NORTHWESTERN UNIVERSITY

Symptom Dimensions of Executive Control, Threat-, and Reward-Related Neural Activity

A DISSERTATION

SUBMITTED TO THE GRADUATE SCHOOL

IN PARTIAL FULFILLMENT OF THE REQUIREMENTS

for the degree

DOCTOR OF PHILOSOHPY

Psychology

By

James Glazer

EVANSTON ILLINOIS

June 2022

Abstract

Anxiety and depression are highly prevalent, recurrent, and major public health problems. Decades of research has uncovered associations between symptom dimensions of anxiety and depression and abnormal neural activation across executive control-, threat-, and reward-related networks. Recent studies have developed a hierarchical symptom structure of anxiety and depression termed the trilevel model that reconceptualizes anxious and depressive disorders as sets of empirically derived phenotypic symptom clusters. This model includes a broad factor (General Distress) comprised of symptoms shared between anxiety and depression disorders and two intermediate factors (Fear and Anhedonia) comprised of anxious and depressive symptom subsets (Prenoveau et al., 2010). However, the neural correlates of trilevel symptom dimensions remain poorly understood. The objective of the current study is to examine associations between shared (i.e., General Distress) and distinct (i.e., Fear and Anhedonia) symptom dimensions of anxiety and depression and abnormal event-related potentials (ERPs) across executive control, threat, and reward processing domains. 61 participants completed trilevel symptom questionnaires and an executive control, threat reactivity, and reward processing task while electroencephalogram (EEG) activity was recorded. First, all three symptom dimensions were hypothesized to be associated with abnormal electrocortical activity during a stop-signal executive control task. Second, Fear and Anhedonia were hypothesized to be associated with abnormal threat-related electrocortical activity during an emotional reactivity task. Third, only Anhedonia was predicted to be associated with abnormal reward-related electrocortical activity during a monetary incentive delay task. Results from the executive control task revealed that General Distress was uniquely associated with increased error-detection (i.e., Error-Related Negativity: ERN) and Fear was uniquely associated with increased error awareness (i.e., Error-Positivity: Pe). By contrast, Anhedonia was unassociated with ERP amplitudes during executive control. However, contrary to predictions, none of the trilevel symptom factors were associated with threat-related electrocortical activity during the emotional reactivity task. Finally, results revealed General Distress was associated with broadly decreased reward-related neural activity across three ERP components elicited by reward cues (i.e., Cue-N2, Cue-P3, and Cue-Late Positive Potential: Cue-LPP) and attenuated affective processing of reward feedback (i.e., Feedback-LPP: FB-LPP) while Anhedonia and Fear were unassociated with reward-related ERPs. These results

reveal specific neural profiles uniquely associated with shared and distinct symptom dimensions of anxiety and depression. Results have important implications for the detection of risk, diagnosis, and treatment of anxiety and depression disorders.

Contents

List of Tables, Illustrations, Figures, and Graphs

Table 9. Behavioral Means and SDs. 103

Introduction

Anxiety and depression are two of the most common mental illnesses in the world. According to the World Health Organization in 2019, anxiety affects approximately 1 in 13 adult individuals while depression is the leading cause of disability worldwide. Decades of research has identified neurobiological correlates of anxiety and depression that has facilitated effective treatment approaches. For example, anxiety is linked to hyperactivation in threat-related neural systems (Craske & Vervliet, 2013), supporting exposure therapy techniques that utilize behavioral conditioning to decrease psychophysiological responses of fear. In contrast, depression is associated with hypoactivation in reward-related neural circuitry (see Treadway & Zald, 2011 for review), supporting therapeutic approaches such as behavioral activation that directly target deficiencies of motivation and pleasure.

However, due to vast inconsistencies in pathophysiological research, no reliable biomedical test exists to evaluate risk, diagnosis, or treatment for anxiety and depression disorders. This is likely driven in part by two major limitations associated with current diagnostic approaches that rely on the Diagnostic and Statistical Manual of Mental Disorders (DSM; American Psychiatric Association, 2013) that classifies disorders individually, atheoretically, and descriptively. First, anxiety and depression are highly comorbid and contain several overlapping symptoms, such as negative affect representing low mood, suggesting some shared degree of neural dysfunction may underpin similar symptom presentations. In support, both disorders are associated with abnormal neural processing during executive control. Second, anxiety and depression are heterogenous disorders comprised of distinct symptom subsets, suggesting separate neurophysiological processes may also underpin their unique symptom dimensions. Together, these two limitations lead to inconsistent pathophysiological research that is unable to separate neural correlates unique to anxiety and depression from transdiagnostic neurophysiological dysfunction associated with comorbidity.

While most prior pathophysiological research relies on DSM classification methods, recent studies have reconceptualized anxiety and depression as clusters of phenotypic symptom presentations rather than through arbitrary diagnostic cutoffs (Prenoveau et al., 2010; Naragon-Gainey et al., 2016). Drawing heavily from previous research (Mineka et al., 1998; Zinbarg & Barlow, 1996), these studies have developed a hierarchical symptom structure of anxiety and depression, termed the trilevel model

(Prenoveau et al., 2010; Naragon-Gainey et al., 2016). The trilevel model includes a general factor reflecting shared symptoms, termed General Distress, and two specific intermediate factors reflecting distinct symptom dimensions of anxiety and depression, termed Fear and Anhedonia. Trilevel model approaches to pathophysiological research may reveal more accurate and precise neurophysiological correlates associated with shared and distinct symptom profiles of anxiety and depression.

However, no extant research has investigated electrophysiological correlates of the trilevel model to date. To fill this gap, the current study used electroencephalography (EEG) to examine associations between shared (i.e., General Distress) and unique (i.e., Fear and Anhedonia) trilevel symptom dimensions of anxiety and depression and abnormal executive control-, threat-, and reward-related neural activity. To accomplish this, the current study was embedded within a parent R01 that utilized functional resonance magnetic imaging (fMRI) to investigate the neuroanatomical correlates of the trilevel model. In the parent R01, 140 participants aged 18-19 were recruited and trilevel symptoms were assessed at baseline, 12 months, 24 months, and 36 months. Neuroimaging data and multimodal indices of threat and reward processing (e.g., self-report, behavioral, and physiological) were collected at baseline and 36 months (see Table 1).

Although neuroimaging methods are spatially precise, they are balanced by poor temporal resolution and therefore cannot decompose the dynamic time course of neural dysfunction. The current study leveraged the strong temporal resolution of event-related potentials (ERPs) to examine associations between trilevel symptom dimensions and neural activity with millisecond-level precision, complementing the strong spatial resolution of neuroimaging methods used in the parent R01. Participants enrolled in the parent R01 were recontacted and recruited to complete a single in-person assessment where EEG and trilevel symptom data were collected.

The objective of the current study is to identify the neural correlates of shared and distinct symptom dimensions of anxiety and depression across executive control, threat, and reward processing domains. Uncovering specific neurophysiological correlates associated with shared and distinct symptom profiles of anxiety and depression has several significant applications to clinical science. First, naturally occurring trilevel symptom clusters likely exhibit more reliable associations with underlying neural dysfunction, potentially resolving inconsistencies in pathophysiological research driven by current DSM

classification methods. Second, results can help develop novel clinical treatment approaches that directly target neural systems underlying specific symptom presentations. Third, results can help potentially identify individuals at risk for anxiety disorders, depression disorders, or both from their underlying neurophysiological profile and facilitate early interventions. Finally, results will have implications for future research seeking to evaluate the utility of neural activity as a prospective predictor of anxiety and depression.

The structure of the introduction is as follows. First, I will introduce the trilevel model of anxiety and depression and detail its historical development. Second, I will review contemporary research supporting the three main hypotheses of the current study: 1) Shared and distinct trilevel factors of anxiety and depression will be associated with abnormal neural profiles of executive control, 2) General Distress and Fear will be uniquely associated with increased threat-related neural activity, and 3) only Anhedonia will be associated with reduced reward-related neural activity. Primary analyses will focus on directly testing each of these three predictions. If hypotheses are confirmed, follow-up analyses will test whether associations remain significant while controlling for the opposing trilevel symptom factors. If hypotheses are not confirmed, exploratory analyses will probe associations between ERP components and each remaining trilevel symptom factor.

Trilevel Model

Unlike many physical disorders, anxiety and depression lack any reliable biological assessment tools or medical tests to determine clinical diagnosis or to evaluate prospective risk. This may be due in part to inconsistencies in pathophysiological research driven by symptom heterogeneity associated with current diagnostic classification methods. Although the DSM has long been the widely accepted “gold standard” for psychopathological diagnosis, disorders are classified atheoretically and descriptively (Watson, 2005). Two major problems emerge from this diagnostic approach. First, high rates of comorbidity between anxiety and depression suggest some degree of overlapping symptom dimensions and likely reflect shared etiological processes and characteristics (Krueger, 1999). In support, phenotypic and genetic studies (Kendler et al., 2003) find strong associations between anxiety and depression at the symptom (Clark & Watson, 1991) and diagnostic level (Kessler et al., 2005). Ignoring substantial

symptom overlap between anxiety and depression inconsistencies in the research by misidentifying shared psychophysiological processes that may rather be transdiagnostic.

Secondly, different individuals diagnosed with the same disorder may display very different phenotypic symptom presentations and etiologies (Watson, 2005), suggesting a high degree of within-diagnosis heterogeneity. In support, an abundance of research indicates anxious and depressive disorders are comprised of several diverse symptom clusters associated with their own set of underlying psychophysiological processes (Brown et al., 1998; Treadway & Zald, 2012). Therefore, in addition to substantial symptom overlap, these results indicate anxiety and depression also contain their own set of unique symptom dimensions. Isolating specific neurophysiological correlates associated with discrete symptom clusters is necessary to account for both overlap between anxious and depressive disorders as well as high degrees of within-diagnosis symptom heterogeneity.

As an alternative, related research has reconceptualized anxiety and depression as clusters of phenotypic symptom dimensions rather than through arbitrary diagnostic cutoffs. These phenotypic structural models deconstruct diagnostic categories into distinct symptom clusters that represent shared or unique features of anxious and depressive disorders. Clark and Watson's (1991) influential tripartite model identified three structural factors corresponding to shared and unique features of anxiety and depression. These factors reflect psychometrically distinct symptom dimensions of negative affect, positive affect, and physiological hyperarousal. While both disorders share symptoms of negative affect (e.g., negative mood, elevated neuroticism, etc.), symptoms of physiological hyperarousal are unique to anxiety disorders (e.g., elevated heart rate, shortness of breath, somatic tension, etc.) whereas symptoms of decreased positive affect reflecting anhedonia are specific to depressive disorders (e.g., loss of pleasure, decreased positive mood, etc.). However, anxiety disorders include diverse symptom clusters (Brown et al., 1998) and are differentially associated with depression and to one another (Kessler et al., 2005), suggesting a single factor may not sufficiently capture the diverse symptom heterogeneity between different anxiety disorders (Zinbarg & Barlow, 1996).

To address this limitation, Mineka and colleagues (Mineka et al., 1998) proposed an integrative hierarchical model that includes symptom-specific narrow factors in addition to a single general factor. Each disorder is characterized by a unique combination of general and specific features that can be

differentiated from one another based on the relative strength of their associations. While this model accounts for within-disorder heterogeneity by including narrow symptom dimensions, parallel research focusing on comorbidity between anxiety and depression suggests a single general factor may be insufficient to represent shared symptom clusters. Focusing on diagnostic comorbidity, Krueger (1999) developed an alternative approach based on phenotypic and genetic structural models under the assumption that comorbid diagnoses likely reflect shared etiological processes. Two factors emerged: “fear” disorders encompassing several anxiety disorders (panic disorder, social anxiety disorder, agoraphobia, and specific phobia) and “anxious-misery” disorders composed of both depression (major depression and dysthymia) and anxiety disorders (generalized anxiety disorder and post-traumatic stress disorder). These results suggest intermediate structural factors may be necessary to fully account for the diversity of symptom clusters present in comorbid presentations.

To unify the integrative hierarchical model developed by Mineka and colleagues (Mineka et al., 1998) with intermediate factors described by Krueger (1999), Prenoveau and colleagues (2010) proposed the trilevel model that includes general, intermediate, and specific symptom clusters. This model accounts for shared and distinct symptom profiles of anxiety and depression and has been validated in three independent samples, including a sizable patient sample (Naragon-Gainey et al., 2016). A broad factor called General Distress represents symptoms shared by anxiety and depression. Consistent with prior models, negative affect loads most strongly onto General Distress. In addition to negative affect, a psychometrically distinct symptom dimension called worry representing increased verbal rumination and worrying thoughts also loaded strongly onto General Distress. Although worry is traditionally associated with anxiety disorders and often referred to as anxious apprehension (Nitschke et al., 2001), these results suggest both negative affect and worry are shared symptom dimensions of anxiety and depressive disorders.

Similar to Krueger (1999), two intermediate trilevel factors termed ‘Fear’ and ‘Anhedonia’ are composed of anxious and depressive symptom subsets. Fear represents symptom dimensions unique to anxiety disorders and is loaded on most strongly by interoceptive-agoraphobic fears, social fears, and fears of specific stimuli. In contrast, Anhedonia represents psychometric dimensions unique to depressive disorders and is loaded on most strongly by items representing decreased motivation and positive affect.

Together, these three trilevel dimensions account for shared and distinct symptom clusters of anxiety and depression and are likely associated with their own set of discrete neurophysiological correlates that underly shared and distinct phenotypic symptom presentations. As discussed below, there is substantial evidence that each factor is associated with their own set of unique neural dysfunction across executive control, threat, and reward domains.

General Distress, Fear, Anhedonia, and Neural Correlates of Executive Control

Substantial prior research has linked anxiety and depression to neural deficits in executive control (Sylvester et al., 2012; Ottowitz et al., 2002). Neuroimaging studies have revealed associations between anxiety disorders and abnormal activation in the anterior cingulate cortex (ACC) during speeded cognitive-control tasks (see Mochcovitch et al., 2014 for review), a neural hub of cognitive control (MacDonald et al., 2000; Bush et al., 2000). In parallel, decades of electrophysiological research have linked anxiety disorders to an abnormally elevated ERP that covaries with ACC activation known as the Error-Related Negativity (ERN; Gehring et al., 1993). The ERN is a frontocentral negative ERP deflection peaking approximately 100 ms following response errors that signals an outcome has gone worse than expected, reflecting increased error-detection (see Simons et al., 2010 for review). This component indexes the activity of an executive system that monitors actions to detect discrepancies between intended and actual outcomes (Holroyd et al., 2004; Yeung et al., 2004). More recent work suggests that errors represent aversive events that pose threats to safety that may require immediate attention and corrective action (Hajcak & Foti, 2008). According to these accounts, the ERN may be in part a neural marker of defensive reactivity involved in mobilizing defensive motivational systems after mistakes (Hajcak, 2012; Weinberg et al., 2012b). Together, these results suggest the ERN may be associated with symptoms unique to anxiety disorders captured by the trilevel factor of Fear that show elevated levels of threat-related processing. In support, trait but not state anxiety is associated with increased ERN (Olvet and Hajcak, 2008), a symptom dimension that loads strongest onto the trilevel factor of Fear (Prenoveau et al., 2010).

In addition to defensive reactivity, prior work indicates an elevated ERN is also associated with symptoms of cognitive worry (Moser et al., 2005, 2012; Hajcak et al., 2003) and negative affect (Luu et

al., 2000; Hajcak et al., 2003, 2004). According to these compensatory accounts (Moser et al., 2013), symptoms of worry may decrease neural efficiency during executive control tasks (Eysenck & Calvo, 1992), leading to compensatory increases in error detection to normalize behavioral performance (Eysenck et al., 2007), indexed by the ERN. While Fear-ERN associations are likely driven by increased defensive reactivity associated with symptoms of trait-anxiety, General Distress-ERN associations may reflect a compensatory mechanism to offset neural inefficiency associated with cognitive worry. Although worry is traditionally associated with anxiety disorders, growing evidence suggests worry may be a transdiagnostic symptom dimension of anxiety and depression (Kendler et al., 2003; Krueger, 1999; Sellbom et al., 2008; Slade & Watson, 2006; Watson, 2005; Mennin et al., 2008). In support, General Distress is most strongly loaded on by items representing worry and negative affect (Naragon-Gainey et al., 2016). Together, these results suggest inefficient executive control indexed by elevated ERNs during error-detection may also reflect shared neural dysfunction associated with General Distress representing common symptom dimensions of anxiety and depressive disorders.

In contrast to anxiety disorders, depressive disorders have been linked to another ERP elicited during executive control tasks known as the Error-Positivity (Pe: Falkenstein et al., 2000; Holmes & Pizzagalli, 2010; Olvet et al., 2010). The Pe is a positive deflection directly following the ERN from approximately 200-500 ms and reflects attentional allocation after errors to optimize future performance (Nieuwenhuis et al., 2001; Ridderinkhof et al., 2009; Steinhauser & Yeung, 2010; Boksem et al., 2006). While the ERN is primarily involved in immediate error-detection, subsequent Pe amplitudes are associated with increased reward sensitivity and post-error behavioral adjustments, suggesting this component may track the motivational significance of errors and contribute to error awareness (Endrass et al., 2005; Leuthold & Sommer, 1999; Nieuwenhuis et al., 2001; Boksem et al., 2006, 2008; see Falkenstein et al., 2000 and Overbeek et al., 2005 for reviews). Decades of clinical research has linked symptoms of anhedonia unique to depressive disorders to neural deficits in reward and motivational processes that interfere with the ability to effectively learn from mistakes (Pizzagalli et al., 2008; Treadway et al. 2012; Treadway & Zald, 2011). These studies suggest reduced Pe amplitudes among major depressive disorder may be associated with decreased task engagement specifically associated with motivational deficits present in anhedonia (Schrijvers et al., 2008, 2009). In support, Pe amplitudes

are associated with depression severity and symptoms (Holmes & Pizzagalli, 2010) and have predicted depression treatment outcomes (Alexopoulosa et al., 2007). Therefore, Anhedonia may uniquely be associated with decreased Pe amplitudes reflecting motivational deficits that inhibit the ability to effectively integrate error-related information to optimize future performance.

General Distress, Fear, and Neural Correlates of Threat

Substantial research has linked anxiety disorders to abnormal profiles of threat-related neural activity across a variety of different experimental contexts (Craske & Vervliet, 2013). Neuroimaging research has linked anxiety disorders with dysregulation in the amygdala and subgenual portion of the anterior cingulate cortex (Rougemont-Bücking et al., 2011; Veit et al., 2002), two regions strongly associated with threat-related neural processing (Delgado et al., 2008; Ghashghaei & Barbas, 2002). Associations between anxiety disorders and amygdala activation are particularly strong following fearful or threatening images (see Cisler & Koster, 2010 for review), suggesting an attentional and emotional bias towards treat. In parallel, electrophysiological studies have linked anxiety disorders to two ERPs following threatening stimuli known as the P300 and Late-Positive Potential (LPP; Bradley et al., 2003). First, the P300 is a positive ERP peaking approximately 300-600 ms following motivationally salient and emotionally significant stimuli representing stimulus categorization and early attentional processes (see Polich, 2007 for review). Several studies have documented increased P300 amplitudes following threatening images across a variety of anxiety disorders (Moser et al., 2008; Schienle et al., 2008). In fact, cognitive-behavioral therapy treatment for anxiety-related phobia predicted decreases in P300 following threatening images, suggesting this component reflects increased attentional bias toward negative stimuli (Leutgeb et al., 2009).

Second, the LPP is a positive ERP that reflects a combination of attentional and extended emotional processing following motivationally salient stimuli (Schupp et al., 2004, 2006; Hajcak et al., 2009). The LPP covaries with amygdala activity (Bradley et al., 2003) and has been referred to as the affective counterpart of the P300 (Groen et al., 2008). Extensive prior research indicates fearful and threatening stimuli increase LPP amplitudes (Huang & Luo, 2006; Schupp et al., 2006; Hajcak & Olvet, 2008), suggesting this component may capture a “negativity bias” during extended processing of

emotional information (Smith et al., 2003). Recent research indicates several anxiety disorders display increased LPP amplitudes following fearful images (Weinberg et al., 2011a; MacNamara et al., 2011, 2019), likely reflecting greater threat reactivity and emotion dysregulation (Dennis & Hajcak, 2009). In fact, the LPP following threatening images has predicted treatment response in pediatric anxiety (Bunford et al., 2017) may constitute a biomarker of risk for future development of anxiety disorders in children (Kujawa et al., 2015; DeCicco et al., 2012).

Although no research has investigated P3 and LPP associations with the trilevel model, several related studies have linked LPP amplitudes to increased automatic arousal (Cuthbert et al., 2000) and trait anxiety (Mocaiber et al., 2009), two symptom dimensions that load most strongly onto the trilevel symptom dimension of Fear. Furthermore, LPP amplitudes have also been linked to negative affect and worry, two symptom dimensions that load strongest onto General Distress (MacNamara, 2018; Moser et al., 2014). In concert, P300 studies indicate that trait anxiety and negative affect are both associated with increased amplitudes following fearful and threatening images (Dennis & Chen, 2007; Moser et al., 2010). Together, these results suggest General Distress and Fear will be associated with increased P3 and LPP following threatening images during an emotional reactivity task.

Anhedonia and Neural Correlates of Reward

Symptoms of anhedonia are considered a cardinal feature of depression (Meehl, 1975) and are typically absent in anxiety disorders (Shankman & Klein, 2003), suggesting anhedonia reflects a distinct symptom dimension unique to depressive disorders. Recent research has documented robust associations between depression and decreased sensitivity to reward-related stimuli across self-report, behavioral, and neurophysiological measures that predict depression onset, severity, and course (Chase et al., 2013), especially measures of anhedonia (Clark & Watson, 1991; Pizzagalli et al., 2008). These results and an abundance of emerging literature suggest a specific role of anhedonic symptoms in abnormal reward-related neurocircuitry (see Treadway & Zald, 2011 for review; Treadway et al. 2012).

However, reward processing does not begin or end with reward attainment and is instead a heterogenous construct encompassing several discrete stages and psychological processes that dynamically unfold over time. Broadly construed, substantial prior research has identified two temporally

distinct stages of reward processing: reward anticipation and reward outcome (Breiter et al., 2001; Knutson et al., 2001; Berridge & Robinson, 2003; Salamone & Correa, 2012; McClure et al., 2003; Rogers et al., 2004). Reward anticipation is characterized by “wanting” and includes motivational processes involving approach toward upcoming reward-related stimuli or actions while reward outcome is associated with “liking” and reflects the hedonic impact of pleasure coupled with reward attainment (Berridge et al., 2009; Knutson et al., 2001). An abundance of prior animal and human research indicates anticipation and outcome stages are associated with distinct neurochemical, neuroanatomical, and neurophysiological correlates, suggesting separate neural systems mediate each stage (Berridge et al., 2009; Schultz, 2007; Liu et al., 2011).

While anhedonia has traditionally been defined as a “loss of pleasure” indicating deficiencies in hedonic pleasure during reward outcome (Meehl, 2001), recent work indicates anhedonia also includes more general motivational deficits associated with reduced anticipatory investment and effort, suggesting deficits during reward anticipation as well (see Treadway et al. 2012 and Whitton et al. 2015 for reviews). In support, prior neuroimaging studies have documented associations between depression and blunted neural activity in the ventral striatum during both reward anticipation and outcome stages (Schultz, 2000; Delgado et al., 2000; Knutson et al., 2003; Breiter et al., 2001), especially for anhedonic symptom profiles (Keedwell et al., 2005). Therefore, isolating stage-specific associations between anhedonia and reward processing deficits in depression is essential to precisely identify corresponding systems of neural dysfunction. Understanding the fine-grained time course of these relationships is essential to develop effective treatment approaches that more accurately and precisely target anticipatory motivational deficits, reductions in hedonic pleasure, or both.

Converging with neuroimaging work (Wacker et al., 2009), recent ERP studies have linked an outcome-related ERP known as the Reward-Positivity (RewP) to depressive disorders, especially symptoms of anhedonia (Holroyd et al., 2008; Proudfit, 2015). The RewP is a frontocentral positivity elicited 250 ms following positive (vs. negative) reward feedback signaling an outcome has gone better than expected and covaries with activation in the basal ganglia, including the ventral straitum (Becker et al., 2014; Carlson et al., 2011; Foti et al., 2011). Reinforcement learning theories argue the RewP reflects powerful learning signals called a reward prediction error (Holroyd & Coles, 2002) that tracks expectation

violations between predicted and actual outcomes via phasic increases in mesencephalic dopamine signaling within the frontostriatal reward circuit (Holroyd & Coles, 2002; Montague, Hyman, & Cohen, 2004; Schultz, 2002). Emerging evidence suggests a blunted RewP amplitude in individuals with a family history of unipolar depression (Kujawa et al., 2014) may prospectively predict risk, onset, and severity of depressive disorders (Bress et al., 2013, 2015b), but remains unassociated with anxiety (Bress et al., 2012, 2015a; Kujawa et al., 2014). Together, these studies provide strong evidence that the trilevel factor of Anhedonia will be uniquely associated with blunted RewP amplitudes.

While neuroimaging methods can examine reward outcome and anticipation separately on the timescale of seconds, ERP methods can probe neural activity with sub-millisecond precision. However, despite strong neuroimaging evidence documenting reduced reward-related neural activation during outcome and anticipation stages (Schultz, 2000, Delgado et al. 2000, Knutson et al., 2003, Breiter et al., 2001; Keedwell et al., 2005; Gotlib et al., 2010; Morgan et al., 2013), far less research has examined associations between depression and ERPs elicited during reward anticipation. To address this gap, the current study leveraged the strong temporal resolution of ERP methods to go beyond the RewP and decompose reward anticipation and outcome into distinct substages that rapidly unfold over time. Each substage is comprised of unique reward-related ERP components that reflect independent psychological processes, display distinct scalp topographies, and covary with separate neuroanatomical correlates (see Glazer et al., 2018 for review). This approach allows for fine-grained temporal analysis that directly measures different neural systems associated with pathophysiological reward dysfunction in depression.

Broadly construed, three substages of reward anticipation have been identified: cue-evaluation, motor-preparation, and feedback-anticipation. During cue-evaluation, individuals evaluate cue stimuli that may or may not predict potential future rewards. Cue-evaluation involves early stimulus categorization and motivated attention that reflect initial preparation for an upcoming task-relevant event that may lead to rewards. Next, during motor-preparation, individuals plan and prepare motor activity and exert effort during the pursuit of upcoming rewards. Finally, individuals must prepare to receive the outcome of their action during feedback anticipation which reflects anticipatory attentional processing before receiving and consuming potential rewards.

During cue-evaluation, three temporally distinct ERP components are elicited: the Cue-N2, Cue-P3, and Cue-LPP. First, the Cue-N2 is a frontocentral negative-going ERP component that is typically reduced for cue stimuli that signal potential future rewards compared to neutral cues unassociated with rewarding outcomes (Donkers et al., 2005; Gehring et al., 1993; Folstein & Van Petten, 2008). This component is thought to reflects a template mismatch between expected reward cues and actual cue stimuli and has been found to covary with activation in the anterior cingulate cortex during conflict monitoring (Potts, 2011; Novak & Foti, 2015; Pornpattananangkul & Nusslock, 2015; Dunning & Hajcak, 2007; Holroyd, 2004). Directly following the frontal Cue-N2, reward cues elicit a subsequent centroparietal ERP component called the Cue-P3 that reflects stimulus categorization processes and context updating in working memory with increased positive amplitudes (Johnson & Donchin, 1980; Donchin & Coles, 1998; see Polich, 2007 for review). Reward compared to non-reward cues increase the Cue-P3 amplitude, an effect that covaries with activation in the ventral striatum (Pfabigan et al., 2014), suggesting this component also reflects motivated attention directed toward stimuli that predict potential future rewards. Finally, after the Cue-P3, another parietal ERP component is elicited by reward cues called the Late-Positive Potential (Cue-LPP). Although very few studies have examined the Cue-LPP, this component likely reflects extended cognitive-emotional processes involved in cue-evaluation and may constitute the “affective counterpart” of the Cue-P3 (Groen et al., 2008).

Following cue-evaluation, individuals must prepare and executive motor actions to pursue upcoming rewards during the motor preparation stage. A frontocentral negative-going ERP called the contingent-negative variation (CNV) is typically measured just prior to motor responses and covaries with activation in the supplementary motor area and thalamus (Plichta et al., 2013). To elicit the CNV, reward processing tasks typically present a target stimulus that requires a quick motor response. Therefore, unlike self-directed actions, the CNV likely reflects a combination of anticipatory attentional processing to efficiently perceive this stimulus in addition to motor-related preparation to facilitate quick responses (Ikeda et al., 1996; Kotani et al., 2011). Although no extant studies have investigated associations between anehdonic symptom clusters and the CNV during reward processing, prior work indicates decreased effort (Falkenstein et al., 2003; Gómez et al., 2007) and motivation (Cant and Bickford, 1967; Irwin et al., 1966) characteristic of anhedonia may reduce CNV amplitude (Novak & Foti, 2016). Finally,

the feedback anticipation stage follows motor responses and directly precedes reward feedback. Another frontocentral negative-going ERP is elicited just before feedback presentation, called the Stimulus-Preceding Negativity (SPN), that covaries with activation in the insula cortex (Bocker et al., 1994; Kotani et al., 2009; Brunia et al., 2000). The SPN is increased just prior to reward compared to neutral feedback and reflects attentional and perceptual anticipatory preparation to receive upcoming feedback stimuli (Chwilla & Brunia, 1991; Kotani et al., 2001, 2003; Masaki et al., 2006; Ohgami et al., 2004, 2006).

