-locked epochs will be examined.

et al., 2021a; Clayson et al., 2021c; Shavelson & Webb, 1991). Dependability as a function of the number of trials needed for a stable ERN score average will be separately estimated for each trial type (correct, error), electrode (Fz, Cz, and Pz), and study site using the ERP Reliability Analysis (ERA) Toolbox (Clayson et al., 2021d; Clayson & Miller, 2017).

Arithmetically derived estimates of the standard error of the mean will be used to characterize data quality of each ERP score separately for each trial type, electrode, and site (Luck et al., 2021). For the sake of comparability to the to-be-replicated study, participants will not be excluded based on the number of trials retained for averaging, estimates of internal consistency, or estimates of data quality.

Manipulation Checks. A 2-Trial Type (correct, error) x 3-Electrode Site (Fz, Cz, Pz) repeated measures analysis of variance (ANOVA) will be performed separately at each study site to verify the expected within-person ERN experimental effects (error-trial amplitude is larger [i.e., more negative] than correct-trial amplitude) and justify further statistical analysis. If the main effect of trial type or a follow-up orthogonal contrast for trial type at any electrode site is statistically significant with a pattern of effects in the expected direction, this manipulation check will be considered a sufficient, outcome-neutral test to move forward with testing the proposed hypotheses.

ERN-Anxiety within Replicating Lab Collaboratives. The primary effect of interest from the original study is that ERN amplitude differs among the three groups: worry group, phobia group, and control group. The primary effect will be analyzed using a 3-Group (worry, phobia, control) x 2-Trial Type (correct, error) x 3-Electrode Site (Fz, Cz, Pz) repeated measures analysis of variance (ANOVA) separately for pooled data from each replicating lab collaborative. Significant effects will be followed up with contrasts of estimated marginal means:

worry group vs. phobia and control groups. The original study observed a significant main effect of the group, with a larger overall ERN in the worry group than in the phobia group and control groups. Results from each replicating lab collaborative will be classified as showing a successful replication if an identical pattern of effects is observed (statistically significant main effect of the group *and* numerically larger [i.e., more negative] overall ERN in the worry group than in phobia and control groups). A p value of .02 will be used as the threshold for statistical significance consistent with the author guidelines for *Cortex*.

ERN-Anxiety across Replicating Laboratories. To pool data across all study sites across collaboratives, we will fit a 2-stage individual participant data meta-analysis (Riley et al., 2010). In this approach, the same model is fit on individual participant data within each study site, and then the full set of model parameters (including regression coefficients, variances, etc.) and their variance-covariance matrices are meta-analyzed using a random-effects meta-analysis model. Employing a random-effects meta-analysis will address and help in estimating the effect of heterogeneity in EEG devices and sample characteristics between lab collaboratives. This approach allows for all effect sizes from each site to be simultaneously meta-analyzed (along with their correlations), and it avoids issues related to Berksonian bias by controlling for within-sample differences in variables means (Riley et al., 2010). Models will be meta-analyzed using multivariate meta-analysis with the metafor package in R, using the REML estimator for random-effects variance.

Based on the meta-analysis, the weighted and unweighted median and mean effect sizes, along with forest plots for individual effect sizes and 95% confidence intervals, will be computed.

Determination of Replication

Replication success was defined in the #EEGManyLabs protocol (Pavlov et al., 2021). The present replication will be considered successful if a statistically significant meta-analytic estimate ($p < .02$) across replicating labs is observed and if the effect is in the expected direction: a larger overall ERN in the worry group than in the phobic and control group (i.e., main effect of group in the Group x Trial Type x Electrode Site ANOVA).

Power Analysis

A power analysis was conducted based on an effect size estimate of the original study. The statistics from the original study for main effect of group in the Group x Trial Type x Electrode Site ANOVA are $F(2,64) = 4.66$, $p < .05$, which resulted in an estimated partial eta squared of .127 ($r = .357$). Therefore, 234 total participants will be needed per group of replicating labs to have 90% statistical power assuming that the effect size is half of what was observed in the original study (one-sided test). At the time of the Stage 1 submission, three replicating lab collaboratives comprising a total of nine study sites had signed up to participate, and we expect a total sample size of 702 participants across all replication groups.