The current study will also examine two additional feedback-related ERP components during reward outcome in addition to the RewP. First, the Feedback-P3 (FB-P3) is a positive-going centroparietal ERP directly following the RewP and generally reflects the motivational salience of feedback (Donchin & Coles, 1998; Johnson & Donchin, 1980; see Polich, 2007 for review). Despite functional and neuroanatomical similarities, recent studies have shown the Cue-P3 and FB-P3 reflect unique variation within anticipatory and outcome stages of reward processing (Novak et al., 2016; Pornpattananangkul & Nusslock, 2015). While the Cue-P3 is primarily involved in motivated attention and stimulus categorization, the FB-P3 also reflects the integration of salient outcome-related information into working memory to update predictive models and maximize future rewards (Donchin, 1981; Polich, 2007; San Martín, 2012). Lastly, the Feedback-LPP (FB-LPP) directly follows the FB-P3. Although few studies have examined the FB-LPP, several studies have suggested this component is similar to its cue-related counterpart (i.e., Cue-LPP) and reflects a combination of attentional and affective feedback processing (see Glazer et al., 2018 for review)

Implications

The current study is the first to examine the electrophysiological correlates of the trilevel model and has important implications for risk, diagnosis, and treatment of anxiety and depression disorders. First, results will identify the neurophysiological correlates of shared and distinct symptom profiles of anxiety and depression. This may help resolve inconsistencies in pathophysiological research that may be driven, in part, by within-disorder symptom heterogeneity and between-disorder comorbidity associated with current DSM classification methods. Second, results will isolate separate neurophysiological profiles across executive control, threat, and reward processing task domains. Each task is specifically designed to leverage the temporal resolution of ERP methods, deepening our

understanding of the precise time course of neural dysfunction in each domain. Third, results will help separate individuals at risk for anxiety disorders, depression disorders, or both to help facilitate early interventions. For example, each hypothesis in the current study includes at least one ERP component that has been previously associated with increased risk for anxiety, depression, or both across several developmental periods (i.e., the ERN, LPP, and RewP). Finally, results will help facilitate the future development of novel clinical approaches that directly target neurophysiological pathways associated with individual symptom presentations rather than general diagnostic categories. The goal of this precision medicine approach is to develop targeted treatment approaches informed by contemporary neurophysiology that ultimately treat individuals rather than disorders.

Hypotheses

The objective of the current study is to leverage the temporal resolution of ERP methods to identify the neural correlates of shared (i.e., General Distress) and distinct symptom dimensions of anxiety and depression (i.e., Fear and Anhedonia) across executive control, threat, and reward processing domains. Although no prior study has examined ERP correlates of the trilevel model, the three major hypotheses of the current study were developed from related previous research described in the preceding sections (see Table 2). First, all three trilevel factors will be associated with abnormal electrocortical activity during an executive control task. Increased General Distress and Fear will be associated with increased error detection (i.e., increased ERN) while heightened or maintained courses of Anhedonia will be uniquely associated with reduced motivated attention following errors (i.e., decreased Pe). Second, General Distress and Fear will be uniquely associated with increased threat-related electrocortical activity during an emotional reactivity task (i.e., increased P300 and LPP). Finally, increased Anhedonia will be uniquely associated with decreased reward-related ERPs during reward anticipation (i.e., Cue-N2, Cue-P3, and Cue-LPP during cue-evaluation, CNV during motor preparation, and SPN during feedback anticipation) and outcome stages (i.e., RewP, FB-P3, and FB-LPP). If primary hypotheses are confirmed, follow-up analyses will test whether these associations remain significant while controlling for opposing symptom dimensions.

Method

Recruitment

The current study was embedded within a parent R01. In the parent R01, participants were recruited at Northwestern University and the University of California, Los Angeles to examine positive and negative valence functioning and the trilevel model from late adolescence to early adulthood. Participants consisted of young adults (ages 18-19) that were preselected from a larger screening sample of 2,461 individuals based on individual differences in self-reported trait neuroticism and reward sensitivity scores to maximize variance in threat- and reward-related sensitivity. Prior research indicates that baseline scores of neuroticism (Eysenck Personality Questionnaire-Neuroticism scale; EPQ-N: Eysenck, Eysenck, 1975) and reward sensitivity (Behavioral Activation System-Reward Responsiveness scale; BAS-RR: Carver & White, 1994) predicted the trilevel symptom factors of General Distress, Fear, and Anhedonia over a 3-year period (Prenoveau et al., 2010). Therefore, participants were prescreened using these self-report measures of threat (EPQ-N) and reward sensitivity (BAS-RR) to approximately capture a complete distribution across the two dimensions. Remaining participants were then divided into five primary sectors regarding trait reward sensitivity and trait threat sensitivity: High, High; Low, Low; High, Low; Low, High; and Medium, Medium. Consistent with prior work (McClelland & Judd, 1993), the four remaining sectors were excluded (i.e., Medium crossed with High or Low) to increase power for detection of interaction effects. Participants who met these requirements proceeded to stage two of recruitment involving a diagnostic evaluation using structured clinical interviews for the DSM-IV (SCIDs) and a functional magnetic resonance (fMRI) screening scale. Following recruitment, 272 participants remained and were enrolled in the 3-year longitudinal parent R01 study (182 female, mean age=19.16 years, SD=0.52). Of these, 140 participants were recruited through the parent R01 at Northwestern University while 132 participants were recruited at the University of California, Los Angeles.

For the current project, participants already enrolled in the parent R01 at Northwestern University were re-contacted for an optional EEG assessment. Each EEG participant completed an identical battery of questionnaires administered in the parent R01 to extract trilevel symptom dimensions of anxiety and depression. These self-report questionnaires were completed online at home within no more than 3 days before or after arriving for the EEG assessment. Upon arrival, participants were consented and hooked up to EEG before completing a series of computerized tasks that separately captured neural activity

specifically associated with threat-, reward-, and executive control-related processing. First, participants completed a resting EEG session where they viewed a fixation cross with their eyes open for 3 minutes and subsequently closed for 3 minutes. Next, both the executive control (stop signal) and reward processing (electrophysiological monetary incentive delay) tasks described below were administered and counterbalanced for each participant. Lastly, the threat-related (emotional reactivity) task described below was always administered last. This was done to prevent possible emotional priming influences on both reward- and executive control-related ERPs (Pedersen & Larson, 2016). Participants were paid $60.00 for their participation in the two-and-a-half hour in-person session plus a bonus amount based on their winnings from the eMID task where participants could win money based on their performance. Following all three experiments, participants were unhooked from EEG, paid, and thoroughly debriefed.

Exclusion Criteria

The parent R01 focused on neuroimaging techniques and therefore utilized prescreened participants using a standard fMRI screening questionnaire with criteria such as traumatic brain injuries, pregnancy, and immoveable metal inside the body. Next, other exclusion criteria were assessed using a Structured Clinical Interview for DSM-IV (SCID). Exclusion criteria included a lifetime psychotic or bipolar disorder, substance or alcohol abuse/dependence, and current use of antipsychotic medications.

Of the 140 participants enrolled in the parent R01 at Northwestern University, 79 opted to participate in the optional EEG assessment described in this study (57 females, mean age: 21.34, SD: 0.79). Participants were only retained for analysis in the present study if they had completed all three tasks and the necessary questionnaire data used to calculate trilevel symptom data. Of the 79 participants recruited for this optional EEG assessment, five did not complete the trilevel symptoms data questionnaires, three did not complete the executive control stop signal task due to computer error during the session, and six did not complete the threat emotional responsivity task (three due to computer error and four due to time constraints during the session). After initial exclusion, 65 participants remained for EEG processing. However, four additional participants were removed for excessive artifacts in their EEG data with over 50% of trials rejected during the EEG preprocessing (see EEG acquisition and analysis section for details). Specifically, two participants were removed for excessive artifacts in the reward

electrophysiological monetary incentive delay task and two more for excessive artifacts in the emotional responsivity task (see Table 8 for artifact rejection details).

After all exclusion, a total of 61 participants were retained for all statistical analyses (45 females, mean age: 21.394, SD: 0.835). Of these 61 participants, 35 identified as White, 13 as Asian, 7 as Black, 1 as Native, and 5 as multiracial (19 Hispanic, 42 non-Hispanic). Among the two (BAS and EPQ-N scores) x three (low, med, and high) screening categories used for recruitment in the parent R01, the BAS/EPQ-N distribution among the 61 retained participants in the current study is as follows: high/high: 6, high/med: 2, high/low: 10, low/low: 12, low/med: 5, low/high: 12, med/low: 7, med/med: 5. 30 out of the 61 completed the EMID reward processing task before the stop-signal executive control task (with the remaining 31 completing the stop-signal task before the EMID reward processing task) and 8 reported current use of psychotropic medications. In all analyses, task order and psychotropic use were entered as covariates to control for medication and experiment order effects.

Questionnaire Measures of Trilevel Symptom Dimensions

In the parent R01, trilevel symptom dimensions of General Distress, Fear, and Anhedonia are derived from self-report symptom scales of anxiety and depression. Sets of individual items from each scale were selected from those that matched the original trilevel model (Prenoveau et al., 2010) and more recent follow-up study (Naragon-Gainey et al., 2016). All selected scales and individual items used in the parent R01 were administered at baseline and every 12 months for 3 years for a total of four assessments. Identical sets of questionnaires and items were administered at the EEG assessment described in the current proposal. Specifically, participants completed 67 items across several questionnaires described in the original trilevel factor structure (Prenoveau et al., 2010) including 10 items from the Albany Panic and Phobia Questionnaire (Rapee et al., 1994), 8 items from the self-consciousness subscale of the Social Phobia Scale (SPS; Mattick & Clarke, 1998; Zinbarg & Barlow, 1996), 7 items from the Fear Survey Schedule II (FSS; Geer, 1965; Zinbarg & Barlow, 1996), 8 items from the Inventory to Diagnose Depression (IDD; Zimmerman et al., 1986), and 34 items from the Mood and Anxiety Symptoms Questionnaire (MASQ: Watson et al., 1995) that measure positive affect (9 items), anxious-arousal/somatic tension (12 items), and mixed depression/anxiety (13 items). Following Naragon-Gainey and colleagues (2016) follow-up replication study on trilevel model factor structure, participants

completed an additional 34 items including 16 items from the Penn State Worry Questionnaire (PSWQ; Meyer et al., 1990; Brown et al., 1992) and 18 items from the Obsessive-Compulsive Inventory Revised (OCI-R; Foa et al., 2002).

Neural Indices of Executive Control: Stop-Signal Task (SST)

Participants completed the SST (see Figure 1) while EEG was recorded to measure neural and behavioral differences in executive control during error-processing and response inhibition (Wessel & Aron, 2013). The trial structure of the SST consists of the presentation of a left- or right-facing arrow where participants respond as quickly as possible to the direction of the arrow. The order of task presentation was counterbalanced with the reward-related EMID task described below. Before each trial, a fixation cross was presented for a jittered time interval between 500 and 1000 ms. Next, a left- or right-facing white arrow was presented, and participants were instructed to press the corresponding left or right response-box key with their right index or middle finger as quickly as possible. The duration of the white arrow was determined by an adaptive algorithm that decreased the duration by 10 ms after correct responses and increased the duration by 10 ms after incorrect responses. However, on some trials, participants were instructed to withhold their response as a measure of response inhibition. During these trials, the color of the presented arrow changed from white to red after a brief delay period matched to each participant reaction time to keep accuracy at roughly 80-90% (Wessel & Aron, 2015). Participant were instructed that if they responded to the white arrow before it disappeared from the screen, or if they withheld their response when the arrow changes colors from white to red, that trial would be counted as “correct”. However, if participants did not respond to the white arrow, or if they pressed the response button after the arrow changed from white to red, that trial would be counted as “incorrect”. Participants were instructed to maximize both their speed and accuracy during the task.

This task will assess neural differences in executive control directly following mistakes of response inhibition by comparing electrocortical responses following two kinds of responses: successful button presses after white arrows (Correct-Related Negativity: CRN) and erroneous button presses following red arrows (ERN and Pe). The stop-signal approach retains numerous advantages over other related speeded executive control tasks, such as the Stroop, Flanker, go/no-go paradigms, by measuring

the precise time window required for each participant to inhibit their dominant response tendency to respond as quickly as possible to the direction of the arrow, providing both a neural and behavioral index of response inhibition. There are 18 blocks for a total of 400 trials and the total task takes about 20 minutes to finish.

Neural Indices of Threat Processing: Emotional Response Task (ERT)

Participants completed the ERT (see Figure 2) while EEG was recorded to examine differences in threat-related neural reactivity to emotional images. The trial structure of the ERT consists of passively viewing an image presented on the screen during each trial. Before each trial, a fixation cross was presented for 2000 ms. Next, a neutral or threatening image was presented for seven seconds while participants passively viewed this image. Task stimuli consisted of threatening and neutral images taken from the International Affective Picture System that were presented in separate blocks. 1000 ms following image onset, participants received an audio cue. Following neutral images, the audio cue consisted of the word “Look” where participants were instructed to simply view the picture naturally. After threatening images, the audio cue consisted of the word “Maintain” where participants were instructed to view the image naturally without trying to change their emotional reaction or look away from the monitor. The P300 was measured following each threatening and neutral image and the LPP was measured following each audio cue as neural representations of threat-related emotional reactivity. The ERT consisted of 50 neutral and 50 threatening images, for a total of 100 trials taking 15 minutes to complete. Participants completed the ERT last to prevent possible emotional priming effects on the reward and executive control tasks.

Neural Indices of Reward Processing: Electrophysiological Monetary Incentive Delay Task (EMID)

Participants completed the eMID (see Figure 3) task while EEG was recorded to examine reward-related neural processing (Broyd et al., 2012; Novak & Foti, 2015). The EMID design has successfully decomposed the neural correlates across multiple stages of reward processing (i.e., cue-evaluation, motor-preparation, feedback-anticipation, and outcome-processing) and was counterbalanced with the SST described above. The eMID task is based on the classic monetary incentive delay task developed for

neuroimaging studies used by the parent R01 of this proposal for fMRI sessions (Knutson et al., 2001; Lutz & Widmer, 2014), with some minor modifications.

The trial structure of the EMID task consists of presenting a cue stimulus, responding quickly to a target stimulus, and receiving positive or negative feedback. Before each trial, a fixation cross was presented for 2000 ms. Next, one of two cues was presented that indicated whether participants could win money in reward conditions or neither win nor lose money in neutral conditions. Reward cue stimuli consisted of a circle with the word “Win” displayed in the top portion and “$1.50” displayed in the bottom portion, indicating that participants had the opportunity to win $1.50 for correct responses on that trial. Neutral cues consisted of a circle with the word “Win” displayed in the top portion and “$0.00” displayed in the bottom portion, indicating that no money could be won or lost on this trial regardless of participant performance. Participants were instructed to try their best to maximize positive feedback on every trial. Following reward and neutral cues, the Cue-N2, Cue-P3, and Cue-LPP were measured during this cue-evaluation stage as reward-related neural indices of cue-reactivity reflecting template mismatches, context updating, and affective impact of reward and neutral cues.

After a brief delay consisting of a fixation cross, a target stimulus was presented (solid white square). Participants were instructed to press single response-box button as quickly as possible following the target stimulus with their right index finger. Participants were further instructed that if they responded “quick enough” before the white square disappeared from the screen, that trial would be counted as “correct” and result in positive feedback. However, if they responded “too slowly” after the white square disappeared from the screen, that trial would be counted as “incorrect” and result in negative feedback. The CNV was measured during this motor preparation stage consisting of the brief delay before the target stimulus as participants prepared perceive the target stimulus and ready quick-as-possible responses. After the white square disappeared, a fixation cross was presented for 1000 ms before performance feedback was presented. The SPN was measured during this feedback anticipation period where participants prepared to receive upcoming performance feedback on their recent responses.

Finally, after the 1000 ms delay, a feedback stimulus was presented indicating whether participants responded “quick enough” represented by positive feedback or responded “too slowly” represented by negative feedback. Feedback stimuli contained both performance- and reward-related

information. During reward trials, positive feedback was delivered with the stimulus "+$1.50" indicating that the participant responded quick enough on that trial and received a monetary gain of $1.50. Negative feedback on reward trials consisted of the stimulus "-$0.00" indicating that the participant responded too slowly on that trial and will not receive any monetary compensation. On neutral trials, positive and negative feedback were delivered with the stimuli "+$0.00" and "-$0.00". These stimuli were chosen to indicate that participants did not win or lose any monetary amount on neutral trials, hence $0.00, while still delivering performance feedback information, indicated by + and – signs, that informed the participant whether they responded quick enough or too slowly on that trial. During this feedback evaluation stage, the RewP, FB-P3, and FB-LPP were measured as an index of reward-related outcome processing. There was a total of 150 trials and the total task takes about 30 minutes to finish. Before the EMID task, participants completed 20 trials of an identical "practice" task. During practice, a research assistant remained in the room with the participant and ensured they understood all of the stimuli and task instructions before starting the subsequent EMID task.

Importantly, the EMID task utilized here implemented an adaptive algorithm that controlled how long the target stimulus remained on the screen. Specifically, the duration of the target white square was decreased by 20 ms after quick enough responses, making the task more difficult, and increased by 20 ms after too slow responses, making the task easier. This adaptive algorithm was used to manipulate task difficulty on a trial-by-trial basis to keep positive and negative feedback fixed at approximately 50% in both reward and neutral conditions. Outcome probability is a major factor that contributes to feedback-related ERP amplitudes, especially the RewP and FB-P3 (see San Martin, 2012 for review), and it is therefore essential to control for outcome probability during feedback-related ERP studies (see Novak & Foti, 2011 for an example using the EMID task). Before the EMID task, participants completed 20 trials of a reaction time task that consisted of a fixation cross jittered between 1500 and 2000 ms followed by a target white square with a presentation duration of 500 ms where participants responded as quickly as possible. An identical adaptive algorithm as used in the EMID task was used during the reaction time task. The final reaction time for each participant after the last trial was used as the initial presentation duration of the white square during the EMID task.

EEG Acquisition and Analysis

Continuous EEG data were recorded during all three tasks using NeuroScan amplifiers (DC to 100 Hz online, NeuroScan Inc.) within an electromagnetic-shielded booth. 58 passive Ag/AgCl scalp electrodes were applied (following 10-20 standard) with conductive gel. One external electrode was applied on the left and right mastoid. Four additional external electrodes were placed above and below the left eye and beside both eyes. EEG data were digitized at a 500 Hz sampling rate and online referenced to the left mastoid. Impedance was kept below 5 kΩ and 10 kΩ for the scalp and eye electrodes, respectively.

Offline, all EEG processing was conducted using EEGLAB (Delorme & Makeig, 2004) and ERPLAB (Lopez-Calderon & Luck, 2014) in MATLAB (Mathworks, 2017b). The initial EEG preprocessing was identical for data collected from all three experiments. First, data were resampled at 250 Hz, re-referenced to the average of both mastoids, and clean-lined with a sliding window to adaptively estimate sine wave amplitude and subtract line noise. Next, for each participant two files were generated for each participant. One file was created with a 0.01 high pass filter and the other was created with a 1.0 Hz high pass filter. The 1.0 Hz filtered data was used only to prepare data for independent component analysis (ICA) used to correct for ocular and muscular artifactual components. In this ICA prepared file, channels with excessive noise were identified using visual inspection of continuous EEG data and kurtosis measures calculated separately for each channel. Noisy channels were marked and removed from the dataset. Next, large scalp artifacts were identified using a combination of visual inspection and an automated artifact detection procedure applied to the continuous EEG data. Specifically, segments of continuous data were marked as artifactual if any scalp electrode exceeded a voltage threshold of 500 μV in a 500 ms time window that moved across the full continuous data in steps of 250 ms, Segments of continuous data marked with artifacts were then removed before conducting ICA on each file. Following this procedure, the resulting ICA weights were applied to the 0.01 high pass filtered data saved earlier in the pipeline before ICA was performed. ICA components corresponding to muscular and ocular artifacts were then identified and removed from this 0.01 Hz dataset using visual inspection. Noisy channels identified and removed earlier were then interpolated. Final processing steps were then applied to data from each of the three tasks using separate pipelines specifically tailored to measure each ERP

component within each experiment. These steps include low pass filtering, epoch extraction, baseline correction, artifact rejection, and averaging.

For the stop signal task, data were low pass filtered at 30 Hz and epoched into segments time-locked to the onset of correct and incorrect responses. Epochs were calculated by extracting 200 ms prior to the response and 800 ms after the response. Each epoch was baseline corrected using the 200 ms pre-response interval. Next, artifactual epochs were identified and removed using a combination of visual inspection and three automated artifact rejection procedures performed on midline electrodes Fz, FCz, Cz, CPz, Pz, and POz. First, epochs were rejected if any electrode exceeded a sample-to-sample difference of 50 uV. Next, if any electrode did not exceed a difference of ± 0.25 uV in a 500 ms window, that electrode was determined as flatlined and the epoch was rejected. Finally, epochs were rejected if any electrode exceeded a 75 μV threshold in a 150 ms window that slid across the entire epoch every 75 ms. After artifact rejection, remaining single-trial epochs were averaged together separately for correct and incorrect responses.

For the emotional reactivity task, data were low pass filtered at 10 Hz and epoched into segments time-locked to the onset of neutral and threatening image presentation. Epochs were calculated by extracting 7000 ms after image presentation and baseline corrected using the 200 ms pre-stimulus interval. Artifactual epochs were identified and removed using a combination of visual inspection and identical sample-to-sample and flatlined procedures described above. Next, epochs were rejected if any electrode exceeded a 100 μV threshold in a 200 ms window that slid across the entire epoch every 100 ms. After artifact rejection, remaining single-trial epochs were averaged together separately for neutral and threatening images.

For the EMID task, two data processing pipelines were applied. For the CNV and SPN, data were low pass filtered at 10 Hz and epoched into segments time-locked to the onset of correct and incorrect responses. Epochs from 2000 ms prior to the response and 2000 ms after the response were then extracted. Baseline correction was performed for both the CNV and SPN using the 2000-1700 ms pre-response interval. This was done for both components to ensure that motor-related activity from the CNV did not contaminate the baseline period for the SPN (Pornpattananangkul & Nusslock, 2015). Artifact rejection procedures were identical to the stop signal task described above. After artifact rejection,

remaining single-trial epochs were averaged together separately for reward and neutral trials as well as correct and incorrect responses. This resulted in four bins reflecting reward correct responses, reward incorrect responses, neutral correct responses, and neutral incorrect responses.

For the cue- and feedback-related EMID trials, data were low pass filtered at 30 Hz and epoched into segments time-locked to cue and feedback stimuli, respectively. Epochs were calculated by extracting 200 ms prior to the cue and feedback stimuli and 1000 ms after cue and feedback stimulus presentation. Each epoch was baseline corrected using the 200 ms pre-response interval. Artifact rejection procedures were identical to the stop signal task described above. After artifact rejection, remaining single-trial epochs were averaged together separately. For cue data, two bins were extracted reflecting reward and neutral cues. For feedback data, four bins were extracted reflecting reward positive feedback, reward negative feedback, neutral positive feedback, and neutral negative feedback.

For each task, participants were excluded from analysis if their artifact rejection rate was 50% or greater in any condition or if their remaining trial count is below recommendations suggested by previous literature. Two participants were excluded for excessive artifact rejection rates in the EMID task resulting in less than 10 trials per feedback condition. Prior research recommends at least 20 trials per-condition are required to sufficiently and optimally measure the RewP (Marco-Pallares et al., 2011). Two additional participants were excluded due to excessive artifact rejection rates in the ERT task resulting in less than 10 trials per image condition. Previous research indicates at least 12 trials are required to accurately measure the LPP amplitude during passive image viewing paradigms, such average as the ERT (Moran et al., 2013). All remaining participants had an of over 20 trials per feedback condition in the EMID and over 20 trials per image condition for the ERT (see Table 8 for artifact rejection details). In total, 61 participants were retained for statistical analysis.

ERP Measurement

Fully processed EEG data were entered into ERPLAB to export ERP components. Each ERP component was measured by calculating the mean activity in a fixed time window that was identified from visual inspection of the grand averaged waveforms and scalp topographies created by averaging across all subjects.

For the executive control SST, the measurement window for the ERN was determined by identifying the peak amplitude for the incorrect – correct difference wave and measuring ± 50 ms around this peak, a standard approach utilized by many prior studies. Visual inspection of grand average waveforms revealed this difference wave was maximal at electrode FCz and peaked at approximately 110 ms. Therefore, the ERN was measured at electrode FCz as the average activity from 60-160 ms, a time window consistent with prior studies (Endrass et al., 2007, 2012a). For the Pe, visual inspection of the Pe incorrect – correct difference in the grand average waveform revealed a rapidly increasing positivity around electrode Pz that peaked at approximately 250 ms and then slowly decreased until approximately 600 ms. Drawing from prior studies, the Pe was decomposed into an earlier and later component (Endrass et al., 2007, 2012b; Murphy et al., 2012). For the early Pe, a mean measurement window of ± 75 ms around this 250 ms peak was chosen based on visual inspection of the grand average waveform, a time window generally consistent with prior studies (Gibbons et al., 2011). However, fewer studies have examined the late Pe component, which displays no discernable peak in the grand average difference waveform. To capture the extended positivity present in this difference wave, a time window of ± 100 ms was chosen based on visual inspection of the grand average waveform. Although fewer studies have examined this later Pe component, this time window is generally consistent with prior studies (Endrass et al., 2007, 2012b; Ruchsow et al., 2005). The mean activity for each component was then calculated as the average activity from 60-160 ms at electrode FCz for the ERN, 175-325 ms at electrode Pz for the early Pe, and 400-600 ms at electrode Pz for the late Pe (see Table 3)

For the emotional reactivity task, three ERP components were extracted from visual inspection of the grand average waveforms. First, images produced a clear and extended P300 component at electrode Pz that was elevated for negative compared to neutral images. Based on visual inspection of the grand average waveform, the P300 displayed a peak positive latency at approximately 600 ms and was calculated using a ± 200 ms window around this peak. The LPP component displayed an extended fronto-central positivity that peaked following the audio cue at 1000 ms and lasted throughout the 7000 ms segmented time window. This component was decomposed into an early and later time window due to this extended positivity and was calculated by simply dividing the 2000-7000 ms in half. Therefore, the P300 was calculated as the mean activity at electrode Pz from 400-800 ms, the early LPP as the mean

activity at electrode FCz from 2000-4500 ms, and the late LPP at electrode FCz from 4500-7000 ms (see Table 4).

For the EMID task, ERP measurement time windows were determined from visual inspection of the grand averaged waveforms and scalp topographies separately for cue, response, and feedback data. First, during cue evaluation, the Cue-N2 peak latency was identified via visual inspection of the reward – neutral difference wave, which peaked at approximately 275 ms at electrode FCz. The time window of measurement for the Cue-P3 was determined by identifying the most positive peak in the grand average waveform for all conditions, which peaked at approximately 425 ms. The Cue-LPP also displayed maximal positivity at electrode Pz and was calculated as the average activity following the Cue-P3 up to 800 ms. Together, the mean measurement time windows were as follows: 225-325 ms at FCz for the Cue-N2, 325-525 ms for the FB-P3, and 525-800 ms for the FB-LPP (see Tables 6-7).

Second, for response data, the CNV and SPN are both negative components that increase in negativity before motor responses and upcoming stimuli, respectively. Therefore, measuring mean activity around the peak latency for these components is untenable. Instead, the CNV was grouped into an earlier and later component based on recommendations from previous research (Pornpattananangkul & Nusslock, 2015) and the SPN was measured beginning from 1000 ms prior to feedback stimulus where differences between conditions began to emerge. Both components were calculated at electrode FCz where negativity was maximal. Therefore, the early CNV was measured as the mean activity from 1000-500 ms prior to responses, the late CNV was measured as the mean activity from 500-0 ms right up until responses, and the SPN was measured as the mean activity from 1000-2000 ms just prior to feedback stimuli.

Finally, for feedback-related ERP components, time windows of measurement were determined from visual inspection of the scalp topographies and grand average waveforms in addition to using prior research as a guide (Sambrook & Goslin, 2015). Specifically, the time window for the RewP was determined in the following way. First, the positive – negative feedback difference wave was maximal at electrode Cz from visual inspection of the scalp topography. Next, the positive peak of the preceding P2 component and the subsequent negative peak of the RewP was identified using visual inspection of the grand average waveform. Finally, the average of these two peak latencies was used to determine the

peak RewP amplitude which resulted in approximately 248 ms. Next, the proceeding FB-P3 component displayed peak positivity at electrode Pz at approximately 340 ms. To avoid overlap with the RewP, the peak latency for the FB-P3 was chosen as 350 ms. Finally, the FB-LPP also displayed maximal positivity at electrode Pz. The length of the FB-LPP component was determined via visual inspection of the grand average waveform when differences between conditions began to converge. Therefore, the time windows of mean measurement for feedback-related ERP components are as follows: 200-300 ms for the RewP at electrode Cz, 300-400 ms for the FB-P3 at electrode Pz, and 400-800 ms at electrode Pz for the FB-LPP (see Table 5).