Timeline and Reproducibility

We expect to submit the Stage 2 report with accompanying open materials within 2.5 years of the Stage 1 manuscript receiving an in-principle acceptance. Consistent with the #EEGManyLabs protocol, we will ensure reproducibility of findings by sharing de-identified data (including raw EEG data), data processing code, code for statistical analysis, and all study materials (e.g., study protocol, paradigms). If there are deviations from the Stage 1 report, they will be documented in the Stage 2 report.

References

American Psychiatric Association. (2000). *Diagnostic and Statistical Manual of Mental Disorders* (4th ed., text rev.).

Baldwin, S. A. (2017). Improving the rigor of psychophysiology research. *International Journal of Psychophysiology*, *111*, 5–16. https://doi.org/10.1016/j.ijpsycho.2016.04.006

Baldwin, S. A., Larson, M. J., & Clayson, P. E. (2015). The dependability of electrophysiological measurements of performance monitoring in a clinical sample: A generalizability and decision analysis of the ERN and Pe. *Psychophysiology, 52*(6), 790-800. https://doi.org/https://doi.org/10.1111/psyp.12401

Bartholow, B. D., Pearson, M. A., Dickter, C. L., Sher, K. J., Fabiani, M., & Gratton, G. (2005). Strategic control and medial frontal negativity: Beyond errors and response conflict. *Psychophysiology*, *42*(1), 33–42. https://doi.org/10.1111/j.1469-8986.2005.00258.x

Bernstein, P. S., Scheffers, M. K., & Coles, M. G. H. (1995). "Where did I go wrong?" A psychophysiological analysis of error detection. *Journal of Experimental Psychology: Human Perception and Performance*, *21*(6), 1312–1322. https://doi.org/10.1037/0096-1523.21.6.1312

Boshuisen, M. L., Ter Horst, G. J., Paans, A. M. J., Reinders, A. A. T. S., & den Boer, J. A. (2002). RCBF differences between panic disorder patients and control subjects during anticipatory anxiety and rest. *Biological Psychiatry*, *52*(2), 126–135. https://doi.org/10.1016/S0006-3223(02)01355-0

Botvinick, M., Nystrom, L. E., Fissell, K., Carter, C. S., & Cohen, J. D. (1999). Conflict monitoring versus selection-for-action in anterior cingulate cortex. *Nature*, *402*(6758), 179–181. https://doi.org/10.1038/46035

Breiter, H. C., Rauch, S. L., Kwong, K. K., Baker, J. R., Weisskoff, R. M., Kennedy, D. N., Kendrick, A. D., Davis, T. L., Jiang, A., Cohen, M. S., Stern, C. E., Belliveau, J. W., Baer, L., O'Sullivan, R. L., Savage, C. R., Jenike, M. A., & Rosen, B. R. (1996). Functional magnetic resonance imaging of symptom provocation in obsessive-compulsive disorder. *Archives of General Psychiatry*, *53*(7), 596–606.

Brennan, R. L. (2001). *Generalizability theory: Statistics for social science and public policy*. Springer-Verlag.

Brown, T. A., Chorpita, B. F., & Barlow, D. H. (1998). Structural relationships among dimensions of the DSM-IV anxiety and mood disorders and dimensions of negative affect, positive affect, and autonomic arousal. *Journal of Abnormal Psychology*, *107*(2), 179–192. https://doi.org/10.1037/0021-843X.107.2.179

Clayson, P. E., Baldwin, S. A., & Larson, M. J. (2021a). Evaluating the internal consistency of subtraction-based and residualized difference scores: Considerations for psychometric reliability analyses of event-related potentials. *Psychophysiology*, *58*(4), e13762. https://doi.org/https://doi.org/10.1111/psyp.13762

Clayson, P. E., Baldwin, S. A., Rocha, H. A., & Larson, M. J. (2021b). The data-processing multiverse of event-related potentials (ERPs): A roadmap for the optimization and standardization of ERP processing and reduction pipelines. *NeuroImage*, *245*, 118712. https://doi.org/10.1016/j.neuroimage.2021.118712

Clayson, P. E., Brush, C. J., & Hajcak, G. (2021c). Data quality and reliability metrics for event-related potentials (ERPs): The utility of subject-level reliability. *International Journal of Psychophysiology*, *165*, 121-136. https://doi.org/10.1016/j.ijpsycho.2021.04.004

Clayson, P. E., Carbine, K. A., Baldwin, S. A., & Larson, M. J. (2019). Methodological reporting behavior, sample sizes, and statistical power in studies of event-related potentials: Barriers to reproducibility and replicability. *Psychophysiology*, *56*(11), e13437. https://doi.org/10.1111/psyp.13437

Clayson, P. E., Carbine, K. A., Baldwin, S. A., Olsen, J. A., & Larson, M. J. (2021d). Using generalizability theory and the ERP Reliability Analysis (ERA) Toolbox for assessing test-retest reliability of ERP scores Part 1: Algorithms, framework, and implementation. *International Journal of Psychophysiology*, *166*, 174-187. https://doi.org/10.1016/j.ijpsycho.2021.01.006

Clayson, P. E., & Miller, G. A. (2017). ERP Reliability Analysis (ERA) Toolbox: An open-source toolbox for analyzing the reliability of event-related potentials. *International Journal of Psychophysiology*, *111*, 68-79. https://doi.org/https://doi.org/10.1016/j.ijpsycho.2016.10.012

Compton, R. J., Carp, J., Chaddock, L., Fineman, S. L., Quandt, L. C., & Ratliff, J. B. (2007). Anxiety and error monitoring: Increased error sensitivity or altered expectations? *Brain and Cognition*, *64*(3), 247–256. https://doi.org/10.1016/j.bandc.2007.03.006

Davis, M., Hitchcock, J. M., & Rosen, J. B. (1988). Anxiety and the amygdala: Pharmacological and anatomical analysis of the fear-potentiated startle paradigm. In *Psychology of Learning and Motivation* (Vol. 21, pp. 263–305). Elsevier. https://doi.org/10.1016/S0079-7421(08)60031-6

Debener, S., Ullsperger, M., Siegel, M., Fiehler, K., Von Cramon, D. Y., & Engel, A. K. (2005). Trial-by-trial coupling of concurrent electroencephalogram and functional magnetic

resonance imaging identifies the dynamics of performance monitoring. *Journal of Neuroscience*, *25*(50), 11730-11737. https://doi.org/10.1523/JNEUROSCI.3286-05.2005

De Bruijn, E. R., Hulstijn, W., Verkes, R. J., Ruigt, G. S., & Sabbe, B. G. (2004). Drug-induced stimulation and suppression of action monitoring in healthy volunteers. *Psychopharmacology, 177*, 151-160. https://doi.org/10.1007/s00213-004-1915-6

Dehaene, S., Posner, M. I., & Tucker, D. M. (1994). Localization of a neural system for error detection and compensation. *Psychological Science, 5*(5), 303-305. https://doi.org/10.1111/j.1467-9280.1994.tb00630.x

Delorme, A., & Makeig, S. (2004). EEGLAB: An open source toolbox for analysis of single-trial EEG dynamics including independent component analysis. *Journal of Neuroscience Methods*, *134*(1), 9–21. https://doi.org/10.1016/j.jneumeth.2003.10.009

Dien, J. (2010). The ERP PCA Toolkit: An open source program for advanced statistical analysis of event-related potential data. *Journal of Neuroscience Methods, 187*, 138-145.

Eaton, N. R., Krueger, R. F., Markon, K. E., Keyes, K. M., Skodol, A. E., Wall, M., Hasin, D. S., & Grant, B. F. (2013). The structure and predictive validity of the internalizing disorders. *Journal of Abnormal Psychology*, *122*(1), 86–92. https://doi.org/10.1037/a0029598

Eysenck, M. W., Derakshan, N., Santos, R., & Calvo, M. G. (2007). Anxiety and cognitive performance: Attentional control theory. *Emotion, 7*(2), 336–353. https://doi.org/10.1037/1528-3542.7.2.336

Falkenstein, M., Hohnsbein, J., Hoormann, J., & Blanke, L. (1991). Effects of crossmodal divided attention on late ERP components. II. Error processing in choice reaction tasks. *Electroencephalography and Clinical Neurophysiology*, *78*(6), 447–455. https://doi.org/10.1016/0013-4694(91)90062-9