Executive Control: SST Behavioral Measures

While primary analyses centered on neural indices of executive control, several behavioral measures were also extracted from the SST (see Table 9). The SST requires participants to respond as quickly as possible to a right- or left-facing white arrow. On “go” trials, this design allows for the measurement of reaction time, reflecting the average time between the presentation of white arrows and correct quick responses. In addition, “stop” trials comprise 10% of trials where the white arrow turns red after a short delay, requiring participants to withhold their responses. When participants erroneously respond on stop trials, their reaction times after these incorrect responses can also be measured. Both reaction time measures were calculated for each participant reflecting successful go response times and unsuccessful stop reaction times.

However, the SST used an adaptive algorithm that changes the delay time between the presentation of white and red arrows on stop trials. This algorithm updates the delay duration after each trial to keep accuracy at approximately 80-90%. The overarching advantage of this approach is controlling for the confounding influence of response accuracy on ERN amplitudes, which increase in proportion to the number of error (vs. correct) responses throughout a task (Clayson et al., 2020). By contrast, one disadvantage of this approach is that response time measures are partially confounded by continual changes in task difficulty that occur on a trial-by-trial basis. For example, when participants are performing too well (e.g., over 90% accuracy), the algorithm increases task difficulty by shortening the delay duration between white and red arrows, making it more difficult to withhold responses. In this case, it is difficult to

separate stable individual differences in responses times from adaptive behavioral changes that dynamically responds to changing task conditions. Although this confound makes it difficult to interpret reaction time data from the SST, average reaction times on successful go and unsuccessful stop trials were extracted to validate the task design as well as the total number of unsuccessful responses compared to successful responses as an index of performance accuracy.

A final advantage of the adaptive algorithm utilized in the SST is that the difference between the time when the stop process being (i.e., the presentation of the red stop signal arrow) and the point at which the stop process finishes can be calculated as an index of response inhibition (Verbruggen & Logan, 2009). This difference provides a measure of the optimal duration of response inhibition for each participant reflecting the time it takes to override dominant response tendencies via executive control. This stop-signal reaction time was calculated using the mean method described by Verbruggen & Logan, 2009.

Reward: EMID Behavioral Measures

Similar to the SST, the EMID task requires participants to respond as quickly as possible to target stimuli. However, while the SST algorithm was used to keep accuracy at roughly 80-90% in accordance with prior ERN studies (see Simons, 2010 for review), the EMID algorithm was used to keep positive and negative feedback at approximately 50% in reward and neutral conditions. Feedback-related ERPs are highly sensitive to the probability of positive and negative feedback with less common outcomes producing increased positive amplitudes among the RewP and FB-P3 components (see San Martin, 2012 for review). Early EMID studies have empirically confirmed that altering the distribution of positive and negative outcomes significantly impacts the RewP and FB-P3 (Novak & Foti, 2011). However, one major disadvantage of the adaptive algorithm approach is that behavioral data are difficult to interpret as the task difficulty changes on a trial-by-trial basis. Therefore, while behavioral data were calculated and reported to validate the EMID task and adaptive algorithm (see Table 9), statistical analyses were not performed on reaction times or accuracy rates.

Trilevel Symptom Dimensions: Factor Analyses

Trilevel symptom dimensions are extracted using factor analytic approach described by Naragon-Gainey and colleagues (2016). Raw data consisted of self-report questionnaire results from selected questionnaire items identical to those described in the original trilevel model (Prenoveau et al., 2010). These data were analyzed using a latent variable software program (Mplus; Muthen & Muthen, 1998-2020). Following prior recommendations for categorical outcomes (Muthen et al., 1998), robust weighted least squares estimation (RMSEA) was utilized for data analysis. Root mean square of approximation was used to evaluate model goodness of fit with a 90% confidence interval. Sufficient model fit was determined using RMSEA values of 0.06 or below and Tucker-Lewis and comparative fit indices of 0.95 or above, following prior recommendations (Hu & Bentler, 1999). In Mplus, the DIFFTEST feature was used to compare between competing models. Models are further evaluated based on their modification indices and the strength of their parameter estimates.

Initial R01 analyses from trilevel symptom data collected at baseline revealed similar results to Naragon-Gainey and colleagues (2016), confirming the presence of an acceptable trilevel structural model in the R01 sample. An identical factor analysis will be performed on trilevel symptom data collected independently at the EEG assessment described in this proposal. However, the EEG assessment included far less participants than the R01 and therefore may or may not produce an acceptable model fit. If a stable model cannot be extracted from the EEG assessment alone due to insufficient power, parameter estimates extracted from each participant at baseline in the R01 will be applied to the raw symptom data collected at the EEG assessment to calculate trilevel factor scores for General Distress, Fear, and Anhedonia.

ERPs and Trilevel Symptoms: Regression Analysis

The primary goal of this proposal is to examine associations between trilevel symptom dimensions and electrocortical activity collected at the same time. Associations between ERP components and symptom dimensions will be tested using linear regression analyses. Gender, age, handedness, and current medication use (i.e., psychotropic drugs) will be entered as covariates in each model. These regression analyses will test the core hypotheses of this proposal: 1. During an executive control task, General Distress and Fear will be associated with elevated ERN while Anhedonia will be

associated with decreased Pe, 2. General Distress and Fear will be associated with elevated P300 and LPP following threatening images during an emotional response task, and 3. Anhedonia will be uniquely associated with several reduced ERPs during a reward processing task during anticipation (Cue-P3, CNV, and SPN) and outcome (RewP) stages. If any hypotheses are confirmed, follow-up regression analyses will be performed by entering the remaining symptom dimensions as covariates. These follow-up analyses will test whether hypothesized associations between electrocortical activity and symptom profiles representing shared or unique features of anxiety and depression remain significant above and beyond the remaining symptom dimensions.

Power Analyses

Power analyses were conducted a priori in G*Power 3.1 (Faul et al., 2009) using the "Correlation: Bivariate normal model" test from the "Exact" test family. A meta-analysis (Moser et al., 2013) found that the association between anxious apprehension and the ERN contained a moderate effect size (r = .35). Although no meta-analyses examining the LPP-anxiety and RewP-depression associations exist, one prior study (MacNamara & Hajcak, 2009) found a significant association with moderate size between anxiety symptoms and the LPP (r = .36) while a recent finding from our lab (Glazer et al., 2019) found a significant, moderately sized association between depression symptoms and the RewP (r = .313). To guide sample size determination, these effect sizes were used with the following specified parameters: "α err prob" = .05, "Power (1- β err prob) = .80", and "Correlation ρ H0 = 0." To detect these moderate associations, results from power analyses indicate a required sample size of approximately 61 participants for the ERN association, approximately 71 participants for the RewP association, and approximately 58 participants for the LPP association.

Results

Results Overview

For each of the three tasks, separate repeated measures ANOVAs were performed on each ERP component to evaluate differences between task conditions. Each ANOVA controlled for psychotropic medications, experiment order, and handedness. Greenhouse-Geisser correction was used for all

ANOVA analyses and follow-up t-tests were performed to explore significant effects. For each significant effect, a difference score was calculated by subtracting ERP amplitude in one condition from the other. Linear regression analyses were performed to evaluate the relationship between these ERP difference waves and trilevel symptom factors. In each linear regression model, covariates were entered to control for psychotropic medication, experiment order, handedness, gender, and age. For each significant result, a second step was added with the addition of the opposing two trilevel symptom factors entered as covariates.

Executive Control SST Results

SST Behavioral Results

Four behavioral variables were extracted from the SST to verify the validity of the task based on prior studies (Wessel & Aron, 2015): go-trial reaction time (GoRT), reaction time on failed stop-trials (FsRT), stop-signal reaction time (SSRT), and accuracy (see Table 9). First, accuracy scores were between 80-90% (*M*: 0.833, *SD*: 0.031), confirming the adaptive algorithm worked as expected. Second, to validate the task, a two-way ANOVA was performed on reaction time condition (FsRT vs. GoRT) with psychotropic medications, experiment order, and handedness entered as covariates. Results confirmed a significant effect of condition ($F(1, 57) = 8.595$, $p = .005$, $\eta_p^2 = .131$) with slower reaction times for GoRT (*M*: 406.725 ms, *SD*: 85.308) compared to FsRT (*M*: 351.630 ms, *SD*: 71.666), validating the SST paradigm. Finally, as an exploratory analysis, correlations between GoRT, FsRT, and SSRT and each of the three trilevel symptom factors were performed. No significant effects emerged (*p*s > .09).

SST ERP Results

Two-way (correct vs. error response) repeated measures ANOVAs were performed separately for each ERP component (i.e., ERN, early Pe, and late Pe; see Figures 4-6). In each ANOVA, psychotropic medications, experiment order, and handedness were entered as covariates.

ERN. Results revealed a significant main effect of outcome ($F(1, 57) = 8.595$, $p = .005$, $\eta_p^2 = .131$) with increased ERN negative amplitude for error responses (*M*: 3.739, *SD*: 4.031) compared to correct responses (*M*: 5.312, *SD*: 3.528). No other significant effects emerged (*ps* > .495).

Early Pe. Results revealed a significant main effect of outcome ($F(1, 57) = 76.832$, $p < .001$, $\eta_p^2 = .574$) with increased early Pe positive amplitude for error responses (*M*: 3.287, *SD*: 4.449) compared to correct responses (*M*: -2.912, *SD*: 4.822). No other significant effects emerged (*ps* > .262).

Late Pe. Results revealed a significant main effect of outcome ($F(1, 57) = 71.469$, $p < .001$, $\eta_p^2 = .556$) with increased late Pe positive amplitude for error responses (*M*: 8.592, *SD*: 5.164) compared to correct responses (*M*: 0.065, *SD*: 3.441). No other significant effects emerged (*ps* > .262).

SST Regression Results

For each ERP component (i.e., ERN, early Pe, and late Pe; see Figure 18), difference waves were created by subtracting correct response conditions from error response conditions. Three linear regressions were performed by entering this difference wave ERP component as a predictor of each trilevel symptom factor (i.e., General Distress, Fears, and Anhedonia). For each regression, psychotropic medication, experiment order, handedness, gender, and age were entered as covariates. Significant effects were followed up with a second step adding the opposing trilevel symptom factors as additional covariates.

ERN. Results revealed a significant model fit between ERN difference wave amplitude and General Distress ($R^2 = .261$, $F(1, 55) = 5.245$, $p = .001$), but associations were not significant with Fear ($p = .732$) or Anhedonia ($p = .200$). Increases in General Distress scores significantly predicted increases in ERN difference wave amplitude ($\beta = .281$, $t(59) = 2.428$, $p = .018$). In the second step with Fear and Anhedonia entered as additional covariates, the association between General Distress and ERN difference wave amplitude remained significant ($\beta = .275$, $t(53) = 2.303$, $p = .025$).

Early Pe. Results revealed no significant associations early Pe difference wave amplitude and General Distress ($p = .232$), Fear ($p = .570$), or Anhedonia ($p = .651$).

Late Pe. Results revealed a significant model fit between the late Pe difference wave amplitude and Fear ($R^2 = .114$, $F(1, 59) = 2.547$, $p = .038$), but no significant associations emerged for General Distress ($p = .974$) or Anhedonia ($p = .846$). Increases in Fear scores significantly predicted increases in late Pe difference wave amplitude ($\beta = .331$, $t(59) = 2.639$, $p = .014$). In the second step with Fear and

Anhedonia entered as additional covariates, the association between General Distress and ERN difference wave amplitude remained significant (β = .331, t(53) = 2.493, p = .016).

Threat ERT Results

Two-way (correct vs. error response) repeated measures ANOVAs were performed separately for each ERP component (i.e., P300, early LPP, late LPP; see Figures 7-8). In each ANOVA, psychotropic medications, experiment order, and handedness were entered as covariates.

P300. Results revealed a significant main effect of condition (F(1, 57) = 27.226, p < .001, η_p^2 = .323) with increased P3 positivity for threatening (*M*: 7.510, *SD*: 6.520) compared to neutral (*M*: 4.171, *SD*: 4.819) images. No other significant effects emerged (*ps* > .187).

Early LPP. Results revealed a significant main effect of condition (F(1, 57) = 6.634, p = .013, η_p^2 = .104) with increased early LPP positivity for threatening (*M*: 1.310, *SD*: 5.453) compared to neutral (*M*: -0.510, *SD*: 4.142) images. No other significant effects emerged (*ps* > .307).

Late LPP. Results revealed no significant effect of condition (p = .133) with no differences between late LPP positivity for threatening (*M*: -0.043, *SD*: 5.246) compared to neutral (*M*: -1.135, *SD*: 4.493) images. No other significant effects emerged (*ps* > .116).

ERT Regression Results

For each ERP component (i.e., ERN, early Pe, and late Pe), difference waves were created by subtracting neutral image conditions from threatening image conditions. Three linear regressions were performed by entering this difference wave ERP component as a predictor of each trilevel symptom factor (i.e., General Distress, Fears, and Anhedonia).

P300. Results revealed no significant associations between P3 difference wave amplitude and General Distress (p = .150), Fear (p = .246), or Anhedonia (p = .070).

Early LPP. Results revealed no significant model fits between image P3 difference wave amplitude and General Distress (p = .855), Fear (p = .754), or Anhedonia (p = .806).

Late LPP. No regression analyses were performed for the late LPP due to no significant differences between conditions as revealed in the ANOVA analyses above.

Reward EMID Results

EMID Behavioral Results

To validate the EMID task adaptive algorithm produced a rate of approximately 50% positive and negative feedback, accuracy was calculated separately for reward and neutral conditions. Results revealed reward (*M*: 0.500 *SD*: 0.021) and neutral (*M*: 0.503, *SD*: 0.022) conditions both produced approximately 50% accuracy, validating the EMID paradigm (see Table 9). Reaction times for correct and incorrect responses were calculated separately for reward and neutral conditions, although these behavioral measures were not analyzed due to the use of an adaptive algorithm.

EMID Cue ERP Results

Two-way (condition: reward and neutral) repeated measures ANOVAs were performed separately for each ERP component (i.e., Cue-N2, Cue-P3, and Cue-LPP; see Figures 9-11). In each ANOVA, psychotropic medications, experiment order, and handedness were entered as covariates.

Cue-N2. Results revealed a significant main effect of cue-condition ($F(1, 57) = 15.587$, $p < .001$, $\eta_p^2 = .215$) with decreased negativity for reward (*M*: 2.759, *SD*: 4.008) compared to neutral (*M*: 0.676, *SD*: 3.771) cues. No other significant effects emerged.

Cue-P3. Results revealed a significant main effect of cue-condition ($F(1, 57) = 24.656$, $p < .001$, $\eta_p^2 = .302$) with increased positivity for reward (*M*: 11.144, *SD*: 5.150) compared to neutral (*M*: 7.786, *SD*: 3.488) cues. No other significant effects emerged.

Cue-LPP. Results revealed a significant main effect of cue-condition ($F(1, 57) = 22.277$, $p < .001$, $\eta_p^2 = .281$) with increased positivity for reward (*M*: 7.764, *SD*: 3.994) compared to neutral (*M*: 4.621, *SD*: 2.907) cues. No other significant effects emerged.

EMID Cue Regression Results

For each ERP component during cue-evaluation (i.e., Cue-N2, Cue-P3, Cue-LPP; see Figure 19), difference waves were created by subtracting neutral cues from reward cues. For each trilevel symptom dimension (General Distress, Fear, and Anhedonia), separate linear regressions were performed to evaluate distinct associations with reward and punishment difference waves. A total of three linear

regressions were performed by entering these reward and punishment difference waves as a predictor of each trilevel symptom factor (i.e., General Distress, Fears, and Anhedonia).

Cue-N2. Results revealed a significant model fit between General Distress and Cue-N2 difference waves amplitudes (R^2 = .238, F(1, 55) = 4.754, p = .001). Increases in General Distress scores significantly predicted decreases in Cue-N2 difference wave amplitude (β = -.241, t(59) = -2.014, p = .049). However, when Fear and Misery were entered as covariates in an additional step, this association became marginal (β = -.243, t(59) = -1.996, p = .051). Reward and punishment difference waves amplitudes were unassociated with Fear (p = .632) or Anhedonia (p = .965).

Cue-P3. Results revealed a significant model fit between General Distress and Cue-P3 difference waves amplitudes (R^2 = .269, F(1, 55) = 5.426, p < .001). Increases in General Distress scores significantly predicted decreases in Cue-P3 difference wave amplitude (β = -.300, t(59) = -2.564, p = .013). This association remained significant when Fear and Misery were entered as covariates in an additional step (β = -.306, t(59) = -2.535, p = .014). Reward and punishment difference waves amplitudes were unassociated with Fear (p = .184) or Anhedonia (p = .619).

Cue-LPP. Results revealed a significant model fit between General Distress and Cue-LPP difference waves amplitudes (R^2 = .261, F(1, 55) = 5.232, p = .001). Increases in General Distress scores significantly predicted decreases in Cue-LPP difference wave amplitude (β = -.288, t(59) = -2.418, p = .019). This association remained significant when Fear and Misery were entered as covariates in an additional step (β = -.301, t(59) = -2.380, p = .021). Reward and punishment difference waves amplitudes were unassociated with Fear (p = .074) or Anhedonia (p = .213).

EMID Response ERP Results

Two (accuracy: correct and incorrect) x two (condition: reward and neutral) repeated measures ANOVAs were performed separately for each ERP component (i.e., Early CNV, Late CNV, and SPN). In each ANOVA, psychotropic medications, experiment order, and handedness were entered as covariates.

Early CNV. Results revealed a significant main effect of condition (F(1, 57) = 18.042, p < .001, η_p^2 = .240) with an increased early CNV negativity for reward (M: -5.126, SD: 3.281) compared to neutral (M: -3.240, SD: 2.759) responses. No other significant effects emerged.

Late CNV. Results revealed a significant main effect of condition ($F(1, 57) = 12.571$, $p = .001$, $\eta_p^2 = .181$) with an increased late CNV negativity for reward (*M*: -7.358, *SD*: 4.903) compared to neutral (*M*: -5.547, *SD*: 3.931) responses. No other significant effects emerged.

SPN. Results revealed a significant main effect of outcome ($F(1, 57) = 5.286$, $p = .025$, $\eta_p^2 = .085$) with an increased SPN negativity for incorrect (*M*: -.020, *SD*: 4.142) compared to correct (*M*: 1.150, *SD*: 3.455) responses. No other significant effects emerged.

EMID Response Regression Results

Early CNV. Results revealed no significant associations between early CNV reward and neutral difference wave amplitudes for General Distress ($p = .137$), Fears ($p = .480$), or Anhedonia ($p = .818$).

Late CNV. Results revealed no significant associations between early CNV reward and neutral difference wave amplitudes for General Distress ($p = .433$), Fears ($p = .203$), or Anhedonia ($p = .522$).

SPN. Results revealed no significant associations between early CNV correct and incorrect difference wave amplitudes for General Distress ($p = .633$), Fears ($p = .161$), or Anhedonia ($p = .715$).

EMID Outcome ERP Results

Two (outcome: positive and negative feedback) x two (condition: reward and neutral) way repeated measures ANOVAs were performed separately for each ERP component (i.e., RewP, FB-P3, and FB-LPP; see Figures 14-17). In each ANOVA, psychotropic medications, experiment order, and handedness were entered as covariates.

RewP. Results revealed a significant main effect of outcome ($F(1, 57) = 19.644$, $p < .001$, $\eta_p^2 = .256$) with increased positivity for positive (*M*: 10.055, *SD*: 5.475) compared to negative (*M*: 7.498, *SD*: 4.578) feedback. Results also revealed a significant main effect of cue-condition ($F(1, 57) = 30.516$, $p < .001$, $\eta_p^2 = .349$) with increased positivity for reward (*M*: 11.022, *SD*: 6.180) compared to neutral (*M*: 6.531, *SD*: 3.989) feedback. There was also a significant outcome x cue-condition interaction ($F(1, 57) = 14.193$, $p < .001$, $\eta_p^2 = .199$). To unpack the interaction, positive – negative feedback difference waves were calculated separately for reward and neutral conditions. Follow-up t-tests revealed the RewP difference wave for reward feedback was significantly greater than neutral feedback ($t(60) = 3.914$, $p < .001$). No other significant effects emerged.

FB-P3. Results revealed a significant main effect of outcome ($F(1, 57) = 42.745$, $p < .001$, $\eta_p^2 = .429$) with increased positivity for positive (*M*: 12.311, *SD*: 5.530) compared to negative (*M*: 9.241, *SD*: 5.308) feedback. Results also revealed a significant main effect of cue-condition ($F(1, 57) = 78.795$, $p < .001$, $\eta_p^2 = .580$) with increased positivity for reward (*M*: 13.709, *SD*: 6.131) compared to neutral (*M*: 7.844, *SD*: 4.727) feedback. There was also a significant outcome x cue-condition interaction ($F(1, 57) = 17.364$, $p < .001$, $\eta_p^2 = .233$). To unpack the interaction, positive – negative feedback difference waves were calculated separately for reward and neutral conditions. Follow-up t-tests revealed the RewP difference wave for reward feedback was significantly greater than neutral feedback ($t(60) = 3.231$, $p = .002$). No other significant effects emerged.

FB-LPP. Results revealed a significant main effect of outcome ($F(1, 57) = 25.658$, $p < .001$, $\eta_p^2 = .310$) with increased positivity for positive (*M*: 7.745, *SD*: 3.990) compared to negative (*M*: 5.193, *SD*: 3.250) feedback. Results also revealed a significant main effect of cue-condition ($F(1, 57) = 25.063$, $p < .001$, $\eta_p^2 = .580$) with increased positivity for reward (*M*: 7.775, *SD*: 3.886) compared to neutral (*M*: 5.164, *SD*: 3.433) feedback. No other significant effects emerged.

EMID Outcome Regression Results

RewP. Results revealed no significant associations between RewP reward – neutral difference wave amplitudes for General Distress ($p = .716$), Fears ($p = .970$), or Anhedonia ($p = .470$). For the positive – negative feedback difference wave in the reward condition, no significant associations emerged with General Distress ($p = .060$), Fears ($p = .643$), or Anhedonia ($p = .670$).

FB-P3. Results revealed no significant associations between RewP reward – neutral difference wave amplitudes for General Distress ($p = .396$), Fears ($p = .326$), or Anhedonia ($p = .400$). For the positive – negative feedback difference wave in the reward condition, no significant associations emerged with General Distress ($p = .273$), Fears ($p = .893$), or Anhedonia ($p = .600$).

FB-LPP. Results revealed a significant model fit between General Distress and FB-LPP positive – negative feedback difference wave amplitudes ($R^2 = .251$, $F(1, 55) = 5.015$, $p = .001$). Increases in General Distress scores significantly predicted decreases in FB-LPP difference wave amplitude ($\beta = -.252$, $t(59) = -2.244$, $p = .029$; see Figure 19). This association remained significant when Fear and

Misery were entered as covariates in an additional step (β = -.260, t(59) = -2.271, p = .027). General Distress was not significantly associated with the reward - neutral difference wave amplitude (p = .292). No significant associations emerged between the FB-LPP the positive – negative feedback difference wave or the reward – neutral difference wave for Fear (p = .497, p = .553) or Anhedonia (p = .638, p = 426).

Discussion

The current study examined associations between shared (General Distress) and distinct (Fear and Anhedonia) symptom dimensions of anxiety and depression and ERP components elicited during executive control, threat, and reward processing tasks. As predicted, General Distress was uniquely associated with an increased ERN amplitude during the executive control task. By contrast, Fear was uniquely associated with increased Pe amplitudes while Anhedonia was unassociated with ERP amplitudes during executive control. However, contrary to hypotheses, none of the trilevel symptom factors were associated with ERP amplitudes elicited during the ERT threat processing task. Instead, General Distress was associated with broadly decreased reward-related neural activity during cue-evaluation across several ERP components (Cue-N2, Cue-P3, and Cue-LPP) as well as attenuated FB-LPP amplitudes during feedback processing. By contrast, Anhedonia and Fear were unassociated with reward-related ERPs. Finally, each result remained significant when controlling for the two opposing trilevel symptom dimensions, suggesting trilevel factors are well-suited to identify unique neurophysiological correlates of shared and distinct symptom dimensions of anxiety and depression. Results reveal important implications for risk, diagnosis, and treatment of anxiety and depression disorders.

In the following discussion sections, I will first discuss results from the executive control task (SST) that revealed significant effects for General Distress and Fear, but not Anhedonia. Second, I will discuss results from the threat processing task (ERT) which revealed no significant associations with any of the three trilevel factors. Third, I will discuss results from the reward processing task (EMID) that revealed significant effects for General Distress, but not for Fear or Anhedonia. Forth, I will consider an important experimental confound that may have significantly distorted feedback-related ERPs during the

reward processing EMID task. Lasty, I will explore limitations of the present results and potential future directions before concluding.

Executive Control and General Distress

Results from the executive control task (SST) revealed that General Distress was uniquely associated with increased ERN amplitudes. The ERN signals an outcome has gone worse than expected and reflects conflict monitoring processes that covary with activation in the ACC (see Simons et al., 2010 for review; Holroyd et al., 2004; Yeung et al., 2004; Gehring et al., 1993). Decades of clinical psychophysiological research suggest increased ERN amplitudes may constitute a heritable, trait-like biomarker that prospectively predicts risk, onset, and treatment of anxiety disorders (Olvet & Hajcak, 2008; Anokhin et al., 2008; see Meyer, 2016 and 2017 for reviews). For example, the ERN is stable in child and adult populations (Weinberg et al., 2011b; Meyer et al., 2014; Larson et al., 2010) and has predicted the onset and symptom severity of various anxiety disorders across several different development periods (Meyer et al., 2015, 2018, 2021). These associations are especially robust for anxiety disorders charactered by symptom dimensions shared with depression, such as Generalized Anxiety and Obsessive-Compulsive Disorders (Endrass et al., 2008; Gehring et al., 2000; Weinberg et al., 2010, 2012a, 2015; Xiao et al., 2011). Elevated ERN amplitudes have also predicted better treatment outcomes to SSRIs and cognitive behavioral therapy in young adults diagnosed with principal anxiety disorders (Gorka et al., 2017), yet remained elevated after treatment in youth and adolescents with social anxiety disorders (Kujawa et al., 2016). Together, these studies suggest the ERN may index a potential endophenotype reflecting trait-like vulnerability for anxiety disorders.

The present results provide novel evidence that ERN-anxiety associations are driven by symptom dimensions shared with depression rather than symptoms specific to anxiety disorders. Contrary to predictions, Fear was unassociated with ERN amplitudes, suggesting General Distress is uniquely associated with the ERN. In support, several previous studies indicate elevated ERN amplitudes are associated with symptoms of cognitive worry, which are shared with depression and load strongest onto General Distress, but not symptoms of anxious arousal, which are specific to anxiety disorders and load strongest onto Fear (Weinberg et al., 2012a; Vaidyanathan et al., 2012; Hajcak et al., 2003; Moser et al.,

2005, 2012). Furthermore, symptoms of worry among healthy college undergraduates are also associated with increased ERN amplitudes (Moser et al., 2011; Hajcak et al., 2003), suggesting the worry-ERN relationship may reflect a transdiagnostic phenotype that characterizes a continuum of executive control dysfunction rather than a distinct category (Watson, 2005; Brown & Barlow, 2009). The present results are the first to demonstrate ERN-specific associations with the trilevel factor of General Distress continue hold above and beyond unique symptom dimensions of Fear and Anhedonia, supporting the transdiagnostic utility of the ERN as an index of shared, rather than distinct, symptom dimensions of anxiety and depression.

Despite increased ERN amplitudes, General Distress was unassociated with behavioral measures of reaction time (i.e., GoRT and FsRT) or response inhibition (i.e., SSRT). Compensatory error monitoring theories maintain that this pattern of increased ERN amplitude without corresponding deficits in behavioral performance is driven by the deleterious impact of cognitive worry on executive control, reflecting the “hidden cost” of anxiety (Moser et al., 2013; Berggren & Derakshan, 2013). Under these accounts, worrisome thoughts compete for limited cognitive and attentional resources that would otherwise be allocated to the executive control task (Beilock, 2008, 2010). This cognitive interference reduces neural efficiency (Eysenck & Calvo, 1992; Eysenck et al., 2007), requiring compensatory increases in cognitive effort to achieve comparable behavioral performance. In other words, symptoms of worry decrease neural efficiency, but not necessarily effectiveness, which is maintained via increased compensatory effort indexed by the ERN (Moran et al., 2012; Moser et al., 2012). As task difficulty increases, ERN amplitude decreases (Pailing & Segalowitz, 2004; Scheffers & Coles, 2000), and compensatory effort may become insufficient to offset the deleterious impact of worry on performance (Beilock, 2008, 2010; Ramirez et al., 2012; Beilock & Carr, 2005). However, the current results suggest that the SST was of low enough difficulty where increased ERN amplitudes associated with elevated General Distress scores were sufficient compensatory neural responses that maintained normal levels of behavioral performance.