Falkenstein, M., Hoormann, J., Christ, S., & Hohnsbein, J. (2000). ERP components on reaction errors and their functional significance: A tutorial. *Biological Psychology*, *51*(2), 87–107. https://doi.org/10.1016/S0301-0511(99)00031-9

Garrett-Ruffin, S., Hindash, A. C., Kaczkurkin, A. N., Mears, R. P., Morales, S., Paul, K., Pavlov, Y. G., & Keil, A. (2021). Open science in psychophysiology: An overview of challenges and emerging solutions. *International Journal of Psychophysiology*, *162*, 69–78. https://doi.org/10.1016/j.ijpsycho.2021.02.005

Gehring, W. J., Goss, B., Coles, M. G. H., Meyer, D. E., & Donchin, E. (1993). A neural system for error detection and compensation. *Psychological Science*, *4*(6), 385–390. https://doi.org/10.1111/j.1467-9280.1993.tb00586.x

Gehring, W. J., Himle, J., & Nisenson, L. G. (2000). Action-monitoring dysfunction in obsessive-compulsive disorder. *Psychological Science*, *11*(1), 1–6. https://doi.org/10.1111/1467-9280.00206

Gorka, S. M., Burkhouse, K. L., Afshar, K., & Phan, K. L. (2017). Error-related brain activity and internalizing disorder symptom dimensions in depression and anxiety. *Depression and Anxiety*, *34*(11), 985–995. https://doi.org/10.1002/da.22648

Gratton, G., Coles, M. G. H., & Donchin, E. (1983). A new method for off-line removal of ocular artifact. *Electroencephalography and Clinical Neurophysiology*, *55*(4), 468–484. https://doi.org/10.1016/0013-4694(83)90135-9

Grillon, C. (2002). Startle reactivity and anxiety disorders: Aversive conditioning, context, and neurobiology. *Biological Psychiatry*, *52*(10), 958–975. https://doi.org/10.1016/S0006-3223(02)01665-7

Hajcak, G., Klawohn, J., & Meyer, A. (2019). The utility of event-related potentials in clinical psychology. *Annual Review of Clinical Psychology*, *15*(1), 71–95. https://doi.org/10.1146/annurev-clinpsy-050718-095457

Hajcak, G., McDonald, N., & Simons, R. F. (2003). Anxiety and error-related brain activity. *Biological Psychology*, *64*(1–2), 77–90. https://doi.org/10.1016/S0301-0511(03)00103-0

Härpfer, K., Carsten, H. P., Spychalski, D., Kathmann, N., & Riesel, A. (2020). Were we erring? The impact of worry and arousal on error-related negativity in a non-clinical sample. *Psychophysiology*, *57*(11), 1–17. https://doi.org/10.1111/psyp.13661

Heller, W., Nitschke, J. B., Etienne, M. A., & Miller, G. A. (1997). Patterns of regional brain activity differentiate types of anxiety. *Journal of Abnormal Psychology*, *106*(3), 376–385. https://doi.org/10.1037/0021-843X.106.3.376

Holroyd, C. B., & Coles, M. G. H. (2002). The neural basis of human error processing: Reinforcement learning, dopamine, and the error-related negativity. *Psychological Review*, *109*(4), 679–709. https://doi.org/10.1037/0033-295X.109.4.679

Holroyd, C. B., Dien, J., & Coles, M. G. H. (1998). Error-related scalp potentials elicited by hand and foot movements: Evidence for an output-independent error-processing system in humans. *Neuroscience Letters*, *242*(2), 65–68. https://doi.org/10.1016/S0304-3940(98)00035-4

International Test Commission. (2018). ITC Guidelines for Translating and Adapting Tests (Second Edition). *International Journal of Testing*, 101–134. https://doi.org/10.1080/15305058.2017.1398166

Ito, S., Stuphorn, V., Brown, J. W., & Schall, J. D. (2003). Performance monitoring by the anterior cingulate cortex during saccade countermanding. *Science*, *302*(5642), 120-122. https://doi.org/10.1126/science.1087847

Judd, L. L., Kessler, R. C., PauIus, M. P., Zeller, P. V., Wittchen, H.-U., & Kunovac, J. L. (1998). Comorbidity as a fundamental feature of generalized anxiety disorders: Results from the National Comorbidity Study (NCS). *Acta Psychiatrica Scandinavica*, *98*(s393), 6–11. https://doi.org/10.1111/j.1600-0447.1998.tb05960.x