Executive Control and Fear

Beyond the ERN, increased late Pe amplitudes for error compared to correct responses were significantly associated with Fear, but not General Distress or Anhedonia. Several studies have linked the late Pe to attentional control and context updating mechanisms involved in adaptive post-error behavioral adjustments during executive control tasks (Moser et al., 2011; Schroder et al., 2017, 2020), especially processes involved in error awareness (Endrass et al., 2005; Leuthold & Sommer, 1999; Nieuwenhuis et al., 2001). For example, when participants subjectively reported their error awareness after each trial, unreported errors continued to elicit an ERN yet did not elicit a Pe (Nieuwenhuis et al., 2001; Endrass et al., 2005; Overbeek et al., 2005; O'Connell et al., 2007; Shalgi et al., 2009; Dhar et al., 2011; Murphy et al., 2012). In the current study, the Fear-Pe relationship is likely driven in part by increased attentional processing and conscious awareness of mistakes, although this effect did not result in performance differences as Fear was unassociated with behavioral measures. Compensatory models of error monitoring suggest this pattern of results may reflect a compensatory attentional mechanism that enhances context updating after mistakes to offset the deleterious effect of Fear-related anxiety symptoms on behavioral performance (Moser et al., 2013).

In contrast to compensatory models that rely on cognitive aspects of error processing, alternative defensive reactivity theories propose that errors represent aversive events that pose threats to safety that may require immediate attention and corrective action (Hajcak & Foti, 2008). These theories draw from recent evidence that the Pe also indexes motivational and affective processing of errors that are essential to facilitate behavioral change and improve future performance (Ridderinkhof et al., 2009; Endrass et al., 2012b; Pailing & Segalowitz 2004; Kim et al., 2017; Leuthold & Sommer, 1999). Errors are known to elicit a rapid cascade of physiological processes before and beyond their neurocognitive effects, such as changes in skin conductance, heart rate variability, and potentiated startle reflexes (Hajcak et al., 2003, 2004, 2008). According to these accounts, the ERN and Pe may reflect neural markers of defensive reactivity involved in mobilizing defensive motivational systems after mistakes (Hajcak, 2012; Weinberg et al., 2012b), suggesting an enhanced Pe may reflect hypervigilance to internal signals of threat. In support, decades of prior research have documented a hyperactive threat processing among fear-related anxiety disorders and symptom dimensions (Craske & Vervliet, 2013). Therefore, while General Distress-ERN associations may be due to the impact of cognitive worry on neural efficiency during executive

control, Fear-Pe associations may be driven by this hypervigilance to threating information that emerges with the conscious awareness of error recognition. Furthermore, Fear-Pe and General Distress-ERN associations remained significant while controlling for the two opposing trilevel symptom dimensions, indicating these associations are independent and unique. Together, these results that the ERN and Pe index unique error-related neural dysfunction that may differentiate between shared symptom profiles of anxiety and depression and specific symptom profiles related to anxiety disorders. The ERN and Pe may therefore constitute promising neurophysiological correlates of differential risk, diagnosis, and treatment for anxiety and depression disorders.

The present results may also resolve several inconsistencies among prior studies. First, unlike the ERN, associations between the Pe and anxiety disorders among prior research are less frequently studied and are often inconsistent. For example, several studies have reported associations between anxiety disorders and increased ERN amplitudes across several different development periods but failed to observe significant associations between anxiety and Pe amplitudes among these same participants (Weinberg et al., 2010; Ladouceur et al., 2006; McDermott et al., 2009; Ruchsow et al., 2005). By contrast, in a more recent intervention study, increased Pe amplitudes predicted better treatment responses to cognitive behavioral therapy in a sample population with social anxiety and major depressive disorders (Kinney, 2021). Second, our results revealed that Anhedonia was unassociated with either the ERN or the Pe, contrary to predictions. Previous research investigating the ERN in depressed populations is also mixed, with some studies reporting depression disorders are associated with increased ERN amplitudes (Chiu & Deldin, 2007; Holmes & Pizzagalli, 2008, 2010) and others reporting no differences or significantly attenuated ERN amplitudes (Olvet et al., 2010; Ruchsow, Herrnberger, et al., 2004, 2006; Schrijvers et al., 2008, 2009). Our results provide novel empirical evidence that these inconsistences among prior studies may be due to the relative distribution of shared and distinct symptoms among their sample populations, consistent with previous suggestions (Olvet et al., 2010). That is, only samples with relatively increased symptoms of Fear unique to anxiety disorders may display significant associations with Pe amplitudes while increases in shared symptoms of General Distress may not. On the other hand, depressed samples with elevated shared symptoms of General Distress may

display increased ERN amplitudes, especially those high in worry, while those with primarily increased symptoms of Anhedonia unique to depression disorders may not.

The present results also suggest an alternative explanation for inconsistent anxiety-Pe relationships reported among prior studies may be due to ERP measurement differences that may significantly impact associations with Fear. Fear was only significantly associated with enhanced late Pe amplitudes in the current study while most studies have focused only on the early Pe component. Using independent and principal component analysis, prior studies have shown that only the late, centroparietal Pe is essentially related to the conscious awareness of mistakes while earlier and frontocentral Pe components are not (Endrass et al., 2007, 2012a, 2012b). In fact, using single-trial analysis, Murphy and colleagues (2012) demonstrated that the centroparietal Pe peak latency precisely tracked the emergence of error awareness rather than error commission, with increased latency associated with diminished Pe amplitudes. It is possible that Fear-Pe relationships may reflect extended motivated attentional processes involved in the conscious awareness of mistakes, rather than quicker, automatic processes such as error detection characteristic of the ERN.

Threat

Results revealed that none of the three trilevel symptom factors were associated with P3 and LPP components elicited by threatening images during the ERT, contrary to predictions that General Distress and Fear would increase threat-related P3 and LPP amplitudes. Despite no significant associations with trilevel factors, ERP results revealed that threatening images elicited increased P3 and early LPP amplitudes compared to neutral images, indicating the task successfully elicited threat-related neural activity reported in prior studies (see Hajcak & Foti, 2020 for review). These results conflict with several prior studies that have linked similar threat-related increases in LPP amplitudes to anxiety disorders and symptom dimensions of anxiety. For example, prior work has observed increased threat-related LPP amplitudes across several anxiety disorders characterized by symptom dimensions of Fear (Bar-Haim, Lamy and Glickman, 2005; Mocaiber et al., 2009; Kujawa et al., 2015, 2016), such as panic (Pauli et al., 1997) and phobia disorders (Moser et al., 2008; Miltner et al., 2005; Michalowski et al., 2009). Related research has also linked unique symptom dimensions of anxiety to increased threat-related LPP

amplitudes, such as automatic arousal and trait anxiety (Cuthbert et al., 2000; Mocaiber et al., 2009; MacNamara & Hajcak, 2010; MacNamara et al. 2011) which load strongest onto the trilevel Fear factor. Although increased threat-related LPP amplitudes have even predicted familial risk for fear-related anxiety disorders (Nelson et al., 2015), our results indicate anxiety-LPP associations may be less robust than this line of literature suggests.

By contrast, this threat-related LPP effect has also been observed among anxiety disorders that share several symptom dimensions with depression, such as generalized and social anxiety disorder (MacNamara & Hajcak, 2010; Kujawa et al., 2016). Two studies have replicated these effects for shared symptom dimensions of worry and negative affect that load strongest onto the General Distress factor (Moser et al., 2014; MacNamara, 2018). Although few LPP studies have parsed symptom dimensions of anxiety and depression, in one recent study both generalized anxiety disorder and symptom dimensions of anxiety were associated with increased LPP amplitudes for emotional images, even when controlling for depression diagnosis and dimensional depression symptom scores (MacNamara et al., 2016). In opposition to these prior studies, the current study found no association with General Distress, suggesting that increased threat-related LPP amplitudes may not emerge when symptom dimensions of anxiety and depression are carefully separated via the trilevel model.

Although previous research generally supports a connection between anxiety disorders and threat-related ERPs, the present null results add to an increasingly complex, inconsistent, and often contradictory emerging literature. For example, while some studies have observed increased threat-related LPP amplitudes were associated with shared symptoms of worry and negative affect that load strongest onto the General Distress factor (MacNamara, 2018; Moser et al., 2014), other studies reported decreased LPP amplitudes to various emotional stimuli were associated with familial risk for distress disorders, including major depression and generalized anxiety (Nelson et al., 2015). Furthermore, in one study, shared symptoms of worry were associated with increased threat-related LPP amplitudes even when controlling for state-related anxiety symptoms (Burkhouse et al., 2015) while another study reported high worriers displayed reduced LPP amplitudes to threatening and emotional stimuli (Grant et al., 2015). Prior studies investigating generalized anxiety disorder have also reported increased LPP amplitudes (MacNamara & Hajcak, 2010), decreased LPP amplitudes (Weinberg & Hajcak, 2010), or observed no

significant effects (Weinberg et al., 2016). In a rare study that parsed symptom dimensions of anxiety and depression, anxiety disorders were unrelated to LPP amplitudes regardless of comorbidity with depression (Weinberg et al., 2016), an effect consistent with the null effects reported here.

Although a stable relationship between the threat-related P3 and LPP and symptoms of anxiety and depression may not exist, one alternative reason for the present null effects may be state-related influences on LPP amplitudes, especially related to fatigue and exhaustion. In the current study, all participants completed the ERT last (i.e., approximately two-hours into study) to prevent carry over effects on subsequent tasks from potentially increased state-anxiety levels, an effect reported in prior research (Pedersen & Larson, 2016). Furthermore, several prior studies have linked decreased P300 and LPP amplitudes to increased fatigue (Sabeti et al., 2018; Cheng et al., 2007; Faber et al., 2012; Mun et al., 2014), suggesting the current results may have been driven by decreased task engagement (Hopstaken et al., 2016; Boksem et al., 2005). For example, depression disorders and symptom dimensions of depression have been associated with blunted LPP amplitudes to positive and emotional stimuli (Sandre et al., 2019; Weinberg et al 2016; MacNamara et al., 2016), putatively reflecting decreased task engagement and affective processing of positive information. Furthermore, several studies have shown that state-related symptoms of anxiety and depression, such as state-anxiety and state-related decreases in motivation, have significantly and independently impacted threat-related LPP amplitudes beyond trait-related symptoms dimensions, such as trait-anxiety and worry (Weinberg et al., 2016; Chronaki et al., 2018; MacNamara & Hajcak, 2009; Kujawa et al., 2016). In another study, working memory load was found to decrease LPP amplitudes, but this effect was attenuated by increased state anxiety symptoms (MacNamara et al., 2011). Together, these inconsistencies suggest state-related influences may constitute an important confound when investigating trait-like symptom dimensions of anxiety and depression. One limitation of the current study is that state-like measures of anxiety and depression were not included. Future studies should consider the influences of state-related measures on P3 and LPP amplitudes during threat processing tasks in the context of anxiety and depression.

Reward and General Distress

Contrary to predictions, results from the EMID reward task revealed General Distress was associated with decreased cue-related neural activity during the EMID reward processing task, while no significant effects emerged for Anhedonia or Fear. Specifically, General Distress was associated with broadly decreased reward-related neural activity across three separate ERP components elicited during cue-evaluation (i.e., Cue-N2, Cue-P3, and Cue-LPP). Although many studies have examined feedback-related ERPs during outcome processing in the context of anxiety and depression, to the author's knowledge the present results are the first to directly link shared symptoms of anxiety and depression to cue-related ERP components during reward processing. Therefore, future studies of anxiety and depression that examine reward-related ERP components during cue-evaluation are needed to confirm these preliminary results.

Taken together, results indicate General Distress was associated with sustained reductions in ERP amplitudes for reward compared to neutral cues from approximately 200-800 ms post-cue onset. Significant effects emerged across three separate ERP components associated with distinct neurophysiological correlates, scalp topographies, and psychological processes (see Glazer et al., 2018 for review). First, the Cue-N2 is a conflict monitoring ERP component that covaries with activation in the ACC and tracks template mismatches between expected reward cues and neutral cue stimuli (Pornpattananangkul & Nusslock, 2015; Donkers et al., 2005; Gehring et al., 1993; Folstein & Van Petten, 2008). Results revealed General Distress was associated with decreased template mismatches between reward and neutral cues, reflecting reduced reward-related conflict monitoring during cue-evaluation (Nieuwenhuis et al., 2003; Yeung et al., 2004). Next, the Cue-P3 reflects stimulus categorization and context updating and covaries with activation in the ventral straitum in addition to several other regions (Goldstein et al., 2006; Hughes et al., 2013; Pfabigan et al., 2014; Donchin & Coles, 1998; Johnson & Donchin, 1980; see Polich, 2007 for review). Recent studies have also linked the Cue-P3 to motivated attention that facilitates goal-oriented actions and approach-related behaviors to maximize upcoming potential rewards (Broyd et al., 2012; Goldstein et al., 2006; Pfabigan et al., 2014; Pornpattananangkul & Nusslock, 2015; Novak & Foti, 2015). The present results suggest General Distress is associated with reduced motivational significance and attenuated context updating of reward compared to neutral cues. Finally, although few studies have examined the LPP during reward processing, related studies suggest

the Cue-LPP encodes the affective impact of emotional stimuli in working memory (Olofsson et al., 2008) and covaries with activation in the amygdala and visual cortex (Bradley et al., 2003). In contrast to the threat-related LPP elicited by threatening images in the ERT, a passive image viewing task that did not require any behavioral responses, the reward-related Cue-LPP elicited during cue-evaluation likely indexes additional cognitive-affective encoding of reward cues to facilitate upcoming behavioral responses and reward pursuit during subsequent motor preparation and feedback anticipation stages (Von Borries et al., 2013; San Martín et al., 2013; Trimber & Luhmann, 2017). Together, these results suggest General Distress was broadly associated with reduced conflict monitoring, motivated attention, and affective impact of reward cues.

Initially, these findings appear to conflict with the results from the executive control task (SST) where General Distress was associated with increased conflict monitoring, as indexed by the ERN. Although few studies have examined associations between anxiety and depression disorders and cue-related ERPs during the EMID, important differences between executive control and reward processing tasks may provide valuable insight. Recall that compensatory error processing models suggest General Distress is associated with increased conflict monitoring due to worry-driven neural inefficiency, requiring compensatory increases in the ERN to normalize behavioral performance (Moran et al., 2012; Moser et al., 2012, 2013). This effect is presumably related to increased neural competition between top-down, goal-orientated cognitive control systems directed toward task performance and bottom-up, stimulus-driven attentional systems directed toward salient and threating information (Eysenck et al., 1992, 2007). When no external source of threat or distraction is present, internal worry may become distracting and deplete goal-driven neural resources (Moser et al., 2013). These two competing systems are described in a recent dual mechanisms of control theory (DMC: Braver et al., 2007; Braver, 2012). Under this account, proactive control involves anticipatory maintenance of goal-related information efficiently sustained over time while reactive control involves transient stimulus-driven reactivation of goal-related information that rapidly mobilizes cognitive resources only when they are immediately required.

Emerging evidence from studies that implement similar cue-response experimental tasks as the EMID indicate anxiety disorders, especially symptoms of increased cognitive worry, bias reactive control systems via decreased cue-related processing and increased compensatory response-related processing

(Gray et al., 2005; Fales et al., 2008; Krug & Carter, 2010, 2012). Unlike response errors generated in executive control tasks that may require transient reactivation in a “just in time” or “late correction” manner, reward and neutral cues in the EMID task do not require any behavioral responses. In fact, there is a lengthy 3000 ms delay between cue and target presentation in the EMID task used in the current study. It is possible that cue-evaluation during the EMID favors proactive maintenance of task goals and rules not only in service of conflict monitoring, indexed by the Cue-N2, but also during stimulus categorization and extended affective processing, indexed by the Cue-P3 and Cue-LPP. According to this interpretation, General Distress is associated with sustained attenuation of reward-related ERPs during cue-evaluation due to an overreliance on reactive control that prevents proactive categorization, integration, and affective evaluation of reward cues.

However, under DMC accounts, reduced proactive control should also attenuate sustained “slow wave” activity, such as the CNV and SPN, perhaps even more-so than quicker cue-related ERPs. By contrast, General Distress was not associated with either the CNV or the SPN in the current study, suggesting potentially intact reward-related neural functioning during motor preparation and feedback anticipation. As mentioned previously, these results are preliminary and require future studies to confirm these unique associations between General Distress and cue-related neural dysfunction during reward anticipation. One promising route would be to manipulate the EMID delay between cue and target presentation to probe whether shorter durations may produce results similar to speeded cognitive control tasks.

Finally, General Distress was also associated with a decreased FB-LPP difference between positive and negative feedback during outcome processing. While the FB-LPP reflects similar processes associated with context updating and motivational salience as the Cue-LPP, positive and negative feedback in the EMID task also delivers important performance information that can be used to update predictive models and maximize future rewards across both reward and neutral conditions. Therefore, it is possible that the FB-LPP may also index goal-directed processes characteristic of proactive control. However, outcome processing stages are difficult to interpret in the present study due to an important experimental confound that likely introduced strong salience effects on feedback-related ERPs, discussed in detail in the following sections. This experimental confound may have artificially inflated differences

between feedback conditions, especially differences between positive and negative feedback, which were associated with General Distress, and therefore these results should be replicated in future studies that control for this experimental confound.

Reward and Anhedonia

Contrary to predications, Anhedonia was unassociated with reward-related ERPs during anticipation and outcome in the EMID task, including the RewP. Although substantial prior research has linked depression disorders and symptoms of anhedonia to reduced RewP amplitudes (Proudfit, 2015), the null relationship reported here may be due to statistical power concerns. For example, a-priori power analyses indicate 78 participants were required to detect Anhedonia-RewP associations. For this reason, 79 participants were recruited and completed the EMID task. However, in the current study, only participants who completed all three tasks and the trilevel symptom questionnaires were included, resulting in a final sample size of 61. This approach was chosen to analyze the neural correlates of trilevel symptom dimensions across executive control, threat, and reward processing domains within the same subjects. Although a priori power analyses indicated that our final sample size of 61 is appropriately powered for all other hypotheses examined in the present study, this final sample size may be underpowered to detect specific Anhedonia-RewP associations. Although a priori power calculations were not conducted to determine the appropriate sample size to detect associations between Anhedonia and reward-related ERPs during anticipation stages due to a lack of prior research in this area, these anticipation-related associations may also require similarly increased sample sizes to detect significant effects. Future studies should examine whether increased sample sizes may produce significant associations between trilevel factor scores of Anhedonia and the RewP and whether increased sample sizes may also produce significant associations among other stages of reward processing, such as cue-evaluation, motor preparation, and outcome processing.

An alternative explanation for the null Anhedonia-RewP association in the current study is that our feedback-related ERP data were significantly impacted by an experimental confound. Specifically, results from a recent study using an identical EMID task design suggest that feedback-related ERPs in the current study, including the RewP, may have been artificially inflated due to stimulus frequency

differences in the presentation of feedback stimuli (Glazer and Nusslock, 2022). Previous studies have confirmed that outcome probability, that is the proportion of positive and negative feedback, significantly impacts RewP amplitudes, with less common outcomes producing increased RewP positivity (San Martin, 2012). The current study attempted to control for this potential experimental confound in the EMID task using an adaptive algorithm that kept the ratio of positive to negative feedback at approximately 50% in both the reward and neutral condition. Although this algorithm successfully produced a positive-to-negative feedback ratio of 50%, Glazer and Nusslock (2022) showed that there are two types of outcome probability: a given feedback stimulus, or stimulus-level (i.e., +$1.50), and what that stimulus abstractly represents, or representation-level (i.e., monetary gain). At the representation-level, the ratio of positive and negative feedback in the current study was successfully kept at 50% for both the reward and neutral condition. However, at the stimulus-level, positive and negative feedback stimuli consisted of “+$1.50” and “-$0.00” in the reward condition and “+$0.00” and “-$0.00” in the neutral condition. In this way, the negative feedback stimulus of “-$0.00” was presented twice as often as the positive feedback stimuli because it was used to denote negative feedback in both the reward and neutral condition.

Using temporospatial principal component analysis, Glazer and Nusslock (2022) showed that infrequent outcomes at the stimulus-level (i.e., “+$1.50” and “+$0.00”) elicited strong salience effects across several feedback-related ERP components that may artificially inflate RewP and FB-P3 differences between positive and negative feedback conditions. Therefore, it is likely thar reward-specific variation in the RewP captured by differences between positive and negative feedback conditions, a measure linked to Anhedonia, was confounded by an overlapping positivity driven by the salience of infrequent feedback stimuli. This experimental confound makes it difficult to draw conclusions from the lack of an association between Anhedonia and feedback-related ERPs in the current study. Furthermore, this overlapping positivity may have also contributed to the significant relationship between General Distress and the FB-LPP component. Therefore, the association between General Distress and FB-LPP amplitudes reported in the current study may have been driven by increased salience of infrequent feedback stimuli (i.e., stimulus-level) rather than reward-specific variation captured by the difference between positive and negative feedback outcomes (i.e., representation-level). However, importantly, this experimental confound was specific to feedback stimuli and only impacted reward outcome stages (i.e.,

RewP, FB-P3, and FB-LPP) while anticipatory ERP components were unaffected. Future research should further examine associations between feedback-related ERPs and trilevel symptom factors while controlling for both representation-level and stimulus-level outcome probability effects.

Limitations.

The current study has several limitations. First, as described above, feedback-related ERPs in the reward EMID task were likely distorted due to differences in stimulus frequency that have recently been shown to inflate differences between positive and negative feedback conditions (Glazer et al., 2022). This experimental confound makes it difficult to interpret novel associations between General Distress and FB-LPP amplitudes as well as the null associations between Anhedonia and RewP amplitudes. However, importantly, this experimental confound was limited to feedback stimuli and therefore did not influence reward-related ERPs elicited during anticipation stages. Second, no state measures were administered in the current study due to time constraints and therefore state-related differences in anxiety and depression symptom dimensions may have contributed to the present results. For example, previous research suggests state-related differences in anxiety, motivation, and especially fatigue may have contributed to the null associations between trilevel symptom dimensions and threat-related ERP amplitudes during the ERT task. Third, the participant sample consisted of mostly females recruited from the community that displayed a normalized distribution of trilevel symptom scores. Although the strength of this approach allowed for regression analyses that examined linear relationships between symptom dimensions and electrocortical activity, this approach is also unable to detect nonlinear associations that may depend on a more extreme symptom distribution. For example, it is possible that Fear-ERN associations may depend on severe symptom presentations while the GD-ERN relationship may emerge even among non-anxious individuals at increased risk for anxiety disorders. Future research is needed to probe trilevel model symptom distributions and their corresponding neural correlates in clinical samples of anxiety and depression.

Lastly, although the parent R01 collected trilevel symptom measures on these same participants at four separate time-points across a three-year longitudinal period, analyses in the current study were limited to cross-sectional data collected during a single EEG assessment. The final sample size was limited to participants already enrolled in the parent R01 who volunteered to participate in this optional

EEG assessment, which was conducted at variable timepoints depending on participant availability to maximize final sample size. Only participants that completed all tasks and questionnaire measures were included to evaluate the neural correlates of the trilevel symptom dimensions in the same subjects. However, while a secondary goal of the current study was to evaluate associations between electrocortical activity and change in trilevel symptoms over time, the final sample size of 61 participants was inadequate to detect these longitudinal effects with sufficient statistical power. Extending the current results to longitudinal and prospective analyses are promising directions for future research. Finally, this sample size may also have been insufficient to detect associations between Anhedonia and RewP amplitudes, which an a priori power analyses indicated may require at least 78 participants.

Conclusions

The current study is the first to examine associations between shared (i.e., General Distress) and distinct (i.e., Fear and Anhedonia) symptom dimensions of anxiety and depression and abnormal electrocortical activity during executive control, threat, and reward processing tasks. Each task leveraged the strong temporal resolution of ERP to measure several different ERP components that reflect independent psychological processes, display distinct scalp topographies, and covary with separate neuroanatomical correlates. Results revealed that General Distress was uniquely associated with increased ERN amplitudes and Fear was uniquely associated with increased Pe amplitudes during the executive control task. The ERN and Pe may therefore constitute promising neurophysiological correlates of differential risk, diagnosis, and treatment for anxiety and depression disorders. However, contrary to predictions, no significant associations emerged between threat-related ERPs and trilevel symptom factors were found. Finally, results revealed novel associations between General Distress and broad reductions in cue-related ERPs during the reward processing task across the Cue-N2, Cue-P3, and Cue-LPP. These results suggest General Distress may be characterized by increased conflict monitoring during executive control and stage-specific reductions in reward-related brain function during cue-evaluation. Together, these results reveal for the first time that shared and distinct trilevel symptom dimensions of anxiety and depression are associated with specific neurophysiological profiles of electrocortical activity across separate processing domains. This preliminary evidence supports the

potential clinical utility of electrophysiology and trilevel models that may ultimately help detect risk, improve diagnosis, and develop targeted treatments informed by contemporary neurophysiology.

Figures.

Figure 1.

Executive Control: Stop Signal Task (SST)

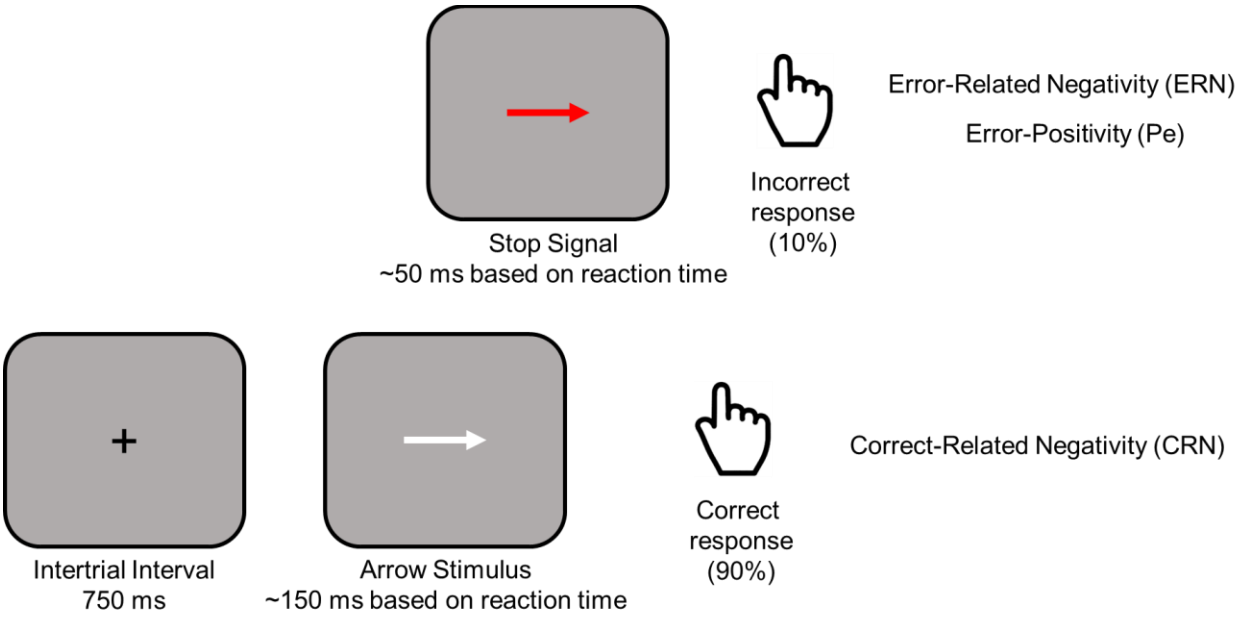

Figure 1 shows the SST trial structure. On 90% of trials, a white arrow is presented for a duration matched to the participant reaction time. Participants respond as quick as possible. On 10% of trials, a red arrow ("stop signal") replaces the white arrow a short time after presentation depending on participant reaction time. Participants are instructed to withhold their response on these trials. The error-related negativity (ERN) and error-positivity (Pe) are measured following erroneous responses after red arrows while the correct-related negativity (CRN) and Pe on correct trials are measured following correct responses after white arrows. A fixation cross is presented during the inter-trial-interval (ITI) jittered between 500 and 1000 ms.

Figure 2.

Threat: Emotional Responsivity Task (ERT)

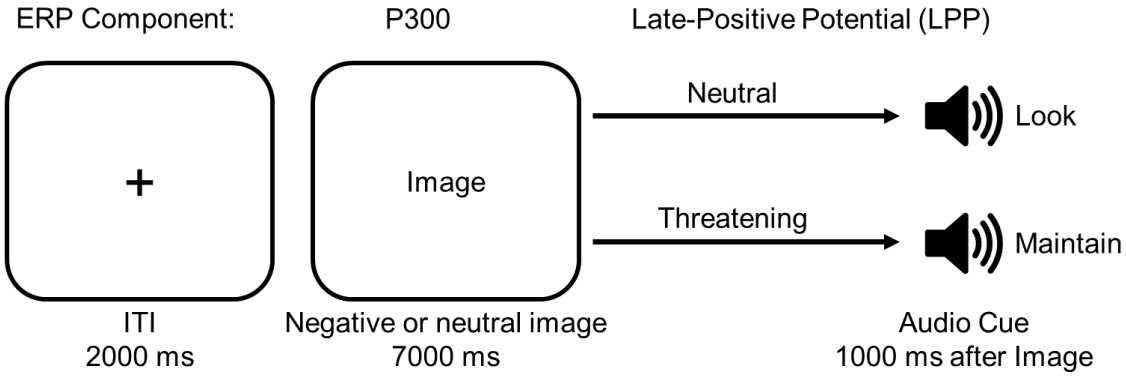

Figure 2 shows the ERT Trial Structure. Before each trial, a fixation cross is presented for 2000 ms. Next, a threatening or neutral image is presented that remains on the screen for 7000 ms. 1000 ms after image presentation, an audio cue is delivered through speakers. After neutral images, the audio cue "Look" is presented instructing participants to view the picture naturally. After threatening images, the audio cue "Maintain" is presented instructing participants to feel what they naturally feel without changing their emotion.