Klorman, R., Weerts, T. C., Hastings, J. E., Melamed, B. G., & Lang, P. J. (1974). Psychometric description of some specific-fear questionnaires. *Behavior Therapy*, *5*(3), 401–409. https://doi.org/10.1016/S0005-7894(74)80008-0

Kotov, R., Krueger, R. F., Watson, D., Achenbach, T. M., Althoff, R. R., Bagby, R. M., Brown, T. A., Carpenter, W. T., Caspi, A., Clark, L. A., Eaton, N. R., Forbes, M. K., Forbush, K. T., Goldberg, D., Hasin, D., Hyman, S. E., Ivanova, M. Y., Lynam, D. R., Markon, K., … Zimmerman, M. (2017). The Hierarchical Taxonomy of Psychopathology (HiTOP): A dimensional alternative to traditional nosologies. *Journal of Abnormal Psychology*, *126*(4), 454–477. https://doi.org/10.1037/abn0000258

Kujawa, A., Weinberg, A., Bunford, N., Fitzgerald, K. D., Hanna, G. L., Monk, C. S., ... & Phan, K. L. (2016). Error-related brain activity in youth and young adults before and after treatment for generalized or social anxiety disorder. *Progress in Neuro-Psychopharmacology and Biological Psychiatry*, *71*, 162-168. https://doi.org/10.1016/j.pnpbp.2016.07.010

LeDoux, J. E., & Pine, D. S. (2016). Using neuroscience to help understand fear and anxiety: A two-system framework. *American Journal of Psychiatry*, *173*(11), 1083–1093. https://doi.org/10.1176/appi.ajp.2016.16030353

Lopez-Calderon, J., & Luck, S. J. (2014). ERPLAB: An open-source toolbox for the analysis of event-related potentials. *Frontiers in Human Neuroscience*, *8*(e3004), 213. https://doi.org/10.3389/fnhum.2014.00213

Luck, S. J., & Gaspelin, N. (2017). How to get statistically significant effects in any ERP experiment (and why you shouldn't). *Psychophysiology*, *54*(1), 146–157. https://doi.org/10.1111/psyp.12639

Luck, S. J., Stewart, A. X., Simmons, A. M., & Rhemtulla, M. (2021). Standardized measurement error: A universal metric of data quality for averaged event-related potentials. *Psychophysiology*, *58*(6), e13793. https://doi.org/https://doi.org/10.1111/psyp.13793

Luu, P., Flaisch, T., & Tucker, D. M. (2000). Medial frontal cortex in action monitoring. *The Journal of Neuroscience*, *20*(1), 464–469. https://doi.org/10.1523/JNEUROSCI.20-01-00464.2000

MacDonald, A. W., Cohen, J. D., Stenger, V. A., & Carter, C. S. (2000). Dissociating the role of the dorsolateral prefrontal and anterior cingulate cortex in cognitive control. *Science*, *288*(5472), 1835-1838. https://doi.org/10.1126/science.288.5472.1835

Meyer, A., Hajcak, G., Torpey, D. C., Kujawa, A., Kim, J., Bufferd, S., Carlson, G., & Klein, D. N. (2013). Increased error-related brain activity in six-year-old children with clinical anxiety. *Journal of Abnormal Child Psychology*, *41*(8), 1257–1266. https://doi.org/10.1007/s10802-013-9762-8

Meyer, T. J., Miller, M. L., Metzger, R. L., & Borkovec, T. D. (1990). Development and validation of the Penn State Worry Questionnaire. *Behaviour Research and Therapy*, *28*(6), 487–495. https://doi.org/10.1016/0005-7967(90)90135-6

Miller, G. A., Gration, G., & Yee, C. M. (1988). Generalized implementation of an eye movement correction procedure. *Psychophysiology*, *25*(2), 241–243. https://doi.org/10.1111/j.1469-8986.1988.tb00999.x

Moran, T. P., Taylor, D., & Moser, J. S. (2012). Sex moderates the relationship between worry and performance monitoring brain activity in undergraduates. *International Journal of Psychophysiology*, *85*(2), 188–194. https://doi.org/10.1016/j.ijpsycho.2012.05.005