Figure 3.

Reward: Electrophysiological Monetary Incentive Delay Task (EMID)

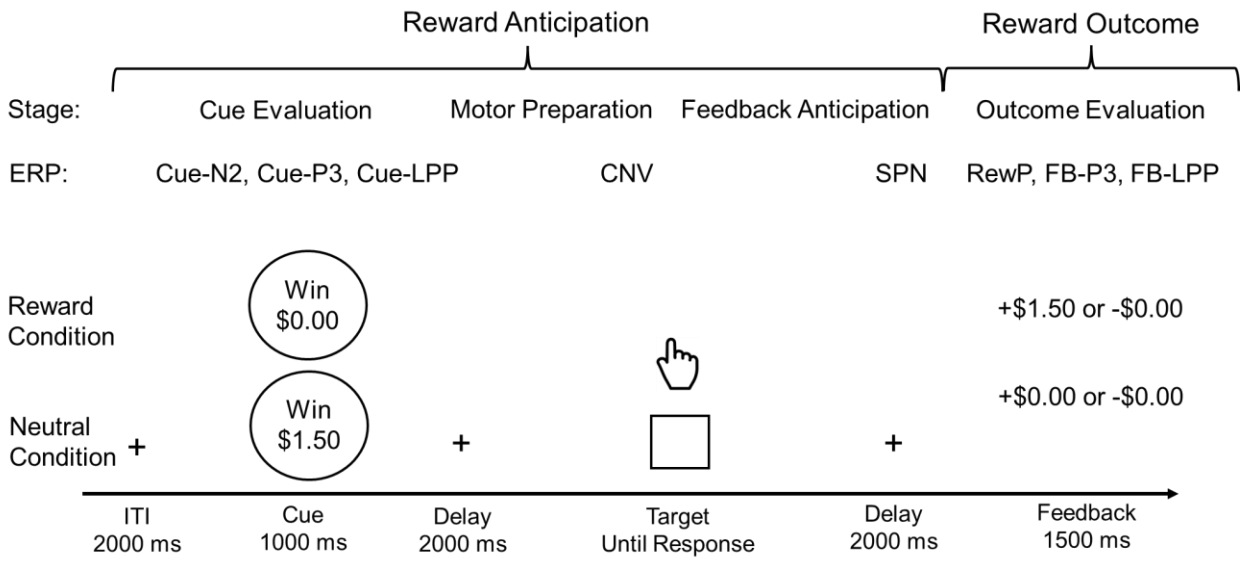

Figure 3 shows the EMID Trial Structure. Before each trial, a fixation cross is displayed for 2000 ms during the inter-trial-interval (ITI). After the ITI, cues before each trial displayed for 1000 ms indicate whether participants can win money ("Win $1.50") in reward conditions or receive performance-only feedback not associated with monetary outcomes in the neutral condition ("Win $0.00"). The Cue-N2, Cue-P3, and Cue-LPP are measured following these reward and neutral cues. Next, a fixation cross is displayed and jittered between 1500 and 2000 ms after the cue where participants "get ready" to respond to an upcoming target stimulus. The CNV in measured before the response. Next, a target stimulus (white box) is displayed for a duration matched to participant reaction time to keep outcomes at 50%. After the response, another fixation cross is displayed for 2000 ms where the SPN is measured in anticipation of feedback. Finally, feedback in presented for 1500 ms that represents positive (i.e., participants responded quickly enough) or negative (i.e., too slow responses) feedback. In reward conditions, positive feedback indicates monetary earnings of $1.50 while negative feedback indicates no earnings (i.e., $0.00). The RewP, FB-P3, and FB-LPP are measured after the feedback stimulus.

Figure 4.

Executive Control SST: ERN Waveforms

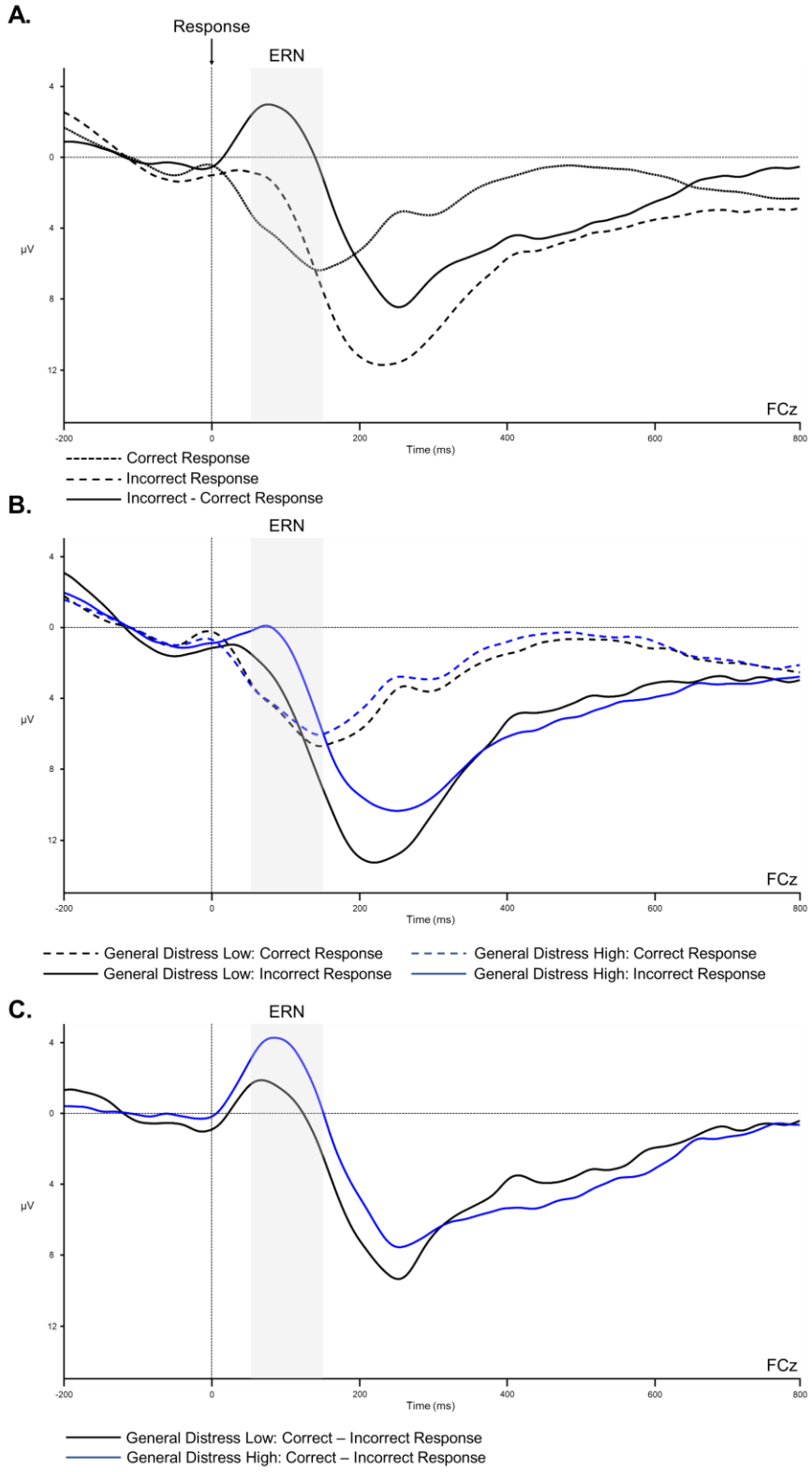

Figure 4 shows the average waveforms for the executive control SST at electrode FCz. In each panel, shaded regions indicate the error-related negativity (ERN) mean measurement period time-locked to the response at 0 ms. Panel A: Grand average waveform showing the ERN for correct responses (heavily dashed black line), incorrect responses (lightly dashed black line), and the incorrect – correct responses difference wave (solid black line). Panel B: Average waveform showing the ERN for correct (dashed lines) and incorrect (solid lines) responses separated by low (black lines) and high (blue lines) median split General Distress scores. Panel C: Average waveform showing correct – incorrect ERN difference wave for median split General Distress scores.

Figure 5.

Executive Control SST: Pe Waveforms

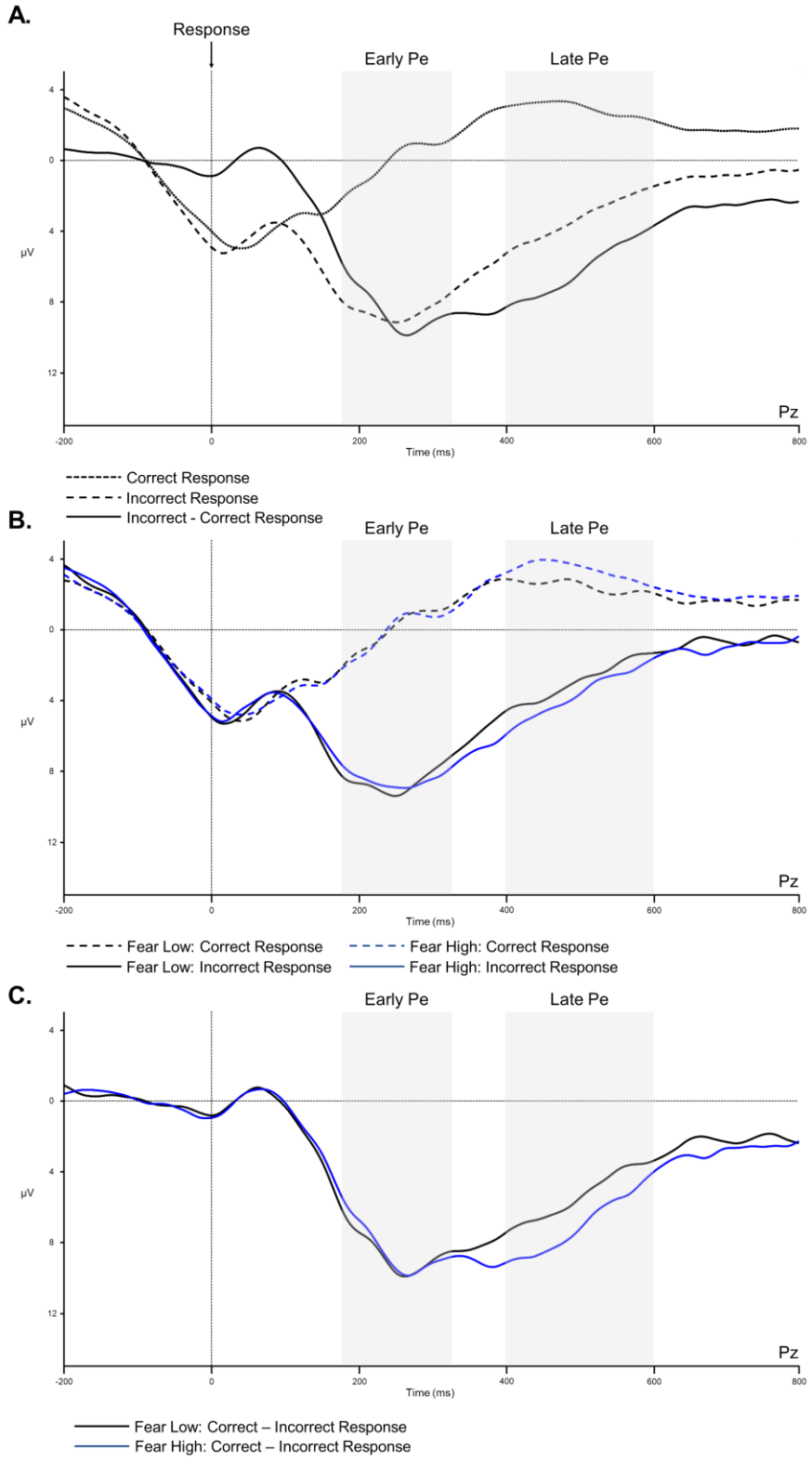

Figure 5 shows the average waveforms for the executive control SST at electrode Pz. In each panel, shaded regions indicate the early and late error-positivity (Pe) mean measurement period time-locked to the response at 0 ms. Panel A: Grand average waveform showing the early and late Pe for correct responses (heavily dashed black line), incorrect responses (lightly dashed black line), and the incorrect – correct responses difference wave (solid black line). Panel B: Average waveform showing the early and late Pe for correct (dashed lines) and incorrect (solid lines) responses separated by low (black lines) and high (blue lines) median split Fear scores. Panel C: Average waveform showing correct – incorrect early and late Pe difference wave for median split Fear scores.

Figure 6.

Executive Control SST: ERN and Pe Scalp Topographies

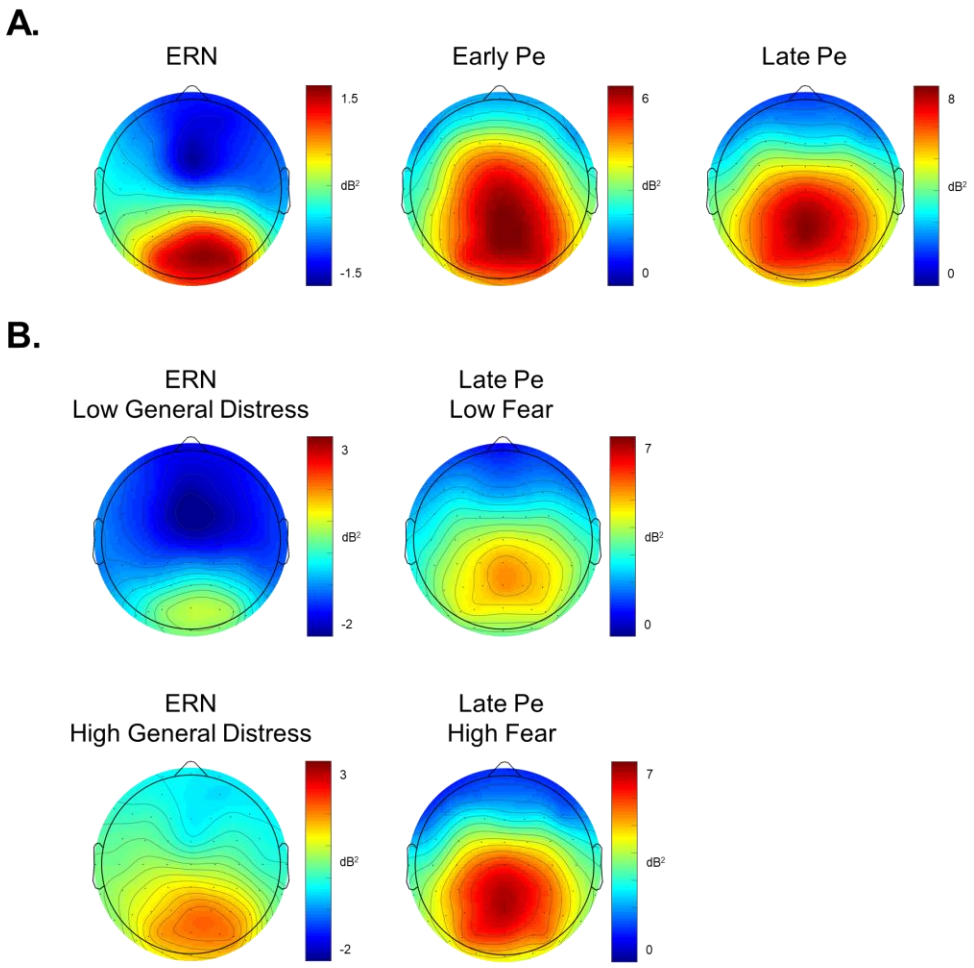

Figure 6 shows the scalp map topographies for the executive control SST generated from incorrect – correct difference waves as the mean amplitude in the window of measurement for the ERN, early Pe, and late Pe. Panel A: Grand average scalp topographies for the ERN (left), early Pe (middle), and late Pe (right). Panel B: Scalp topographies for the ERN (left) and late Pe (right) median split by General Distress (high: bottom left, low: top left) and Fear (high: bottom right, low: top right) scores.

Figure 7.

Threat ERT: P300 and LPP Waveforms

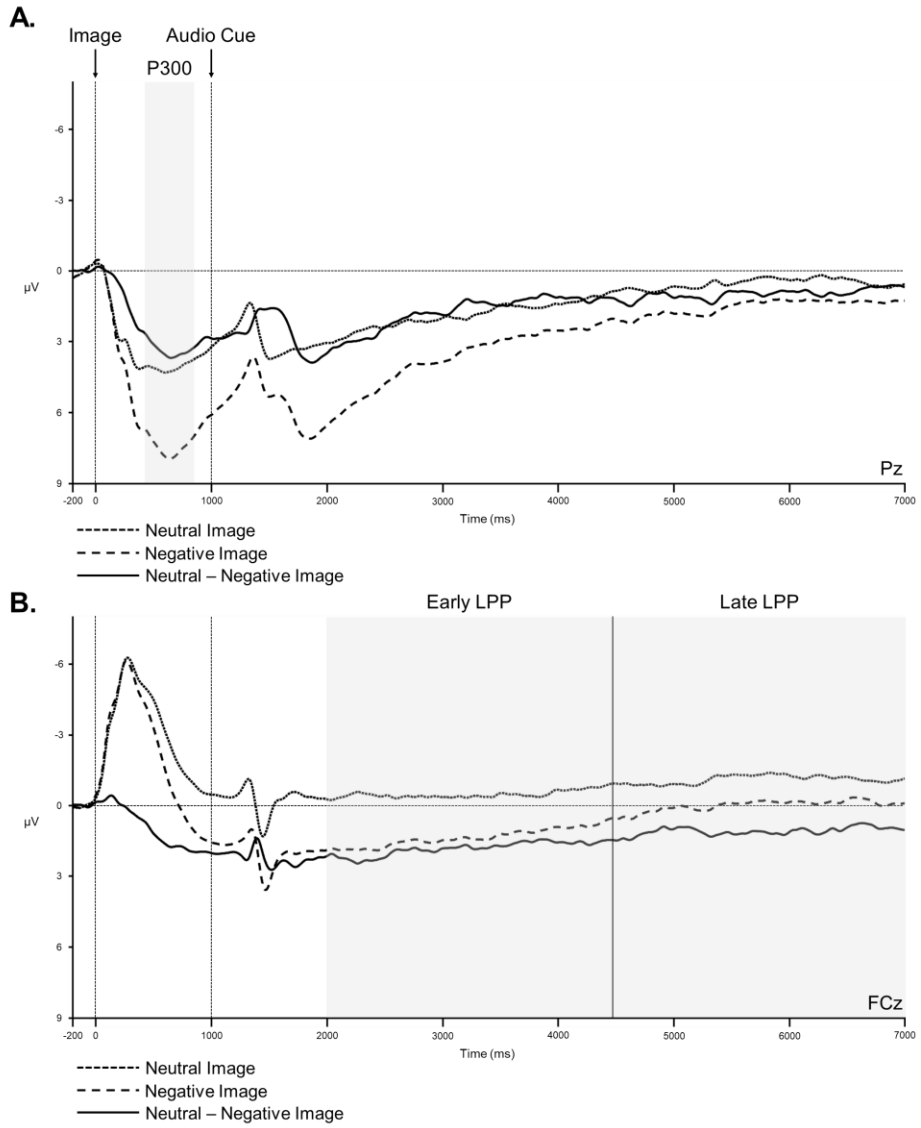

Figure 7 shows the average waveforms for the threat ERT. In each panel, threatening or neutral images are presented at 0 ms followed by a “maintain” or “look” audio cue presented at 1000 ms. Panel A: Grand average waveform showing at electrode Pz showing the P300 following neutral (heavily dashed line) and threatening (lightly dashed line) images as well as the threat – neutral difference wave (solid line). Shaded region indicates mean measurement period for the P300. Panel B: Grand average waveform showing at electrode FCz showing the early and late LPP following neutral (heavily dashed

line) and threatening (lightly dashed line) images as well as the threat – neutral difference wave (solid line). Shaded region indicates mean measurement period for the early LPP (left) and late LPP (right).

Figure 8.

Threat ERT: P300 and LPP Scalp Topographies

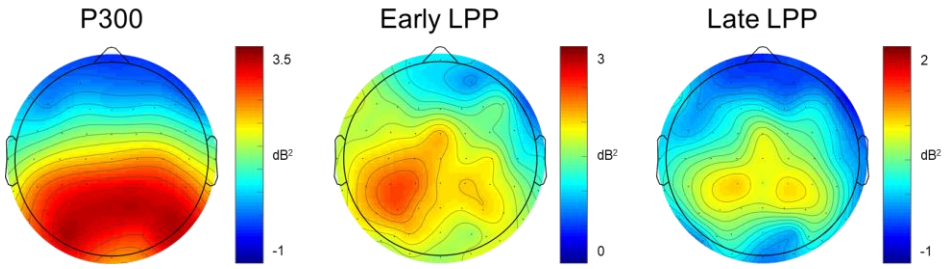

Figure 8 shows the scalp map topographies for the threat ERT. Topographies were generated from threat - neutral difference waves as the mean amplitude in the window of measurement for the P300 (left), early LPP (middle), and late LPP (right).

Figure 9.

Reward EMID: Cue-N2 Waveforms

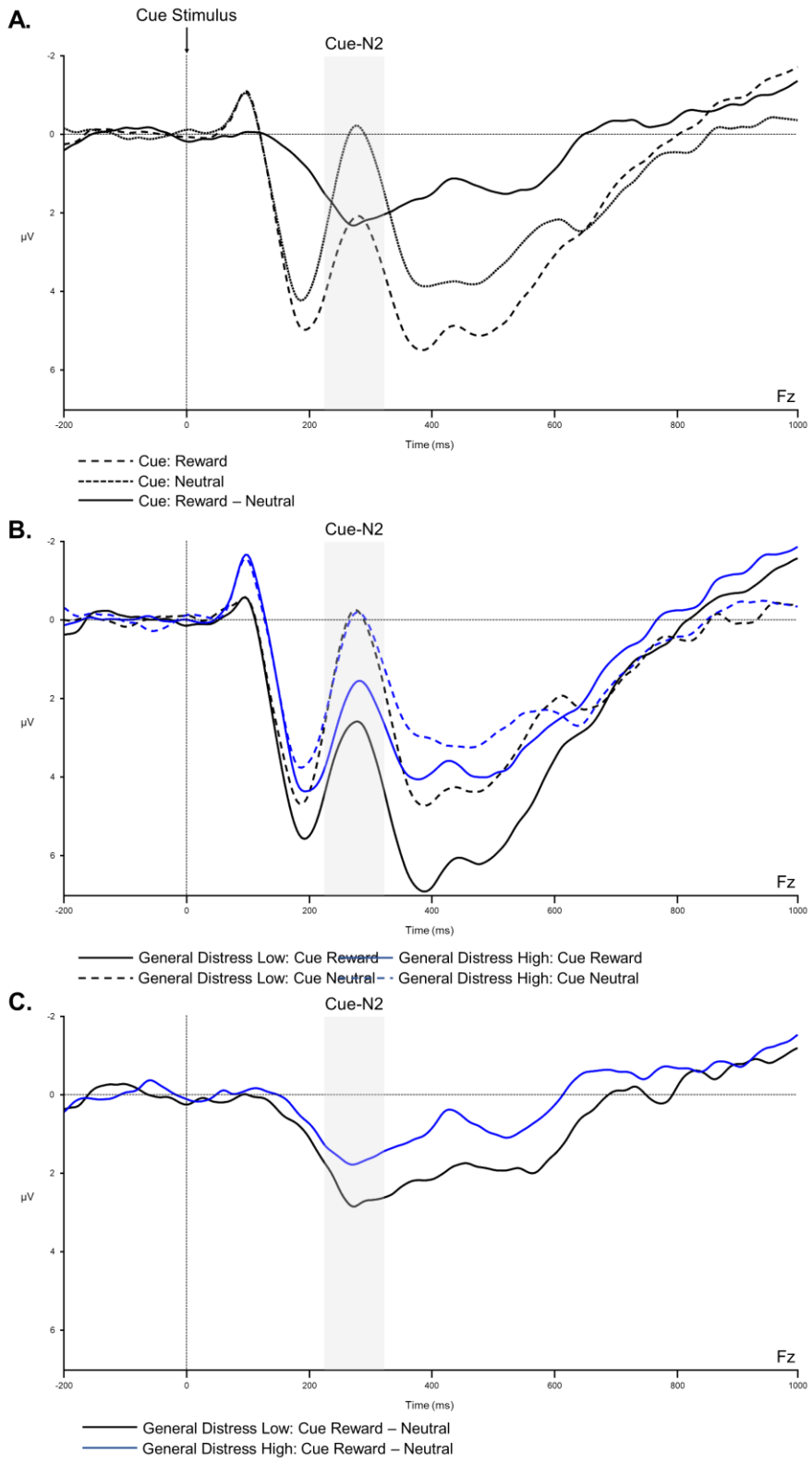

Figure 9 shows the average waveforms for the cue-evaluation period of reward anticipation during the EMID task at electrode Fz. In each panel, shaded regions indicate the Cue-N2 mean measurement period time-locked to the cue stimulus at 0 ms. Panel A: Grand average waveform showing the Cue-N2 for reward cues (lightly dashed black line), neutral cues (heavily dashed black line), and the reward – neutral cue difference wave (solid black line). Panel B: Average waveform showing the Cue-N2 for reward cues (lightly dashed black line) and neutral cues (heavily dashed black line) separated by low (black lines) and high (blue lines) median split General Distress scores. Panel C: Average waveform showing reward – neutral cue difference wave for median split General Distress scores.

Figure 10.

Reward EMID: Cue-P3 and Cue-LPP Waveforms

Figure 10 shows the average waveforms for the cue-evaluation period of reward anticipation during the EMIDs task at electrode Pz. In each panel, shaded regions indicate the Cue-P3 (left) and Cue-LPP (right) mean measurement period time-locked to the cue stimulus at 0 ms. Panel A: Grand average waveform showing the Cue-P3 and Cue-LPP for reward cues (lightly dashed black line), neutral cues (heavily dashed black line), and the reward – neutral cue difference wave (solid black line). Panel B: Average waveform showing the Cue-P3 and Cue-LPP for reward cues (lightly dashed black line) and neutral cues (heavily dashed black line) separated by low (black lines) and high (blue lines) median split General Distress scores. Panel C: Average waveform showing reward – neutral cue difference wave for median split General Distress scores for the Cue-P3 and Cue-LPP.

Figure 11.

Reward EMID: Cue-N2, Cue-P3, and Cue-LPP Scalp Topographies

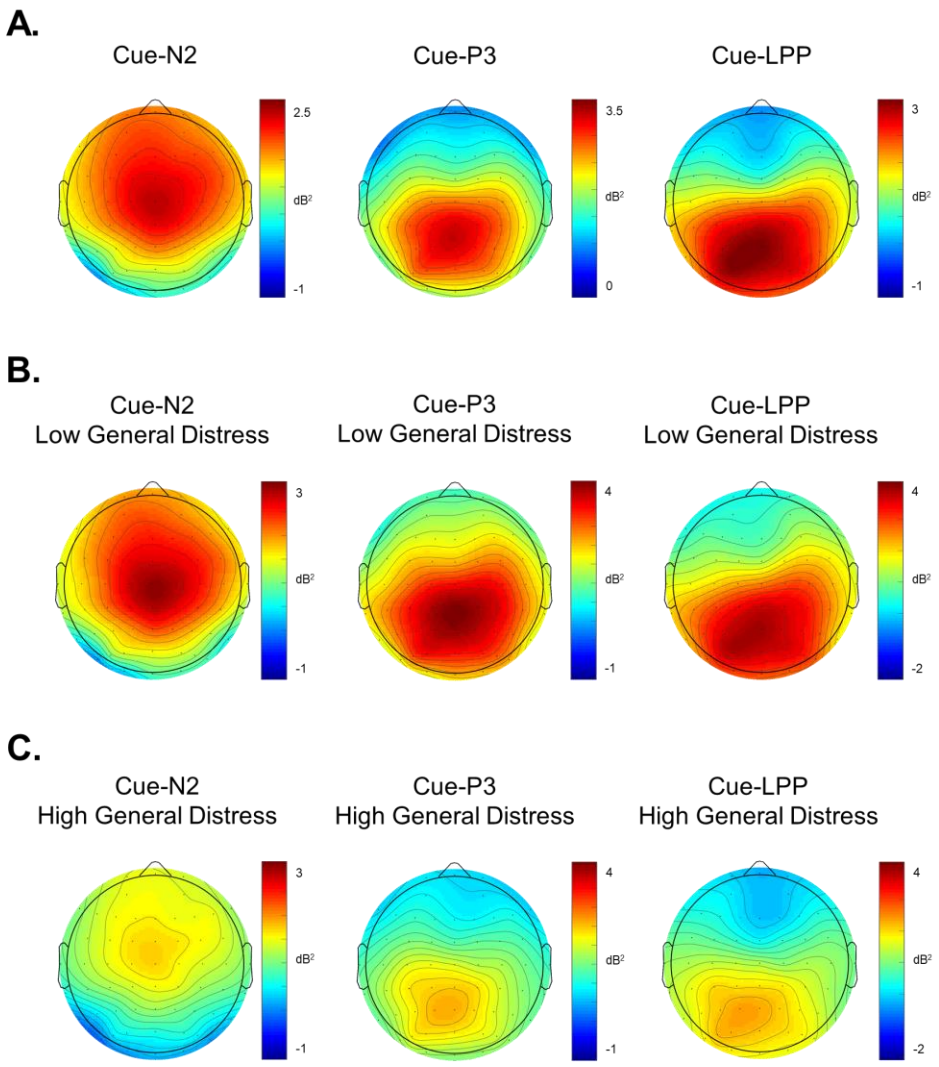

Figure 11 shows the scalp map topographies for the cue-evaluation period of reward anticipation during the EMID task. Topographies were generated from reward – neutral difference waves as the mean amplitude in the window of measurement for the Cue-N2 (left column), Cue-P3 (middle column), and Cue-LPP (right column). Panel A: Grand average scalp topographies for the Cue-N2 (left), Cue-P3 (middle), and Cue-LPP (right). Panel B and C: Median split scalp topographies for the Cue-N2 (left), Cue-P3 (middle), and Cue-LPP (right) for low (top row) and high (bottom row) General Distress Scores.

Figure 12. Reward EMID: CNV and SPN Waveforms.

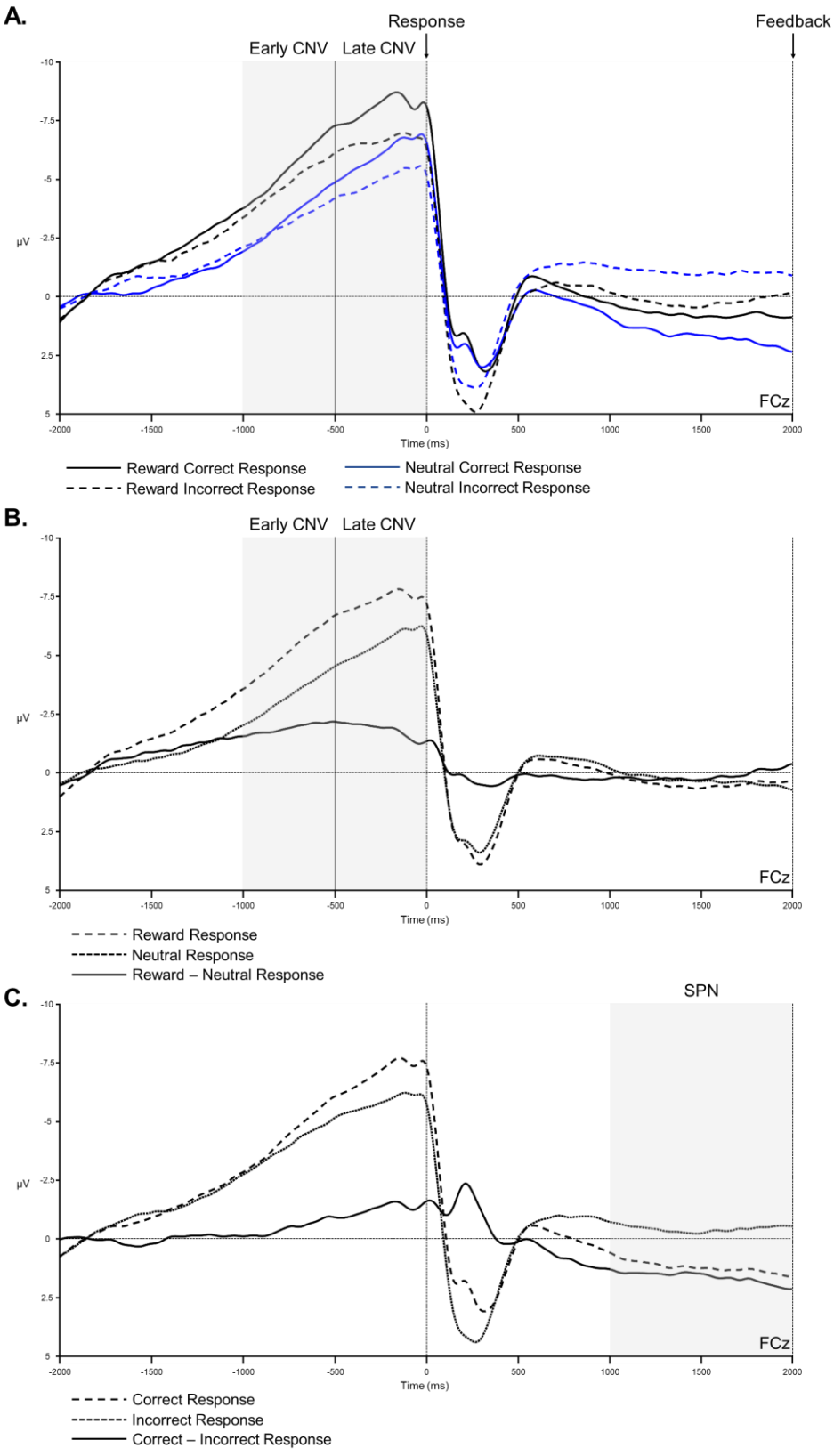

Figure 12 shows the average waveforms for the motor preparation and feedback anticipation periods of reward anticipation during the EMID task at electrode FCz. In each panel, ERPs are time-locked to the response at 0 ms and indicate the feedback presentation time at 2000 ms. Panel A: Grand average waveform with shaded regions showing the early CNV (left) and late CNV (right) for correct (solid lines) and incorrect (dashed lines) responses separated by reward (black lines) and neutral (blue lines) conditions. Panel B: Grand average waveform with shaded regions showing the early CNV (left) and late CNV (right) for reward (lightly dashed lines) responses, neutral (heavily dashed lines) responses, and reward – neutral difference wave (solid line). Panel C: Average waveform with shaded region showing the SPN mean measurement period just prior to feedback presentation grouped by correct responses (lightly dashed line), incorrect responses (heavily dashed line), and correct – incorrect response difference waves (solid line).

Figure 13.

Reward EMID: CNV and SPN Scalp Topographies

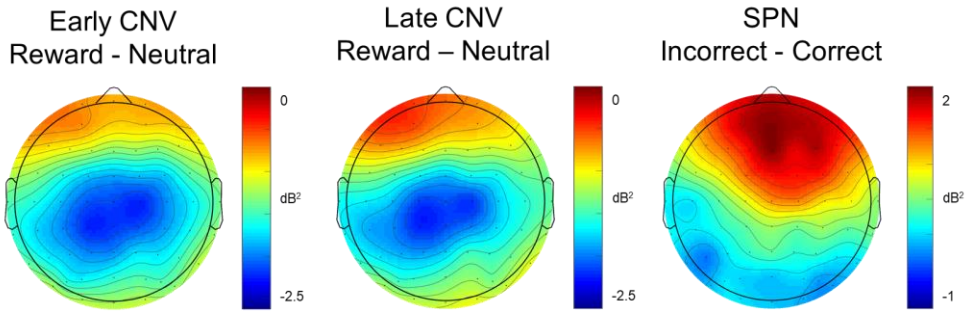

Figure 13 shows the scalp map topographies for the motor preparation and feedback anticipation periods of reward anticipation during the EMID task. Topographies for the early CNV (left) and late CNV (middle) were generated from reward – neutral difference waves while the SPN topography (right) was generated from the correct – incorrect difference wave.

Figure 14.

Reward EMID: RewP Waveforms

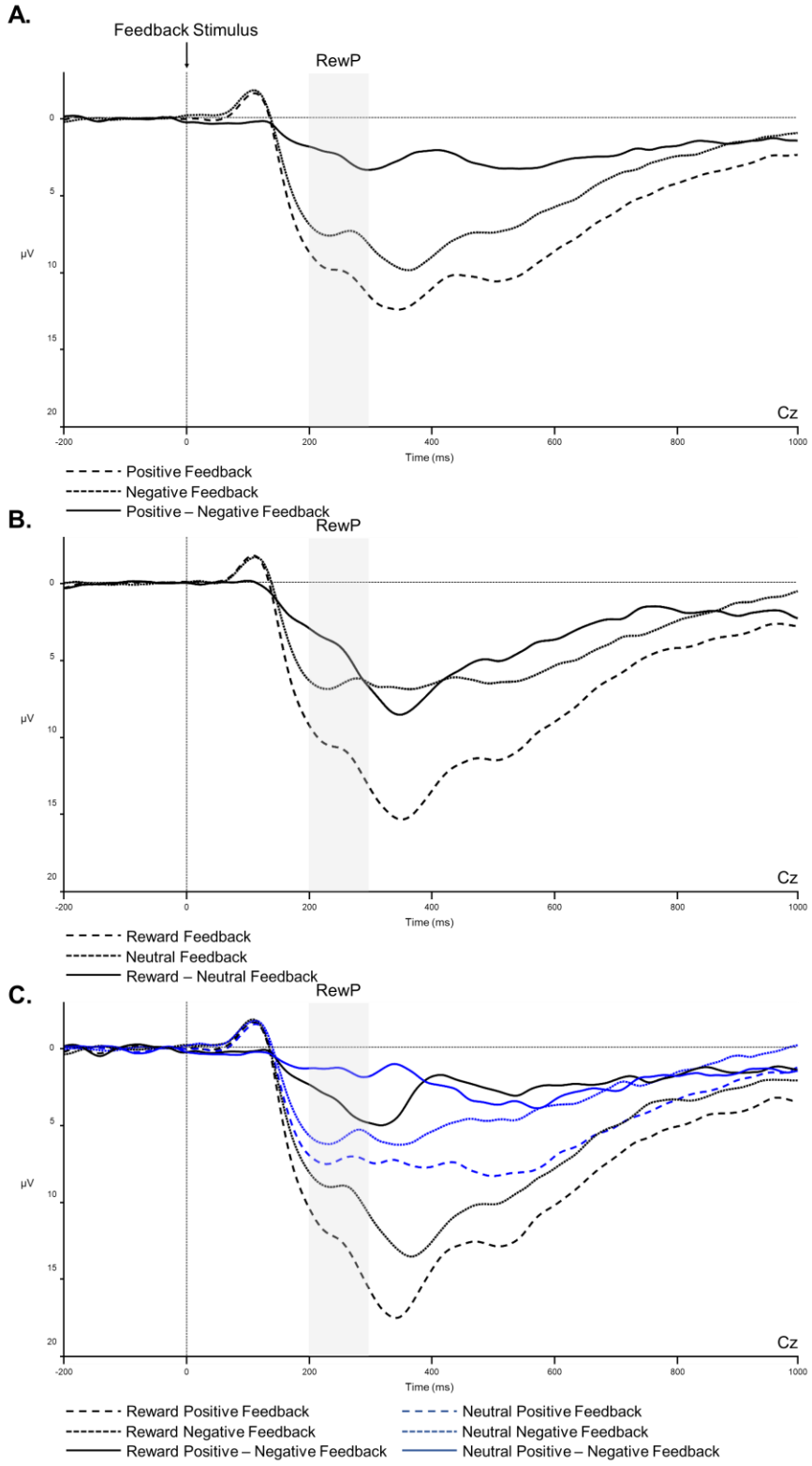

Figure 14 shows the average waveforms for the feedback evaluation stage of reward outcome anticipation during the EMID task at electrode Cz. In each panel, ERPs are time-locked to the feedback stimulus at 0 ms and shaded regions indicate the mean measurement period for the RewP. Panel A: Grand average waveform showing the RewP for positive feedback (lightly dashed line), negative feedback (heavily dashed line), and positive – negative feedback (solid line). Panel B: Grand average waveform showing the RewP for reward feedback (lightly dashed line), neutral feedback (heavily dashed line), and reward – neutral feedback difference wave (solid line). Panel C: Grand average waveform showing the RewP for reward feedback (black lines) and neutral feedback (blue lines) separated by positive feedback (lightly dashed lines), negative feedback (heavily dashed lines), and positive – negative feedback difference waves (solid lines).

Figure 15.

Reward EMID: FB-P3 and FB-LPP Waveforms

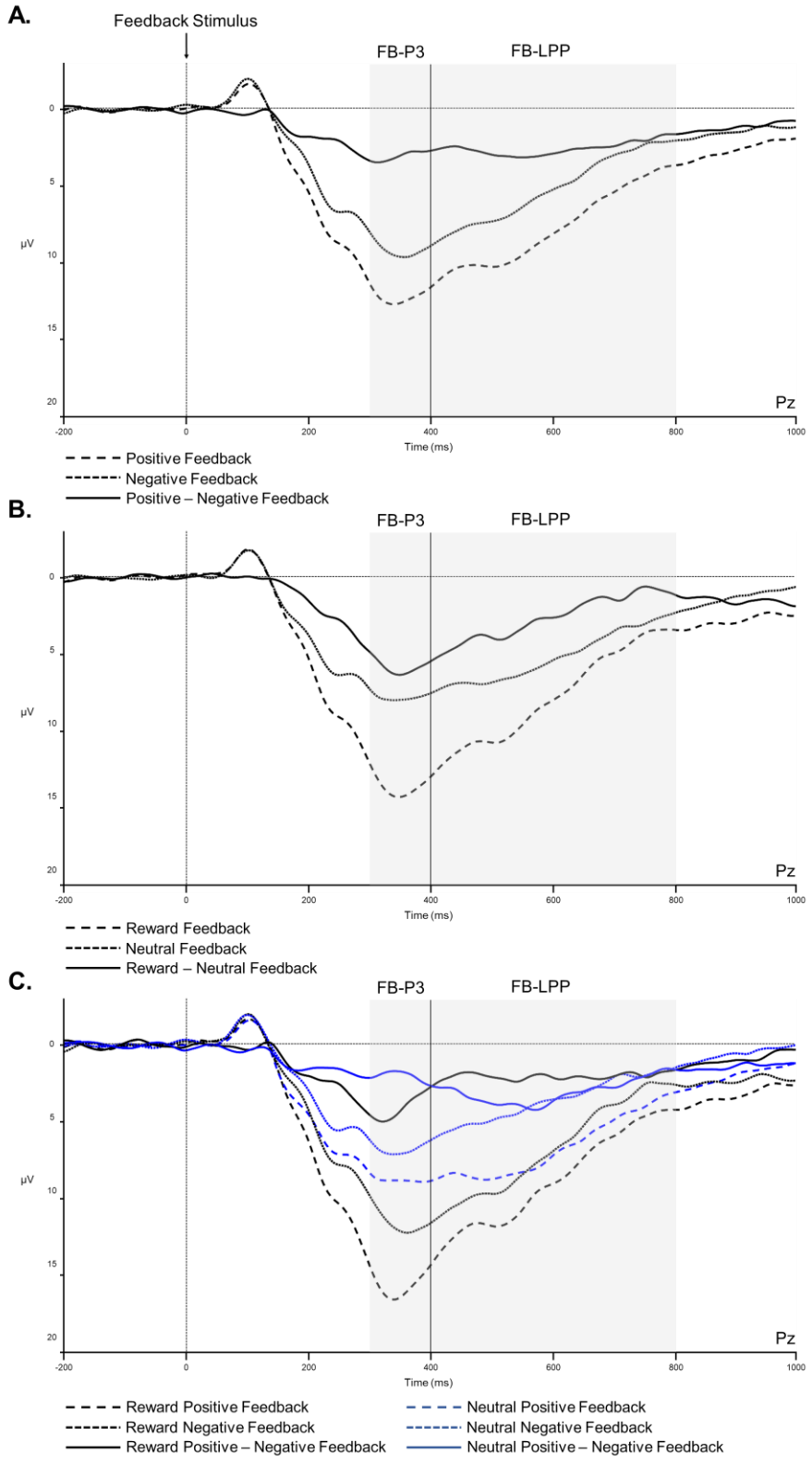

Figure 15 shows the average waveforms for the feedback evaluation stage of reward outcome anticipation during the EMID task at electrode Pz. In each panel, ERPs are time-locked to the feedback stimulus at 0 ms and shaded regions indicate the mean measurement period for the FB-P3 (left) and FB-LPP (right). Panel A: Grand average waveform showing the FB-P3 and FB-LPP for positive feedback (lightly dashed line), negative feedback (heavily dashed line), and positive – negative feedback (solid line). Panel B: Grand average waveform showing the FB-P3 and FB-LPP for reward feedback (lightly dashed line), neutral feedback (heavily dashed line), and reward – neutral feedback difference wave (solid line). Panel C: Grand average waveform showing the FB-P3 and FB-LPP for reward feedback (black lines) and neutral feedback (blue lines) separated by positive feedback (lightly dashed lines), negative feedback (heavily dashed lines), and positive – negative feedback difference waves (solid lines).

Figure 16.

Reward EMID: FB-P3 and FB-LPP Waveforms and General Distress

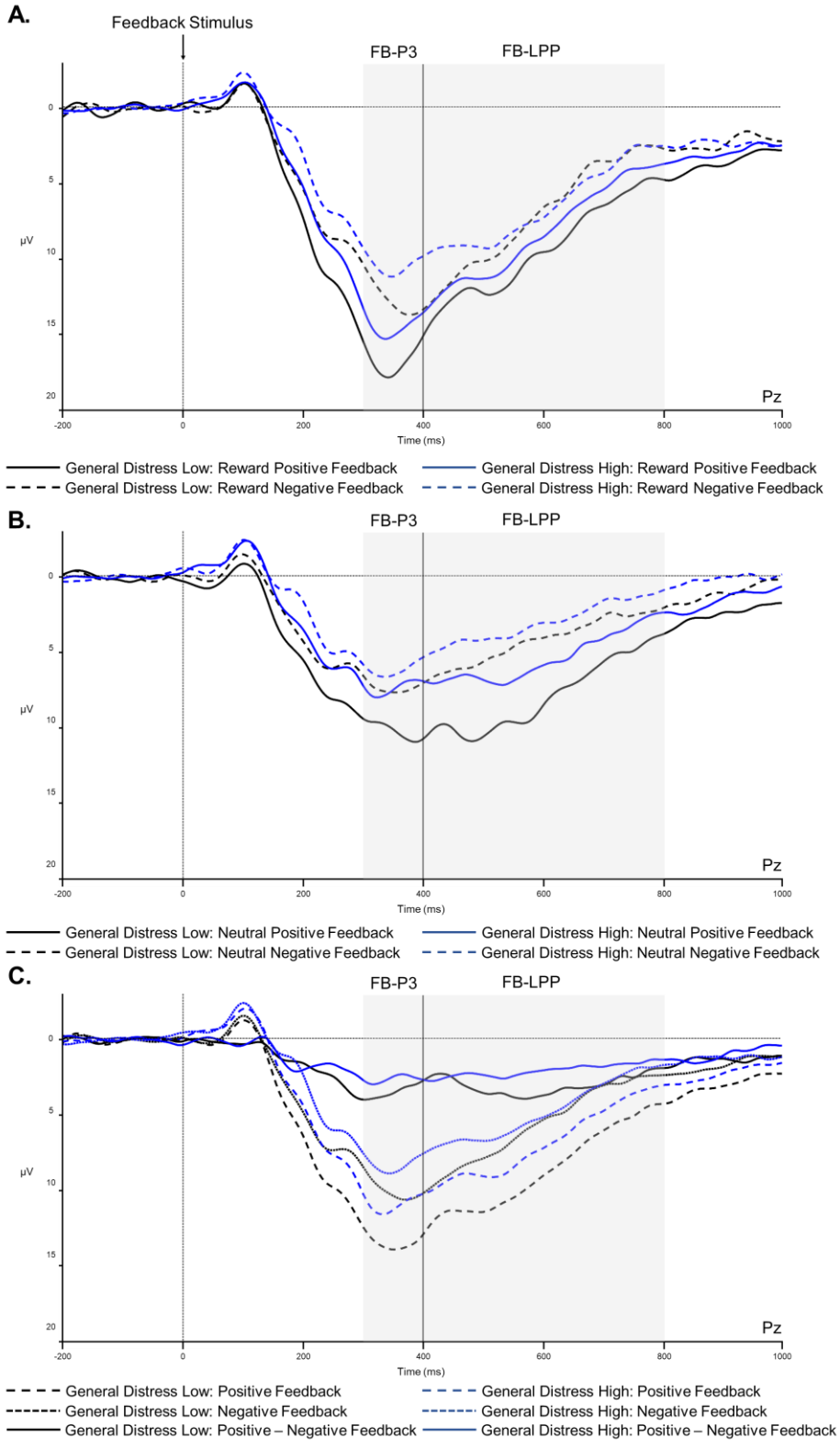

Figure 16 shows the average waveforms for the feedback evaluation stage of reward outcome anticipation during the EMID task showing median-split high and low General Distress. In each panel, ERPs are time-locked to the feedback stimulus at 0 ms and shaded regions indicate the mean measurement period for the FB-P3 (left) and FB-LPP (right). Panel A: Average waveform for the Reward condition showing the FB-P3 and FB-LPP for reward positive feedback (solid lines) and reward negative feedback (dashed lines) for median-split high (blue) and low (black) General Distress scores. Panel B: Average waveform for the Neutral condition showing the FB-P3 and FB-LPP for neutral positive feedback (solid lines) and neutral negative feedback (dashed lines) for median-split high (blue) and low (black) General Distress scores. Panel C: Average waveform showing the FB-P3 and FB-LPP for positive feedback (lightly dashed lines), negative feedback (heavily dashed lines), and positive – negative feedback difference waves (solid lines) separated by median-split into low (black) and high (blue) General Distress scores.

Figure 17.

Reward EMID: RewP, FB-P3, and FB-LPP Scalp Topographies

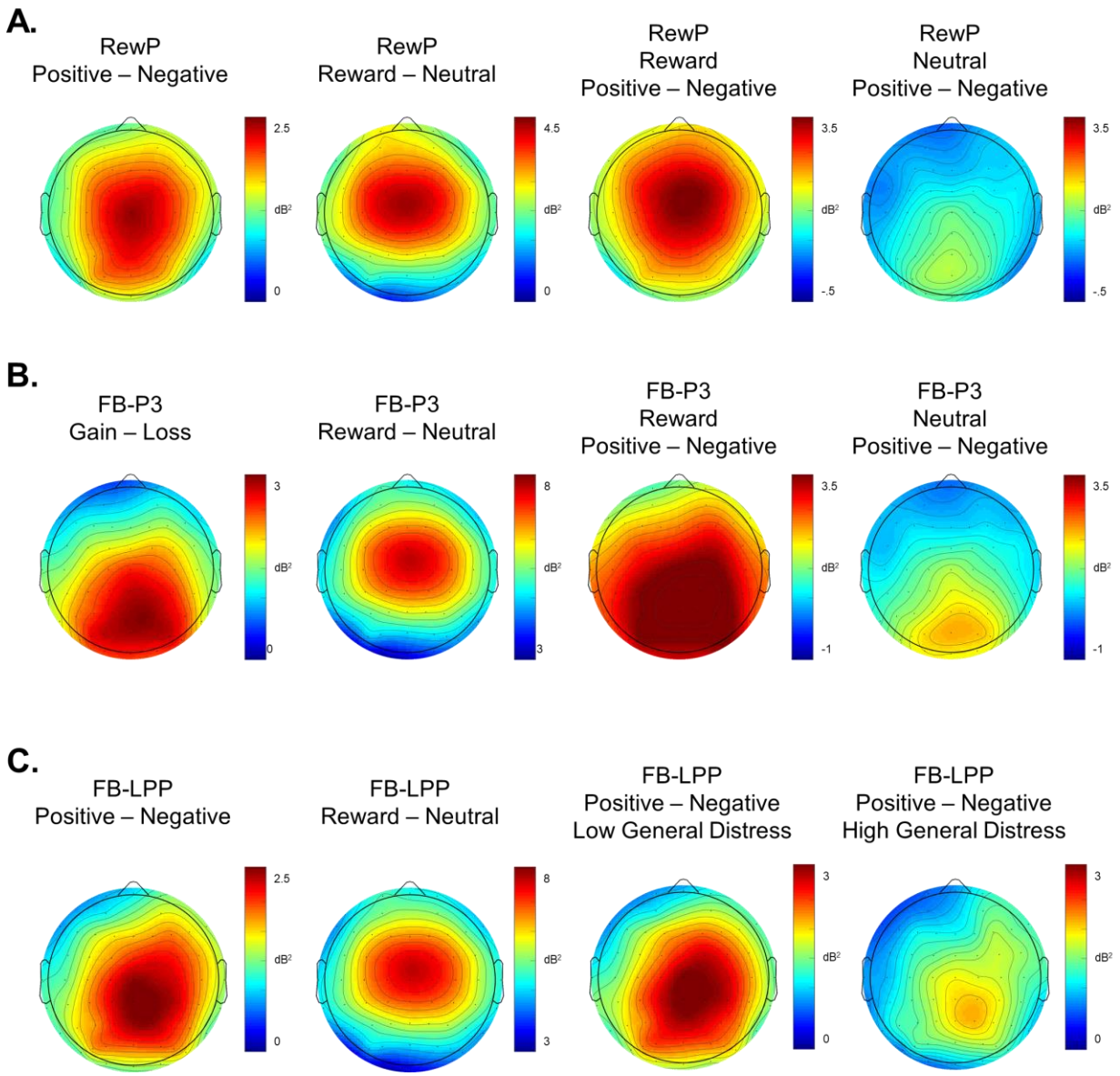

Figure 17 shows the scalp map topographies for the feedback evaluation stage of reward outcome anticipation during the EMID task. Panel A. Topographies show the mean measurement activity of the RewP generated from positive – negative feedback (left), reward – neutral feedback (middle-left), positive – negative feedback in the reward condition (middle-right), and positive – negative feedback in the neutral condition (middle-left). Panel B: Topographies show the mean measurement activity of the FB-

P3 generated from positive – negative feedback (left), reward – neutral feedback (middle-left), positive – negative feedback in the reward condition (middle-right), and positive – negative feedback in the neutral condition (middle-left). Panel C: On the left, topographies show the mean measurement activity of the FB-LPP generated from positive – negative feedback (left) and reward – neutral feedback (middle left). On the right, topographies show the mean measurement activity of the FB-LPP generated from positive – negative feedback difference waves median split by high low (middle right) and high (right) General Distress scores.

Figure 18.

Executive Control SST: General Distress/Fear Regression Scatter Plots

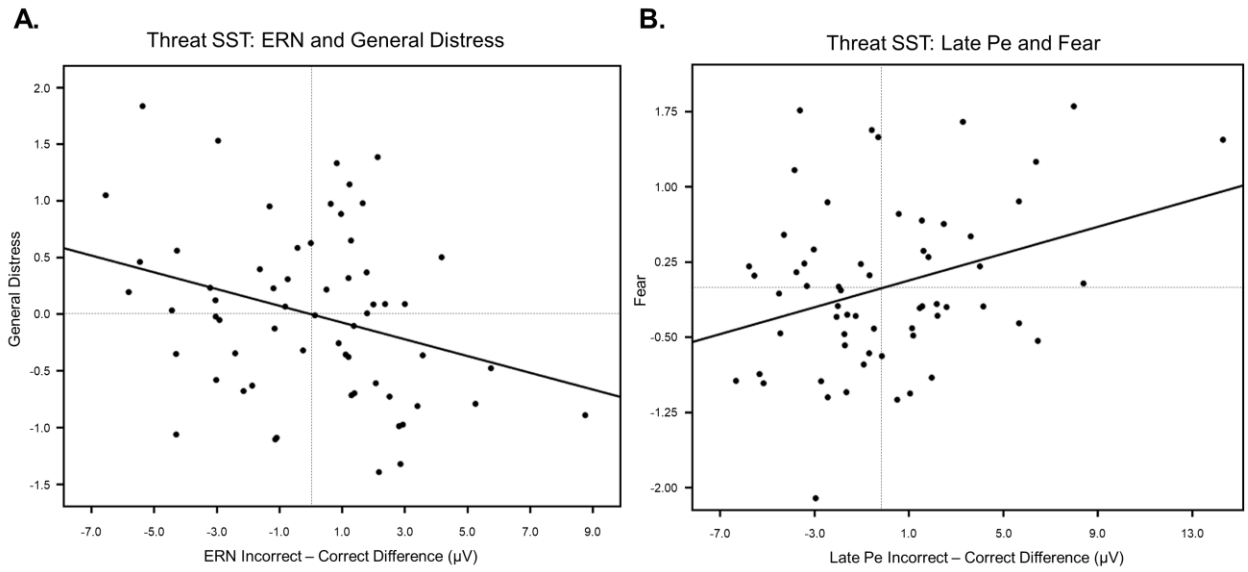

Figure 18 shows the regression scatter plot for the executive control SST. Panel A: Displays the relationship between General Distress (y axis) and ERN difference wave amplitude (x axis) calculated as incorrect – correct responses. Regression analysis controlled for experiment order, handedness, psychotropic medication, gender, age, and the opposing trilevel symptom factors of Fear and Anhedonia. The ERN is a negative component that is increased for incorrect compared to correct responses; therefore, the plot shows that increases in General Distress are associated with increases in ERN difference wave amplitude. Panel B: Displays the relationship between Fear (y axis) and Pe difference wave amplitude (x axis) calculated as incorrect – correct responses. Regression analysis controlled for experiment order, handedness, psychotropic medication, gender, age, and the opposing trilevel symptom factors of Fear and Anhedonia. The Pe is a positive component that is increased for incorrect compared to correct responses; therefore, the plot shows that increases in Fear are associated with increases in Pe difference wave amplitude.