Moser, J. S., Moran, T. P., & Jendrusina, A. A. (2012). Parsing relationships between dimensions of anxiety and action monitoring brain potentials in female undergraduates. *Psychophysiology*, *49*(1), 3–10. https://doi.org/10.1111/j.1469-8986.2011.01279.x

Moser, J. S., Moran, T. P., Schroder, H. S., Donnellan, M. B., & Yeung, N. (2013). On the relationship between anxiety and error monitoring: A meta-analysis and conceptual framework. *Frontiers in Human Neuroscience*, *7*, 466. https://doi.org/10.3389/fnhum.2013.00466

Moser, J. S., Schroder, H. S., Heeter, C., Moran, T. P., & Lee, Y.-H. (2011). Mind your errors: Evidence for a neural mechanism linking growth mind-set to adaptive posterior adjustments. *Psychological Science*, *22*(12), 1484–1489. https://doi.org/10.1177/0956797611419520

Nee, D. E., Kastner, S., & Brown, J. W. (2011). Functional heterogeneity of conflict, error, task-switching, and unexpectedness effects within medial prefrontal cortex. *NeuroImage, 54*(1), 528-540. https://doi.org/10.1016/j.neuroimage.2010.08.027

Newman, M. G., Llera, S. J., Erickson, T. M., Przeworski, A., & Castonguay, L. G. (2013). Worry and generalized anxiety disorder: A review and theoretical synthesis of evidence on nature, etiology, mechanisms, and treatment. *Annual Review of Clinical Psychology*, *9*(1), 275–297. https://doi.org/10.1146/annurev-clinpsy-050212-185544

Öhman, A. (1993). Fear and anxiety as emotional phenomena: Clinical phenomenology, evolutionary perspectives, and information-processing mechanisms. In M. Lewis & J. M. Haviland (Eds.), *Handbook of Emotions* (pp. 511–536). The Guilford Press.

Pailing, P. E., & Segalowitz, S. J. (2004). The effects of uncertainty in error monitoring on associated ERPs. *Brain and Cognition*, *56*(2), 215–233. https://doi.org/10.1016/j.bandc.2004.06.005

Pasion, R., & Barbosa, F. (2019). ERN as a transdiagnostic marker of the internalizing-externalizing spectrum: A dissociable meta-analytic effect. *Neuroscience & Biobehavioral Reviews*, *103*, 133–149. https://doi.org/10.1016/j.neubiorev.2019.06.013

Paul, M., Govaart, G. H., & Schettino, A. (2021). Making ERP research more transparent: Guidelines for preregistration. *International Journal of Psychophysiology*, *164*, 52–63. https://doi.org/10.1016/j.ijpsycho.2021.02.016

Pavlov, Y. G., Adamian, N., Appelhoff, S., Arvaneh, M., Benwell, S. Y., Beste, C., Bland, A. R., Bradford, D. E., Busch, N. A., Clayson, P. E., Cruse, D., Dreber, A., Dumas, G., Ehinger, B., He, X., Hinojosa, J. A., Huber-Huber, C., Jack, B. N., Johannesson, M., … Mushtaq, F. (2021). #EEGManyLabs: Investigating the replicability of influential EEG experiments. *Cortex*, *144*, 213–229. https://doi.org/10.1016/j.cortex.2021.03.013

Peirce, J., Gray, J. R., Simpson, S., MacAskill, M., Höchenberger, R., Sogo, H., Kastman, E., & Lindeløv, J. K. (2019). PsychoPy2: Experiments in behavior made easy. *Behavior Research Methods*, *51*(1), 195–203. https://doi.org/10.3758/s13428-018-01193-y

Perrin, F., Pernier, J., Bertrand, O., & Echallier, J. F. (1989). Spherical splines for scalp potential and current density mapping. *Electroencephalography and Clinical Neurophysiology*, *72*(2), 184-187. https://doi.org/10.1016/0013-4694(89)90180-6

Rauch, S. L., van der Kolk, B. A., Fisler, R. E., Alpert, N. M., Orr, S. P., Savage, C. R., Fischman, A. J., Jenike, M. A., & Pitman, R. K. (1996). A symptom provocation study of posttraumatic stress disorder using positron emission tomography and script-driven imagery. *Archives of General Psychiatry*, *53*(5), 380–387. https://doi.org/10.1001/archpsyc.1996.01830050014003.