Figure 19.

Reward EMID: General Distress Regression Scatter Plots

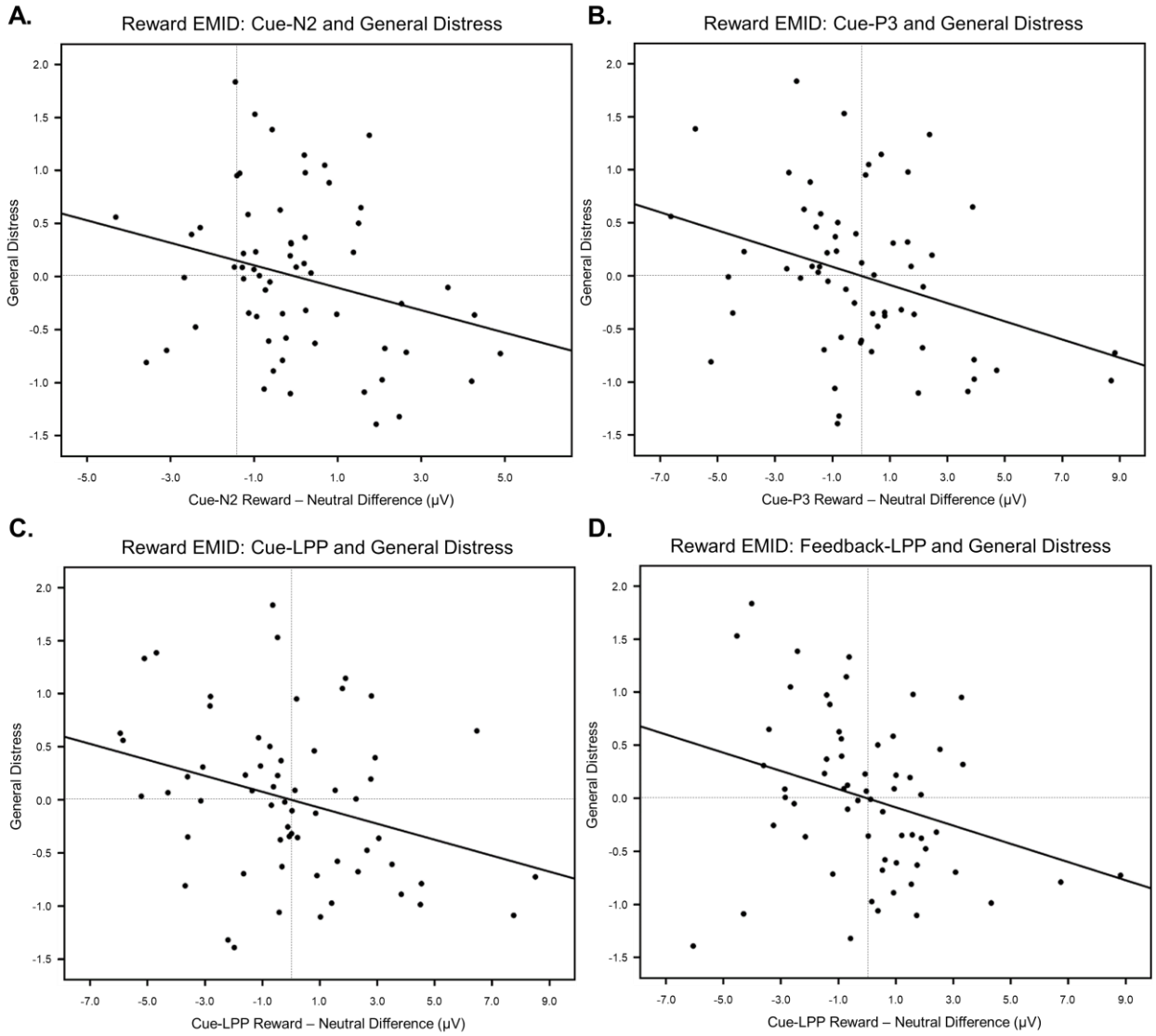

Figure 19 shows the regression scatter plot for the reward EMID task. Panel A: Displays the relationship between General Distress (y axis) and Cue-N2 difference wave amplitude (x axis) calculated as reward – neutral cue stimuli. Regression analysis controlled for experiment order, handedness, psychotropic medication, gender, age, and the opposing trilevel symptom factors of Fear and Anhedonia. Although the Cue-N2 is a negative component, Cue-N2 amplitude was increased for neutral compared to reward cues. Therefore, the plot shows that increases in General Distress are associated with decreases in Cue-N2 difference wave amplitude. Panel B: Displays the relationship between General Distress (y

axis) and Cue-P3 difference wave amplitude (x axis) calculated as reward – neutral cue stimuli. Regression analysis controlled for experiment order, handedness, psychotropic medication, gender, age, and the opposing trilevel symptom factors of Fear and Anhedonia. The Cue-P3 is a positive component that is increased for reward compared to neutral cues; therefore, the plot shows that increases in General Distress are associated with decreases in Cue-P3 difference wave amplitude. Panel C: Displays the relationship between General Distress (y axis) and Cue-LPP difference wave amplitude (x axis) calculated as reward – neutral cue stimuli. Regression analysis controlled for experiment order, handedness, psychotropic medication, gender, age, and the opposing trilevel symptom factors of Fear and Anhedonia. The Cue-LPP is a positive component that is increased for reward compared to neutral cues; therefore, the plot shows that increases in General Distress are associated with decreases in Cue-P3 difference wave amplitude. Panel D: Displays the relationship between General Distress (y axis) and FB-LPP difference wave amplitude (x axis) calculated as positive – negative feedback. Regression analysis controlled for experiment order, handedness, psychotropic medication, gender, age, and the opposing trilevel symptom factors of Fear and Anhedonia. The FB-LPP is a positive component that is increased for positive compared to negative feedback; therefore, the plot shows that increases in General Distress are associated with decreases in FB-P3 difference wave amplitude.

Tables.

Table 1.

Schedule of Assessments for Current Study and Parent R01

Assessment	Baseline	12-Months	24-Months	36-Months
Trilevel Symptoms (R01)	X	X	X	X
Structured Clinical Interview (SCID: R01)	X	X	X	X
Functional Magnetic Resonance Imaging (R01)	X	NA	NA	X
Self-Report, Behavioral, Other Measures (R01)	X	NA	NA	X
EEG and Trilevel Symptoms (Current Study)	**NA**		**X**	

Table 1 displays the schedule of assessments for the current study (bottom) and parent R01. In the parent R01, trilevel symptom dimensions and structured clinical interviews were measured at four timepoints, once at baseline and three more times 12-months apart. At baseline and 36-months, functional magnetic resonance imaging data were collected along with several self-repot, behavioral, and other measures. In the current study (bottom), EEG data and trilevel symptom dimensions were measured during a single assessment conducted during baseline and 36-months.

Table 2.

Hypotheses

Domain	Task	Trilevel Symptom	ERP Component	ΔERP
Executive Control	Stop-Signal Task (SST)	General Distress and Fear	ERN	Increased
		Anhedonia	Pe	Decreased
Threat	Emotional Reactivity Task (ERT)	General Distress and Fear	P300 and LPP	Increased
Reward	Electrophysiological Monetary Incentive Delay (EMID)	Anhedonia	Cue-N2, Cue-P3, and Cue-LPP CNV SPN RewP, FB-P3, and FB-LPP	Decreased

Table 2 shows the hypotheses for each processing domain, task, trilevel symptom dimension, ERP component, and the predicted direction of change. All three symptom dimensions were hypothesized to be associated with abnormal electrocortical activity during a stop-signal executive control task (top row). Fear and Anhedonia were hypothesized to be associated with abnormal threat-related electrocortical activity during an emotional reactivity task (middle row). Only Anhedonia was predicted to be associated with abnormal reward-related electrocortical activity during a monetary incentive delay task (bottom row).

Table 3.

Executive Control SST: ERP Means and SDs

ERP	Condition	Mean	SD
ERN	Correct	5.312	3.528
	Incorrect	3.739	4.031
	Correct - Incorrect	-1.574	3.226
Early Pe	Correct	-2.912	4.822
	Incorrect	3.287	4.499
	Correct - Incorrect	6.199	4.239
Late Pe	Correct	0.065	3.441
	Incorrect	8.592	5.164
	Correct - Incorrect	8.528	5.402

Table 3 shows the means and standard deviations for ERP amplitudes elicited during the executive control task.

Table 4.

Threat ERT: ERP Means and SDs

ERP	Image Condition	Mean	SD
P300	Neutral	4.171	4.819
	Threatening	7.510	6.520
	Threat - Neutral	3.339	3.105
Early LPP	Neutral	-0.510	4.142
	Threatening	1.310	5.453
	Threat - Neutral	1.820	4.785
Late LPP	Neutral	-1.135	4.493
	Threatening	-0.043	5.246
	Threat - Neutral	1.092	4.955

Table 4 shows the means and standard deviations for ERP amplitudes elicited during the threat task.

Table 5.

Reward EMID: Cue ERP Means and SDs

ERP	Condition	Mean	SD
Cue-N2	Reward	2.759	4.008
	Neutral	0.676	3.771
	Reward - Neutral	2.083	1.988
Cue-P3	Reward	11.144	5.150
	Neutral	7.786	3.488
	Reward - Neutral	3.357	3.093
Cue-LPP	Reward	7.764	3.994
	Neutral	4.621	2.907
	Reward - Neutral	3.144	3.455

Table 5 shows the means and standard deviations for cue-related ERP amplitudes elicited during the reward processing task.

Table 6.

Reward EMID: Response ERP Means and SDs

ERP	Condition	Response	Mean	SD
Early CNV	Reward	Correct	-5.450	3.374
		Incorrect	-4.801	3.790
	Neutral	Correct	-3.356	3.189
		Incorrect	-3.124	3.221
	Difference Wave	Reward - Neutral	-1.885	2.550
Late CNV	Reward	Correct	-8.043	4.980
		Incorrect	-6.674	5.352
	Neutral	Correct	-6.084	4.582
		Incorrect	-5.010	4.246
	Difference Wave	Reward - Neutral	-1.811	3.159
SPN	Reward	Correct	0.768	5.226
		Incorrect	0.201	5.039
	Neutral	Correct	1.712	4.209
		Incorrect	-1.037	5.129
	Difference Wave	Correct - Incorrect	1.658	3.337

Table 7.

Reward EMID: Feedback ERP Means and SDs

ERP	Condition	Outcome	Mean	SD
RewP	Reward	Positive	12.843	7.087
		Negative	9.200	5.680
		Positive - Negative	3.643	3.495
	Neutral	Positive	7.266	4.469
		Negative	5.795	4.041
		Positive - Negative	1.472	2.990
	Difference Waves	Reward - Neutral	4.492	3.497
		Positive - Negative	2.557	2.426
FB-P3	Reward	Positive	15.772	6.458
		Negative	11.646	6.417
		Positive - Negative	4.126	3.921
	Neutral	Positive	8.851	5.287
		Negative	6.836	4.700
		Positive - Negative	2.015	3.271
	Difference Waves	Reward - Neutral	5.865	2.982
		Positive - Negative	3.070	2.555
FB-LPP	Reward	Positive	8.798	4.416
		Negative	6.751	4.179
	Neutral	Positive	6.692	4.412
		Negative	3.635	3.292
	Difference Waves	Reward - Neutral	2.611	2.769
		Positive - Negative	2.552	2.618

Table 7 shows the means and standard deviations for feedback-related ERP amplitudes elicited during the reward processing task.

Table 8.

Artifact Rejection for Executive Control, Threat, and Reward Tasks

Task	Trial Type	Accepted Trials		Rejected Trials	
		Mean	SD	Mean	SD
SST	Correct Response	184.656	15.184	4.902	11.541
	Incorrect Response	50.607	7.528	1.770	4.233
ERT	Neutral Image	46.656	3.172	0.754	2.109
	Threatening Image	49.508	3.128	0.459	3.106
EMID Cue	Reward	57.754	4.759	0.852	2.071
	Neutral	57.541	5.479	0.787	2.089
EMID Response	Reward Correct	29.066	5.934	1.787	5.454
	Reward Incorrect	28.016	5.434	1.492	5.036
	Neutral Correct	28.721	5.070	1.344	4.655
	Neutral Incorrect	28.836	5.466	1.410	5.116
EMID Feedback	Reward Positive	29.541	3.619	0.246	0.669
	Reward Negative	29.180	2.849	0.508	1.489
	Neutral Positive	28.590	3.010	0.525	1.154
	Neutral Negative	28.213	3.608	0.656	1.525

Table 8 shows the means and standard deviations of total number of accepted and rejected trial counts separately for each condition in the executive control, threat, and reward processing task.

Table 9.

Behavioral Measures Means and SDs

Task	Behavioral Variable	Mean	SD
SST	Accuracy	0.833	0.031
	Successful Go RT	406.725	85.308
	Unsuccessful Stop RT	351.630	71.666
	Stop signal RT	204.975	89.531
EMID	Reward Correct RT	189.856	23.691
	Reward Incorrect RT	223.139	34.792
	Reward Accuracy	0.500	0.021
	Neutral Correct RT	208.538	29.458
	Neutral Incorrect RT	267.999	51.644
	Neutral Accuracy	0.503	0.022

Table 9 shows the means and standard deviations for behavioral data separately by task condition collected during the executive control task (top) and reward processing task (bottom).

Works Cited

Alexopoulos, G. S., Murphy, C. F., Gunning-Dixon, F. M., Kalayam, B., Katz, R., Kanellopoulos, D., ... & Foxe, J. J. (2007). Event-related potentials in an emotional go/no-go task and remission of geriatric depression. *Neuroreport*, *18*(3), 217-221.

Anokhin, A. P., Golosheykin, S., & Heath, A. C. (2008). Heritability of frontal brain function related to action monitoring. *Psychophysiology*, *45*(4), 524-534.

Bar-Haim, Y., Lamy, D., & Glickman, S. (2005). Attentional bias in anxiety: A behavioral and ERP study. *Brain and cognition*, *59*(1), 11-22.

Becker, M. P., Nitsch, A. M., Miltner, W. H., & Straube, T. (2014). A single-trial estimation of the feedback-related negativity and its relation to BOLD responses in a time-estimation task. *Journal of Neuroscience*, *34*(8), 3005-3012.

Beilock, S. L., & Carr, T. H. (2005). When high-powered people fail: Working memory and "choking under pressure" in math. *Psychological science*, *16*(2), 101-105.

Beilock, S. L. (2008). Math performance in stressful situations. *Current Directions in Psychological Science*, *17*(5), 339-343.

Beilock, S. (2010). *Choke: What the secrets of the brain reveal about getting it right when you have to*. Simon and Schuster.

Berggren, N., & Derakshan, N. (2013). Attentional control deficits in trait anxiety: Why you see them and why you don't. *Biological Psychology*, *92*(3), 440-446.

Berridge, K. C., & Robinson, T. E. (2003). Parsing reward. *Trends in neurosciences*, *26*(9), 507-513.

Berridge, K. C., Robinson, T. E., & Aldridge, J. W. (2009). Dissecting components of reward:'liking','wanting', and learning. *Current opinion in pharmacology*, *9*(1), 65-73.

Böcker, K. B., Brunia, C. H., & van den Berg-Lenssen, M. (1994). A spatiotemporal dipole model of the stimulus preceding negativity (SPN) prior to feedback stimuli. *Brain topography*, *7*(1), 71-88.

Boksem, M. A., Meijman, T. F., & Lorist, M. M. (2005). Effects of mental fatigue on attention: an ERP study. *Cognitive brain research*, *25*(1), 107-116.

Boksem, M. A., Meijman, T. F., & Lorist, M. M. (2006). Mental fatigue, motivation and action monitoring. *Biological psychology*, *72*(2), 123-132.

Boksem, M. A., Tops, M., Kostermans, E., & De Cremer, D. (2008). Sensitivity to punishment and reward omission: evidence from error-related ERP components. *Biological Psychology*, *79*(2), 185-192.

Bradley, M. M., Sabatinelli, D., Lang, P. J., Fitzsimmons, J. R., King, W., & Desai, P. (2003). Activation of the visual cortex in motivated attention. *Behavioral neuroscience*, *117*(2), 369.

Braver, T. S., Gray, J. R., & Burgess, G. C. (2007). Explaining the many varieties of working memory variation: Dual mechanisms of cognitive control. *Variation in working memory*, *75*, 106.

Braver, T. S. (2012). The variable nature of cognitive control: a dual mechanisms framework. *Trends in cognitive sciences*, *16*(2), 106-113.

Breiter, H. C., Aharon, I., Kahneman, D., Dale, A., & Shizgal, P. (2001). Functional imaging of neural responses to expectancy and experience of monetary gains and losses. *Neuron*, *30*(2), 619-639.

Bress, J. N., Smith, E., Foti, D., Klein, D. N., & Hajcak, G. (2012). Neural response to reward and depressive symptoms in late childhood to early adolescence. *Biological psychology*, *89*(1), 156-162.

Bress, J. N., Foti, D., Kotov, R., Klein, D. N., & Hajcak, G. (2013). Blunted neural response to rewards prospectively predicts depression in adolescent girls. *Psychophysiology*, *50*(1), 74-81.

Bress, J. N., Meyer, A., & Proudfit, G. H. (2015a). The stability of the feedback negativity and its relationship with depression during childhood and adolescence. *Development and psychopathology*, *27*(4pt1), 1285-1294.

Bress, J. N., Meyer, A., & Hajcak, G. (2015b). Differentiating anxiety and depression in children and adolescents:

Brown, T. A., Antony, M. M., & Barlow, D. H. (1992). Psychometric properties of the Penn State Worry Questionnaire in a clinical anxiety disorders sample. *Behaviour research and therapy*, *30*(1), 33-37.

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.

Brown, T. A., & Barlow, D. H. (2009). A proposal for a dimensional classification system based on the shared features of the DSM-IV anxiety and mood disorders: implications for assessment and treatment. *Psychological assessment*, *21*(3), 256.

Broyd, S. J., Richards, H. J., Helps, S. K., Chronaki, G., Bamford, S., & Sonuga-Barke, E. J. (2012). An electrophysiological monetary incentive delay (e-MID) task: a way to decompose the different components of neural response to positive and negative monetary reinforcement. *Journal of neuroscience methods*, *209*(1), 40-49.

Brunia, C. H. M., De Jong, B. M., Van den Berg-Lenssen, M. M. C., & Paans, A. M. J. (2000). Visual feedback about time estimation is related to a right hemisphere activation measured by PET. *Experimental Brain Research*, *130*(3), 328-337.

Bunford, N., Kujawa, A., Fitzgerald, K. D., Swain, J. E., Hanna, G. L., Koschmann, E., ... & Phan, K. L. (2017). Neural reactivity to angry faces predicts treatment response in pediatric anxiety. *Journal of abnormal child psychology*, *45*(2), 385-395.

Burkhouse, K. L., Woody, M. L., Owens, M., & Gibb, B. E. (2015). Influence of worry on sustained attention to emotional stimuli: Evidence from the late positive potential. *Neuroscience letters*, *588*, 57-61.

Bush, G., Luu, P., & Posner, M. I. (2000). Cognitive and emotional influences in anterior cingulate cortex. *Trends in cognitive sciences*, *4*(6), 215-222.

Cant, B. R., & Bickford, R. G. (1967). The effect of motivation on the contingent negative variation (CNV). *Electroencephalography and clinical neurophysiology*, *23*(6), 594.

Carlson, J. M., Foti, D., Mujica-Parodi, L. R., Harmon-Jones, E., & Hajcak, G. (2011). Ventral striatal and medial prefrontal BOLD activation is correlated with reward-related electrocortical activity: a combined ERP and fMRI study. *Neuroimage*, *57*(4), 1608-1616.

Carver, C. S., & White, T. L. (1994). Behavioral inhibition, behavioral activation, and affective responses to impending reward and punishment: the BIS/BAS scales. *Journal of personality and social psychology*, *67*(2), 319.

Chase, H. W., Nusslock, R., Almeida, J. R., Forbes, E. E., LaBarbara, E. J., & Phillips, M. L. (2013). Dissociable patterns of abnormal frontal cortical activation during anticipation of an uncertain reward or loss in bipolar versus major depression. *Bipolar disorders*, *15*(8), 839-854.

Cheng, S. Y., Lee, H. Y., Shu, C. M., & Hsu, H. T. (2007). Electroencephalographic study of mental fatigue in visual display terminal tasks. *Journal of Medical and Biological Engineering*, *27*(3), 124-131.

Chronaki, G., Broyd, S. J., Garner, M., Benikos, N., Thompson, M. J., Sonuga-Barke, E. J., & Hadwin, J. A. (2018). The moderating effect of self-reported state and trait anxiety on the late positive potential to emotional faces in 6–11-year-old children. *Frontiers in psychology*, *9*, 125.

Chiu, P. H., & Deldin, P. J. (2007). Neural evidence for enhanced error detection in major depressive disorder. *American Journal of Psychiatry*, *164*(4), 608-616.

Chwilla, D. J., & Brunia, C. H. (1991). Event-related potentials to different feedback stimuli. *Psychophysiology*, *28*(2), 123-132.

Cisler, J. M., & Koster, E. H. (2010). Mechanisms of attentional biases towards threat in anxiety disorders: An integrative review. *Clinical psychology review*, *30*(2), 203-216.

Clayson, P. E., Carbine, K. A., & Larson, M. J. (2020). A registered report of error-related negativity and reward positivity as biomarkers of depression: P-Curving the evidence. *International Journal of Psychophysiology*, *150*, 50-72.

Clark, L. A., & Watson, D. (1991). Tripartite model of anxiety and depression: psychometric evidence and taxonomic implications. *Journal of abnormal psychology*, *100*(3), 316.

Craske, M. G., & Vervliet, B. (2013). Extinction learning and its retrieval. *Changing emotions*, 53-59.

Cuthbert, B. N., Schupp, H. T., Bradley, M. M., Birbaumer, N., & Lang, P. J. (2000). Brain potentials in affective picture processing: covariation with autonomic arousal and affective report. *Biological psychology*, *52*(2), 95-111.

DeCicco, J. M., Solomon, B., & Dennis, T. A. (2012). Neural correlates of cognitive reappraisal in children: an ERP study. *Developmental cognitive neuroscience*, *2*(1), 70-80.

Delgado, M. R., Nystrom, L. E., Fissell, C., Noll, D. C., & Fiez, J. A. (2000). Tracking the hemodynamic responses to reward and punishment in the striatum. *Journal of neurophysiology*, *84*(6), 3072-3077.

Delgado, M. R., Nearing, K. I., LeDoux, J. E., & Phelps, E. A. (2008). Neural circuitry underlying the regulation of conditioned fear and its relation to extinction. *Neuron*, *59*(5), 829-838.

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.

Dennis, T. A., & Chen, C. C. (2007). Emotional face processing and attention performance in three domains: Neurophysiological mechanisms and moderating effects of trait anxiety. *International Journal of Psychophysiology*, *65*(1), 10-19.

Dennis, T. A., & Hajcak, G. (2009). The late positive potential: a neurophysiological marker for emotion regulation in children. *Journal of child psychology and psychiatry*, *50*(11), 1373-1383.

Dhar, M., Wiersema, J. R., & Pourtois, G. (2011). Cascade of neural events leading from error commission to subsequent awareness revealed using EEG source imaging. *PLoS One*, *6*(5), e19578.

Donchin, E., & Coles, M. G. (1998). Context updating and the P300. *Behavioral and brain sciences*, *21*(1), 152-154.

Donkers, F. C., Nieuwenhuis, S., & Van Boxtel, G. J. (2005). Mediofrontal negativities in the absence of responding. *Cognitive brain research*, *25*(3), 777-787.

Dunning, J. P., & Hajcak, G. (2007). Error-related negativities elicited by monetary loss and cues that predict loss. *Neuroreport*, *18*(17), 1875-1878.

Endrass, T., Franke, C., & Kathmann, N. (2005). Error awareness in a saccade countermanding task. *Journal of Psychophysiology*, *19*(4), 275-280.

Endrass, T., Reuter, B., & Kathmann, N. (2007). ERP correlates of conscious error recognition: aware and unaware errors in an antisaccade task. *European Journal of Neuroscience*, *26*(6), 1714-1720.

Endrass, T., Klawohn, J., Schuster, F., & Kathmann, N. (2008). Overactive performance monitoring in obsessive-compulsive disorder: ERP evidence from correct and erroneous reactions. *Neuropsychologia*, *46*(7), 1877-1887.

Endrass, T., Klawohn, J., Gruetzmann, R., Ischebeck, M., & Kathmann, N. (2012a). Response-related negativities following correct and incorrect responses: Evidence from a temporospatial principal component analysis. *Psychophysiology*, *49*(6), 733-743.

Endrass, T., Klawohn, J., Preuss, J., & Kathmann, N. (2012b). Temporospatial dissociation of Pe subcomponents for perceived and unperceived errors. *Frontiers in human neuroscience*, *6*, 178.

Eysenck, H. J., & Eysenck, S. B. G. (1975). *Manual of the Eysenck Personality Questionnaire (junior and adult)*. Hodder and Stoughton.

Eysenck, M. W., & Calvo, M. G. (1992). Anxiety and performance: The processing efficiency theory. *Cognition & emotion*, *6*(6), 409-434.

Eysenck, M. W., Derakshan, N., Santos, R., & Calvo, M. G. (2007). Anxiety and cognitive performance: attentional control theory. *Emotion*, *7*(2), 336.

Faber, L. G., Maurits, N. M., & Lorist, M. M. (2012). Mental fatigue affects visual selective attention. *PloS one*, *7*(10), e48073.

Fales, C. L., Barch, D. M., Burgess, G. C., Schaefer, A., Mennin, D. S., Gray, J. R., & Braver, T. S. (2008). Anxiety and cognitive efficiency: differential modulation of transient and sustained neural activity during a working memory task. *Cognitive, affective, & behavioral neuroscience*, *8*(3), 239-253.

Falkenstein, M., Hoormann, J., Christ, S., & Hohnsbein, J. (2000). ERP components on reaction errors and their functional significance: a tutorial. *Biological psychology*, *51*(2-3), 87-107.

Falkenstein, M., Hoormann, J., Hohnsbein, J., & Kleinsorge, T. (2003). Short-term mobilization of processing resources is revealed in the event-related potential. *Psychophysiology*, *40*(6), 914-923.

Faul, F., Erdfelder, E., Buchner, A., & Lang, A. G. (2009). Statistical power analyses using G* Power 3.1: Tests for correlation and regression analyses. *Behavior research methods*, *41*(4), 1149-1160.

Foa, E. B., Huppert, J. D., Leiberg, S., Langner, R., Kichic, R., Hajcak, G., & Salkovskis, P. M. (2002). The Obsessive-Compulsive Inventory: development and validation of a short version. *Psychological assessment*, *14*(4), 485.

Foti, D., Weinberg, A., Dien, J., & Hajcak, G. (2011). Event-related potential activity in the basal ganglia differentiates rewards from nonrewards: Temporospatial principal components analysis and source localization of the feedback negativity. *Human brain mapping*, *32*(12), 2207-2216.

Folstein, J. R., & Van Petten, C. (2008). Influence of cognitive control and mismatch on the N2 component of the ERP: a review. *Psychophysiology*, *45*(1), 152-170.

Geer, J. H. (1965). The development of a scale to measure fear. *Behaviour Research and Therapy*, *3*(1), 45-53.

Gehring, W. J., Goss, B., Coles, M. G., Meyer, D. E., & Donchin, E. (1993). A neural system for error detection and compensation. *Psychological science*, *4*(6), 385-390.

Gehring, W. J., Himle, J., & Nisenson, L. G. (2000). Action-monitoring dysfunction in obsessive-compulsive disorder. *Psychological science*, *11*(1), 1-6.

Ghashghaei, H. T., & Barbas, H. (2002). Pathways for emotion: interactions of prefrontal and anterior temporal pathways in the amygdala of the rhesus monkey. *Neuroscience*, *115*(4), 1261-1279.

Gibbons, H., Fritzsche, A. S., Bienert, S., Armbrecht, A. S., & Stahl, J. (2011). Percept-based and object-based error processing: An experimental dissociation of error-related negativity and error positivity. *Clinical neurophysiology*, *122*(2), 299-310.