Riley, R. D., Lambert, P. C., & Abo-Zaid, G. (2010). Meta-analysis of individual participant data: Rationale, conduct, and reporting. *BMJ*, *340*, c221. https://doi.org/10.1136/bmj.c221

Saunders, B., & Inzlicht, M. (2020). Assessing and adjusting for publication bias in the relationship between anxiety and the error-related negativity. *International Journal of Psychophysiology*, *155*, 87–98. https://doi.org/10.1016/j.ijpsycho.2020.05.008

Scheffers, M. K., & Coles, M. G. H. (2000). Performance monitoring in a confusing world: Error-related brain activity, judgments of response accuracy, and types of errors. *Journal of Experimental Psychology: Human Perception and Performance*, *26*(1), 141–151. https://doi.org/10.1037/0096-1523.26.1.141

Schultz, W. (2002). Getting formal with dopamine and reward. *Neuron, 36*(2), 241-263. https://doi.org/10.1016/S0896-6273(02)00967-4

Shavelson, R. J., & Webb, N. M. (1991). *Generalizability theory: A primer*. SAGE Publications Inc.

Stroop, J. R. (1935). Studies of interference in serial verbal reactions. *Journal of Experimental Psychology*, *18*(6), 643–662. https://doi.org/10.1037/h0054651

Ullsperger, M., & Von Cramon, D. Y. (2001). Subprocesses of performance monitoring: a dissociation of error processing and response competition revealed by event-related fMRI and ERPs. *NeuroImage*, *14*(6), 1387-1401. https://doi.org/10.1006/nimg.2001.0935

Van't Ent, D., & Apkarian, P. (1999). Motoric response inhibition in finger movement and saccadic eye movement: A comparative study. *Clinical Neurophysiology*, *110*(6), 1058–1072. https://doi.org/10.1016/S1388-2457(98)00036-4

Vidal, F., Burle, B., Bonnet, M., Grapperon, J., & Hasbroucq, T. (2003). Error negativity on correct trials: A reexamination of available data. *Biological Psychology*, *64*(3), 265–282. https://doi.org/10.1016/S0301-0511(03)00097-8

Vidal, F., Hasbroucq, T., Grapperon, J., & Bonnet, M. (2000). Is the 'error negativity' specific to errors? *Biological Psychology*, *51*(2–3), 109–128. https://doi.org/10.1016/S0301-0511(99)00032-0

Weinberg, A., Kotov, R., & Proudfit, G. H. (2015). Neural indicators of error processing in generalized anxiety disorder, obsessive-compulsive disorder, and major depressive disorder. *Journal of Abnormal Psychology*, *124*(1), 172–185. https://doi.org/10.1037/abn0000019

Weinberg, A., Meyer, A., Hale-Rude, E., Perlman, G., Kotov, R., Klein, D. N., & Hajcak, G. (2016). Error-related negativity (ERN) and sustained threat: Conceptual framework and

empirical evaluation in an adolescent sample: ERN and sustained threat. *Psychophysiology*, *53*(3), 372–385. https://doi.org/10.1111/psyp.12538

Weinberg, A., Riesel, A., & Hajcak, G. (2012). Integrating multiple perspectives on error-related brain activity: The ERN as a neural indicator of trait defensive reactivity. *Motivation and Emotion*, *36*(1), 84–100. https://doi.org/10.1007/s11031-011-9269-y

Xiao, Z., Wang, J., Zhang, M., Li, H., Tang, Y., Wang, Y., Fan, Q., & Fromson, J. A. (2011). Error-related negativity abnormalities in generalized anxiety disorder and obsessive–compulsive disorder. *Progress in Neuro-Psychopharmacology and Biological Psychiatry*, *35*(1), 265–272. https://doi.org/10.1016/j.pnpbp.2010.11.022

Zambrano-Vazquez, L., & Allen, J. J. B. (2014). Differential contributions of worry, anxiety, and obsessive compulsive symptoms to ERN amplitudes in response monitoring and reinforcement learning tasks. *Neuropsychologia*, *61*, 197–209. https://doi.org/10.1016/j.neuropsychologia.2014.06.023