Glazer, J. E., Kelley, N. J., Pornpattananangkul, N., Mittal, V. A., & Nusslock, R. (2018). Beyond the FRN: Broadening the time-course of EEG and ERP components implicated in reward processing. *International Journal of Psychophysiology*, *132*, 184-202.

Glazer, J. E., Kelley, N. J., Pornpattananangkul, N., & Nusslock, R. (2019). Hypomania and depression associated with distinct neural activity for immediate and future rewards. *Psychophysiology*, *56*(3), e13301.

Glazer, J., & Nusslock, R. (2022). Outcome valence and stimulus frequency affect neural responses to rewards and punishments. *Psychophysiology*, *59*(3), e13981.

Goldstein, R. Z., Cottone, L. A., Jia, Z., Maloney, T., Volkow, N. D., & Squires, N. K. (2006). The effect of graded monetary reward on cognitive event-related potentials and behavior in young healthy adults. *International Journal of Psychophysiology*, *62*(2), 272-279.

Gómez, C. M., Flores, A., & Ledesma, A. (2007). Fronto-parietal networks activation during the contingent negative variation period. *Brain research bulletin*, *73*(1-3), 40-47.

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.

Gotlib, I. H., Hamilton, J. P., Cooney, R. E., Singh, M. K., Henry, M. L., & Joormann, J. (2010). Neural processing of reward and loss in girls at risk for major depression. *Archives of general psychiatry*, *67*(4), 380-387.

Grant, D. M., Judah, M. R., White, E. J., & Mills, A. C. (2015). Worry and discrimination of threat and safety cues: An event-related potential investigation. *Behavior therapy*, *46*(5), 652-660.

Gray, J. R., Burgess, G. C., Schaefer, A., Yarkoni, T., Larsen, R. J., & Braver, T. S. (2005). Affective personality differences in neural processing efficiency confirmed using fMRI. *Cognitive, Affective, & Behavioral Neuroscience*, *5*(2), 182-190.

Groen, Y., Wijers, A. A., Mulder, L. J., Waggeveld, B., Minderaa, R. B., & Althaus, M. (2008). Error and feedback processing in children with ADHD and children with Autistic Spectrum Disorder: an EEG event-related potential study. *Clinical neurophysiology*, *119*(11), 2476-2493.

Hajcak, G., McDonald, N., & Simons, R. F. (2003). Anxiety and error-related brain activity. *Biological psychology*, *64*(1-2), 77-90.

Hajcak, G., McDonald, N., & Simons, R. F. (2004). Error-related psychophysiology and negative affect. *Brain and cognition*, *56*(2), 189-197.

Hajcak, G., & Foti, D. (2008). Errors are aversive: Defensive motivation and the error-related negativity. *Psychological science*, *19*(2), 103-108.

Olofsson, J. K., Nordin, S., Sequeira, H., & Polich, J. (2008). Affective picture processing: an integrative review of ERP findings. *Biological psychology*, *77*(3), 247-265.

Olvet, D. M., & Hajcak, G. (2008). The error-related negativity (ERN) and psychopathology: Toward an endophenotype. *Clinical psychology review*, *28*(8), 1343-1354.

Olvet, D. M., Klein, D. N., & Hajcak, G. (2010). Depression symptom severity and error-related brain activity. *Psychiatry research*, *179*(1), 30-37.

Hajcak, G., Dunning, J. P., & Foti, D. (2009). Motivated and controlled attention to emotion: time-course of the late positive potential. *Clinical neurophysiology*, *120*(3), 505-510.

Hajcak, G. (2012). What we've learned from mistakes: Insights from error-related brain activity. *Current Directions in Psychological Science*, *21*(2), 101-106.

Hajcak, G., & Foti, D. (2020). Significance?... Significance! Empirical, methodological, and theoretical connections between the late positive potential and P300 as neural responses to stimulus significance: An integrative review. *Psychophysiology*, *57*(7), e13570.

Holmes, A. J., & Pizzagalli, D. A. (2008). Spatiotemporal dynamics of error processing dysfunctions in major depressive disorder. *Archives of general psychiatry*, *65*(2), 179-188.

Holmes, A. J., & Pizzagalli, D. A. (2010). Effects of task-relevant incentives on the electrophysiological correlates of error processing in major depressive disorder. *Cognitive, Affective, & Behavioral Neuroscience*, *10*(1), 119-128.

Holroyd, C. B., & Coles, M. G. (2002). The neural basis of human error processing: reinforcement learning, dopamine, and the error-related negativity. *Psychological review*, *109*(4), 679.

Holroyd, C. (2004). A note on the oddball N200 and the feedback ERN. In *Errors, conflicts, and the brain: Current opinions on performance monitoring* (pp. 211-218). Max Planck Institute.

Holroyd, C. B., Pakzad-Vaezi, K. L., & Krigolson, O. E. (2008). The feedback correct-related positivity: Sensitivity of the event-related brain potential to unexpected positive feedback. *Psychophysiology*, *45*(5), 688-697.

Hopstaken, J. F., van der Linden, D., Bakker, A. B., Kompier, M. A., & Leung, Y. K. (2016). Shifts in attention during mental fatigue: Evidence from subjective, behavioral, physiological, and eye-tracking data. *Journal of Experimental Psychology: Human Perception and Performance*, *42*(6), 878.

Hu, L. T., & Bentler, P. M. (1999). Cutoff criteria for fit indexes in covariance structure analysis: Conventional criteria versus new alternatives. *Structural equation modeling: a multidisciplinary journal*, *6*(1), 1-55.

Huang, Y. X., & Luo, Y. J. (2006). Temporal course of emotional negativity bias: an ERP study. *Neuroscience letters*, *398*(1-2), 91-96.

Hughes, G., Mathan, S., & Yeung, N. (2013). EEG indices of reward motivation and target detectability in a rapid visual detection task. *Neuroimage*, *64*, 590-600.

Ikeda, A., Shibasaki, H., Kaji, R., Terada, K., Nagamine, T., Honda, M., ... & Kimura, J. (1996). Abnormal sensorimotor integration in writer's cramp: study of contingent negative variation. *Movement disorders: official journal of the Movement Disorder Society*, *11*(6), 683-690.

Irwin, D. A., Knott, J. R., McAdam, D. W., & Rebert, C. S. (1966). Motivational determinants of the "contingent negative variation". *Electroencephalography and Clinical Neurophysiology*, *21*(6), 538-543.

Johnson Jr, R., & Donchin, E. (1980). P300 and stimulus categorization: Two plus one is not so different from one plus one. *Psychophysiology*, *17*(2), 167-178.

Keedwell, P. A., Andrew, C., Williams, S. C., Brammer, M. J., & Phillips, M. L. (2005). The neural correlates of anhedonia in major depressive disorder. *Biological psychiatry*, *58*(11), 843-853.

Kendler, K. S., Prescott, C. A., Myers, J., & Neale, M. C. (2003). The structure of genetic and environmental risk factors for common psychiatric and substance use disorders in men and women. *Archives of general psychiatry*, *60*(9), 929-937.

Kessler, R. C., Chiu, W. T., Demler, O., & Walters, E. E. (2005). Prevalence, severity, and comorbidity of 12-month DSM-IV disorders in the National Comorbidity Survey Replication. *Archives of general psychiatry*, *62*(6), 617-627.

Kim, M. H., Marulis, L. M., Grammer, J. K., Morrison, F. J., & Gehring, W. J. (2017). Motivational processes from expectancy–value theory are associated with variability in the error positivity in young children. *Journal of Experimental Child Psychology*, *155*, 32-47.

Kinney, K. L. (2021). *The Role of Error-Related Negativity in Social Anxiety, Depression, and Treatment Outcome* (Doctoral dissertation, University of Illinois at Chicago).

Kotani, Y., Hiraku, S., Suda, K., & Aihara, Y. (2001). Effect of positive and negative emotion on stimulus-preceding negativity prior to feedback stimuli. *Psychophysiology*, *38*(6), 873-878.

Kotani, Y., Kishida, S., Hiraku, S., Suda, K., Ishii, M., & Aihara, Y. (2003). Effects of information and reward on stimulus-preceding negativity prior to feedback stimuli. *Psychophysiology*, *40*(5), 818-826.

Kotani, Y., Ohgami, Y., Kuramoto, Y., Tsukamoto, T., Inoue, Y., & Aihara, Y. (2009). The role of the right anterior insular cortex in the right hemisphere preponderance of stimulus-preceding negativity (SPN): an fMRI study. *Neuroscience Letters*, *450*(2), 75-79.

Kotani, Y., Ohgami, Y., Arai, J. I., Kiryu, S., & Inoue, Y. (2011). Motor and nonmotor components of event-brain potential in preparation of motor response. *Journal of Behavioral and Brain Science*, *1*(04), 234.

Knutson, B., Fong, G. W., Adams, C. M., Varner, J. L., & Hommer, D. (2001). Dissociation of reward anticipation and outcome with event-related fMRI. *Neuroreport*, *12*(17), 3683-3687.

Knutson, B., Fong, G. W., Bennett, S. M., Adams, C. M., & Hommer, D. (2003). A region of mesial prefrontal cortex tracks monetarily rewarding outcomes: characterization with rapid event-related fMRI. *Neuroimage*, *18*(2), 263-272.

Krueger, R. F. (1999). The structure of common mental disorders. *Archives of General Psychiatry, 56,* 921–926.

Krug, M. K., & Carter, C. S. (2010). Adding fear to conflict: a general purpose cognitive control network is modulated by trait anxiety. *Cognitive, Affective, & Behavioral Neuroscience*, *10*(3), 357-371.

Krug, M. K., & Carter, C. S. (2012). Proactive and reactive control during emotional interference and its relationship to trait anxiety. *Brain research*, *1481*, 13-36.

Kujawa, A., Proudfit, G. H., & Klein, D. N. (2014). Neural reactivity to rewards and losses in offspring of mothers and fathers with histories of depressive and anxiety disorders. *Journal of abnormal psychology*, *123*(2), 287.

Kujawa, A., MacNamara, A., Fitzgerald, K. D., Monk, C. S., & Phan, K. L. (2015). Enhanced neural reactivity to threatening faces in anxious youth: evidence from event-related potentials. *Journal of abnormal child psychology*, *43*(8), 1493-1501.

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.

Ladouceur, C. D., Dahl, R. E., Birmaher, B., Axelson, D. A., & Ryan, N. D. (2006). Increased error-related negativity (ERN) in childhood anxiety disorders: ERP and source localization. *Journal of Child Psychology and Psychiatry*, *47*(10), 1073-1082.

Larson, M. J., Baldwin, S. A., Good, D. A., & Fair, J. E. (2010). Temporal stability of the error-related negativity (ERN) and post-error positivity (Pe): The role of number of trials. *Psychophysiology*, *47*(6), 1167-1171.

Leutgeb, V., Schäfer, A., & Schienle, A. (2009). An event-related potential study on exposure therapy for patients suffering from spider phobia. *Biological psychology*, *82*(3), 293-300.

Leuthold, H., & Sommer, W. (1999). ERP correlates of error processing in spatial SR compatibility tasks. *Clinical Neurophysiology*, *110*(2), 342-357.

Liu, X., Hairston, J., Schrier, M., & Fan, J. (2011). Common and distinct networks underlying reward valence and processing stages: a meta-analysis of functional neuroimaging studies. *Neuroscience & Biobehavioral Reviews*, *35*(5), 1219-1236.

Lopez-Calderon, J., & Luck, S. J. (2014). ERPLAB: an open-source toolbox for the analysis of event-related potentials. *Frontiers in human neuroscience*, *8*, 213.

Lutz, K., & Widmer, M. (2014). What can the monetary incentive delay task tell us about the neural processing of reward and punishment. *Neuroscience and Neuroeconomics*, *3*, 33-35.

Luu, P., Collins, P., & Tucker, D. M. (2000). Mood, personality, and self-monitoring: negative affect and emotionality in relation to frontal lobe mechanisms of error monitoring. *Journal of experimental psychology: General*, *129*(1), 43.

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.

MacNamara, A., & Hajcak, G. (2009). Anxiety and spatial attention moderate the electrocortical response to aversive pictures. *Neuropsychologia*, *47*(13), 2975-2980.

MacNamara, A., & Hajcak, G. (2010). Distinct electrocortical and behavioral evidence for increased attention to threat in generalized anxiety disorder. *Depression and anxiety*, *27*(3), 234-243.

MacNamara, A., Ferri, J., & Hajcak, G. (2011). Working memory load reduces the late positive potential and this effect is attenuated with increasing anxiety. *Cognitive, Affective, & Behavioral Neuroscience*, *11*(3), 321-331.

MacNamara, A., Kotov, R., & Hajcak, G. (2016). Diagnostic and symptom-based predictors of emotional processing in generalized anxiety disorder and major depressive disorder: An event-related potential study. *Cognitive therapy and research*, *40*(3), 275-289.

MacNamara, A. (2018). In the mind's eye: The late positive potential to negative and neutral mental imagery and intolerance of uncertainty. *Psychophysiology*, *55*(5), e13024.

MacNamara, A., Jackson, T. B., Fitzgerald, J. M., Hajcak, G., & Phan, K. L. (2019). Working memory load and negative picture processing: Neural and behavioral associations with panic, social anxiety, and positive affect. *Biological Psychiatry: Cognitive Neuroscience and Neuroimaging*, *4*(2), 151-159.

Marco-Pallares, J., Cucurell, D., Münte, T. F., Strien, N., & Rodriguez-Fornells, A. (2011). On the number of trials needed for a stable feedback-related negativity. *Psychophysiology*, *48*(6), 852-860.

Masaki, H., Takeuchi, S., Gehring, W. J., Takasawa, N., & Yamazaki, K. (2006). Affective-motivational influences on feedback-related ERPs in a gambling task. *Brain research*, *1105*(1), 110-121.

Mattick, R. P., & Peters, L. (1988). Treatment of severe social phobia: effects of guided exposure with and without cognitive restructuring. *Journal of Consulting and Clinical Psychology*, *56*(2), 251.

McClelland, G. H., & Judd, C. M. (1993). Statistical difficulties of detecting interactions and moderator effects. *Psychological bulletin*, *114*(2), 376.

McClure, S. M., Berns, G. S., & Montague, P. R. (2003). Temporal prediction errors in a passive learning task activate human striatum. *Neuron*, *38*(2), 339-346.

McDermott, J. M., Perez-Edgar, K., Henderson, H. A., Chronis-Tuscano, A., Pine, D. S., & Fox, N. A. (2009). A history of childhood behavioral inhibition and enhanced response monitoring in adolescence are linked to clinical anxiety. *Biological psychiatry*, *65*(5), 445-448.

Meehl, P. E. (1975). Hedonic capacity: Some conjectures. *Bulletin of the Menninger Clinic*, *39*(4), 295-307.

Meehl, P. E. (2001). Primary and secondary hypohedonia. *Journal of Abnormal Psychology*, *110*(1), 188.

Mennin, D. S., Heimberg, R. G., Fresco, D. M., & Ritter, M. R. (2008). Is generalized anxiety disorder an anxiety or mood disorder? Considering multiple factors as we ponder the fate of GAD. *Anxiety and depression*, *25*(4), 289-299.

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.

Meyer, A., Bress, J. N., & Proudfit, G. H. (2014). Psychometric properties of the error-related negativity in children and adolescents. *Psychophysiology*, *51*(7), 602-610.

Meyer, A., Hajcak, G., Torpey-Newman, D. C., Kujawa, A., & Klein, D. N. (2015). Enhanced error-related brain activity in children predicts the onset of anxiety disorders between the ages of 6 and 9. *Journal of abnormal psychology*, *124*(2), 266.

Meyer, A. (2016). Developing psychiatric biomarkers: A review focusing on the error-related negativity as a biomarker for anxiety. *Current Treatment Options in Psychiatry*, *3*(4), 356-364.

Meyer, A. (2017). A biomarker of anxiety in children and adolescents: A review focusing on the error-related negativity (ERN) and anxiety across development. *Developmental cognitive neuroscience*, *27*, 58-68.

Meyer, A., Nelson, B., Perlman, G., Klein, D. N., & Kotov, R. (2018). A neural biomarker, the error-related negativity, predicts the first onset of generalized anxiety disorder in a large sample of adolescent females. *Journal of Child Psychology and Psychiatry*, *59*(11), 1162-1170.

Meyer, A., Mehra, L., & Hajcak, G. (2021). Error-related negativity predicts increases in anxiety in a sample of clinically anxious female children and adolescents over 2 years. *Journal of Psychiatry and Neuroscience*, *46*(4), E472-E479.

Michalowski JM, Melzig CA, Weike AI, Stockburger J, Schupp HT, Hamm AO (2009). Brain dynamics in spider-phobic individuals exposed to phobia-relevant and other emotional stimuli. *Emotion 9*, 306–315.

Miltner WHR, Trippe RH, Krieschel S, Gutberlet I, Hecht H, Weiss T (2005). Event-related brain potentials and affective responses to threat in spider/snake-phobic and non-phobic subjects. *International Journal of Psychophysiology 57,* 43–52.

Mineka, S., Watson, D., & Clark, L. A. (1998). Comorbidity of anxiety and unipolar mood disorders. *Annual review of psychology*, *49*(1), 377-412.

Mocaiber, I., Pereira, M. G., Erthal, F. S., Figueira, I., Machado-Pinheiro, W., Cagy, M., ... & de Oliveira, L. (2009). Regulation of negative emotions in high trait anxious individuals: An ERP study. *Psychology & Neuroscience*, *2*(2), 211.

Mochcovitch, M. D., da Rocha Freire, R. C., Garcia, R. F., & Nardi, A. E. (2014). A systematic review of fMRI studies in generalized anxiety disorder: evaluating its neural and cognitive basis. *Journal of affective disorders*, *167*, 336-342.

Montague, P. R., Hyman, S. E., & Cohen, J. D. (2004). Computational roles for dopamine in behavioural control. *Nature*, *431*(7010), 760-767.

Moran, T. P., Jendrusina, A. A., & Moser, J. S. (2013). The psychometric properties of the late positive potential during emotion processing and regulation. *Brain research*, *1516*, 66-75.

Morgan, J. K., Olino, T. M., McMakin, D. L., Ryan, N. D., & Forbes, E. E. (2013). Neural response to reward as a predictor of increases in depressive symptoms in adolescence. *Neurobiology of disease*, *52*, 66-74.

Moser, J. S., Hajcak, G., & Simons, R. F. (2005). The effects of fear on performance monitoring and attentional allocation. *Psychophysiology*, *42*(3), 261-268.

Moser, J. S., Huppert, J. D., Duval, E., & Simons, R. F. (2008). Face processing biases in social anxiety: an electrophysiological study. *Biological psychology*, *78*(1), 93-103.

Moser, J. S., Most, S. B., & Simons, R. F. (2010). Increasing negative emotions by reappraisal enhances subsequent cognitive control: a combined behavioral and electrophysiological study. *Cognitive, affective, & behavioral neuroscience*, *10*(2), 195-207.

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 posterror adjustments. *Psychological science*, *22*(12), 1484-1489.

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.

Moser, J., Moran, T., Schroder, H., Donnellan, B., & Yeung, N. (2013). On the relationship between anxiety and error monitoring: a meta-analysis and conceptual framework. *Frontiers in human neuroscience*, *7*, 466.

Moser, J. S., Hartwig, R., Moran, T. P., Jendrusina, A. A., & Kross, E. (2014). Neural markers of positive reappraisal and their associations with trait reappraisal and worry. *Journal of Abnormal Psychology*, *123*(1), 91.

Mun, S., Kim, E. S., & Park, M. C. (2014). Effect of mental fatigue caused by mobile 3D viewing on selective attention: An ERP study. *International Journal of Psychophysiology*, *94*(3), 373-381.

Muthen, B., du Toit, S. H. C., & Spisic, D. (1998). 1997. *Mplus user's guide*.

Murphy, P. R., Robertson, I. H., Allen, D., Hester, R., & O'Connell, R. G. (2012). An electrophysiological signal that precisely tracks the emergence of error awareness. *Frontiers in human neuroscience*, *6*, 65.

Naragon-Gainey, K., Prenoveau, J. M., Brown, T. A., & Zinbarg, R. E. (2016). A comparison and integration of structural models of anxiety and depression in a clinical sample: Support for and validation of the trilevel model. *Journal of abnormal psychology*, *125*(7), 853.

Nelson, B. D., Perlman, G., Hajcak, G., Klein, D. N., & Kotov, R. (2015). Familial risk for distress and fear disorders and emotional reactivity in adolescence: an event-related potential investigation. *Psychological medicine*, *45*(12), 2545-2556.

Nieuwenhuis, S., Ridderinkhof, K. R., Blom, J., Band, G. P., & Kok, A. (2001). Error-related brain potentials are differentially related to awareness of response errors: Evidence from an antisaccade task. *Psychophysiology*, *38*(5), 752-760.

Nieuwenhuis, S., Yeung, N., Van Den Wildenberg, W., & Ridderinkhof, K. R. (2003). Electrophysiological correlates of anterior cingulate function in a go/no-go task: effects of response conflict and trial type frequency. *Cognitive, affective, & behavioral neuroscience*, *3*(1), 17-26.

Nitschke, J. B., Heller, W., Imig, J. C., McDonald, R. P., & Miller, G. A. (2001). Distinguishing dimensions of anxiety and depression. *Cognitive Therapy and Research*, *25*(1), 1-22.

Novak, K. D., & Foti, D. (2015). Teasing apart the anticipatory and consummatory processing of monetary incentives: An event-related potential study of reward dynamics. *Psychophysiology*, *52*(11), 1470-1482.

Novak, B. K., Novak, K. D., Lynam, D. R., & Foti, D. (2016). Individual differences in the time course of reward processing: stage-specific links with depression and impulsivity. *Biological psychology*, *119*, 79-90.

O'Connell, R. G., Dockree, P. M., Bellgrove, M. A., Kelly, S. P., Hester, R., Garavan, H., ... & Foxe, J. J. (2007). The role of cingulate cortex in the detection of errors with and without awareness: a high-density electrical mapping study. *European Journal of Neuroscience*, *25*(8), 2571-2579.

Ohgami, Y., Kotani, Y., Hiraku, S., Aihara, Y., & Ishii, M. (2004). Effects of reward and stimulus modality on stimulus-preceding negativity. *Psychophysiology*, *41*(5), 729-738.

Ohgami, Y., Kotani, Y., Tsukamoto, T., Omura, K., Inoue, Y., Aihara, Y., & Nakayama, M. (2006). Effects of monetary reward and punishment on stimulus-preceding negativity. *Psychophysiology*, *43*(3), 227-236.

Olvet, D. M., & Hajcak, G. (2008). The error-related negativity (ERN) and psychopathology: Toward an endophenotype. *Clinical psychology review*, *28*(8), 1343-1354.

Olvet, D. M., Klein, D. N., & Hajcak, G. (2010). Depression symptom severity and error-related brain activity. *Psychiatry research*, *179*(1), 30-37.

Ottowitz, W. E., Tondo, L., Dougherty, D. D., & Savage, C. R. (2002). The neural network basis for abnormalities of attention and executive function in major depressive disorder: implications for application of the medical disease model to psychiatric disorders. *Harvard review of psychiatry*, *10*(2), 86-99.

Overbeek, T. J., Nieuwenhuis, S., & Ridderinkhof, K. R. (2005). Dissociable components of error processing: On the functional significance of the Pe vis-à-vis the ERN/Ne. *Journal of Psychophysiology*, *19*(4), 319-329.

Pailing, P. E., & Segalowitz, S. J. (2004). The effects of uncertainty in error monitoring on associated ERPs. *Brain and cognition*, *56*(2), 215-233.

Pauli P, Dengler W, Wiedemann G, Montoya P, Flor H, Birbaumer N, Buchkremer G (1997). Behavioral and neurophysiological evidence for altered processing of anxiety-related words in panic disorder. Journal of Abnormal Psychology 106, 213–220.

Pedersen, W. S., & Larson, C. L. (2016). State anxiety carried over from prior threat increases late positive potential amplitude during an instructed emotion regulation task. *Emotion*, *16*(5), 719.

Pfabigan, D. M., Seidel, E. M., Sladky, R., Hahn, A., Paul, K., Grahl, A., ... & Windischberger, C. (2014). P300 amplitude variation is related to ventral striatum BOLD response during gain and loss anticipation: an EEG and fMRI experiment. *NeuroImage*, *96*, 12-21.

Pizzagalli, D. A., Iosifescu, D., Hallett, L. A., Ratner, K. G., & Fava, M. (2008). Reduced hedonic capacity in major depressive disorder: evidence from a probabilisftic reward task. *Journal of psychiatric research*, *43*(1), 76-87.

Plichta, M. M., Wolf, I., Hohmann, S., Baumeister, S., Boecker, R., Schwarz, A. J., ... & Brandeis, D. (2013). Simultaneous EEG and fMRI reveals a causally connected subcortical-cortical network during reward anticipation. *Journal of Neuroscience*, *33*(36), 14526-14533.

Polich, J. (2007). Updating P300: an integrative theory of P3a and P3b. *Clinical neurophysiology*, *118*(10), 2128-2148.

Pornpattananangkul, N., & Nusslock, R. (2015). Motivated to win: Relationship between anticipatory and outcome reward-related neural activity. *Brain and cognition*, *100*, 21-40.

Potts, G. F. (2011). Impact of reward and punishment motivation on behavior monitoring as indexed by the error-related negativity. *International Journal of Psychophysiology*, *81*(3), 324-331.

Proudfit, G. H. (2015). The reward positivity: From basic research on reward to a biomarker for depression. *Psychophysiology*, *52*(4), 449-459.

Prenoveau, J. M., Zinbarg, R. E., Craske, M. G., Mineka, S., Griffith, J. W., & Epstein, A. M. (2010). Testing a hierarchical model of anxiety and depression in adolescents: A trilevel model. *Journal of Anxiety Disorders*, *24*(3), 334-344.Youth Emotion Project.

Ramirez, G., Gunderson, E. A., Levine, S. C., & Beilock, S. L. (2012). Spatial anxiety relates to spatial abilities as a function of working memory in children. *Quarterly journal of experimental psychology*, *65*(3), 474-487.

Rapee, R. M., Craske, M. G., & Barlow, D. H. (1994). Assessment instrument for panic disorder that includes fear of sensation-producing activities: The Albany Panic and Phobia Questionnaire. *Anxiety*, *1*(3), 114-122.

Ridderinkhof, K. R., Ramautar, J. R., & Wijnen, J. G. (2009). To PE or not to PE: A P3-like ERP component reflecting the processing of response errors. *Psychophysiology*, *46*(3), 531-538.

Rogers, R. D., Ramnani, N., Mackay, C., Wilson, J. L., Jezzard, P., Carter, C. S., & Smith, S. M. (2004). Distinct portions of anterior cingulate cortex and medial prefrontal cortex are activated by reward processing in separable phases of decision-making cognition. *Biological psychiatry*, *55*(6), 594-602.

Rougemont-Bücking, A., Linnman, C., Zeffiro, T. A., Zeidan, M. A., Lebron-Milad, K., Rodriguez-Romaguera, J., ... & Milad, M. R. (2011). Altered processing of contextual information during fear extinction in PTSD: an fMRI study. *CNS neuroscience & therapeutics*, *17*(4), 227-236.

Ruchsow, M., Herrnberger, B., Wiesend, C., Grön, G., Spitzer, M., & Kiefer, M. (2004). The effect of erroneous responses on response monitoring in patients with major depressive disorder: A study with event-related potentials. *Psychophysiology*, *41*(6), 833-840.

Ruchsow, M., Grön, G., Reuter, K., Spitzer, M., Hermle, L., & Kiefer, M. (2005). Error-related brain activity in patients with obsessive-compulsive disorder and in healthy controls. *Journal of Psychophysiology*, *19*(4), 298-304.

Ruchsow, M., Herrnberger, B., Beschoner, P., Grön, G., Spitzer, M., & Kiefer, M. (2006). Error processing in major depressive disorder: Evidence from event-related potentials. *Journal of psychiatric research*, *40*(1), 37-46.

Sabeti, M., Boostani, R., & Rastgar, K. (2018). How mental fatigue affects the neural sources of P300 component? *Journal of Integrative Neuroscience*, *17*(1), 93-111.

Salamone, J. D., & Correa, M. (2012). The mysterious motivational functions of mesolimbic dopamine. *Neuron*, *76*(3), 470-485.

Sambrook, T. D., & Goslin, J. (2015). A neural reward prediction error revealed by a meta-analysis of ERPs using great grand averages. *Psychological bulletin*, *141*(1), 213.

San Martín, R. (2012). Event-related potential studies of outcome processing and feedback-guided learning. *Frontiers in human neuroscience*, *6*, 304.

San Martín, R., Appelbaum, L. G., Pearson, J. M., Huettel, S. A., & Woldorff, M. G. (2013). Rapid brain responses independently predict gain maximization and loss minimization during economic decision making. *Journal of Neuroscience*, *33*(16), 7011-7019.

Sandre, A., Bagot, R. C., & Weinberg, A. (2019). Blunted neural response to appetitive images prospectively predicts symptoms of depression, and not anxiety, during the transition to university. *Biological psychology*, *145*, 31-41.

Scheffers, M. K., & Coles, M. G. (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.

Schienle, A., Schäfer, A., & Naumann, E. (2008). Event-related brain potentials of spider phobics to disorder-relevant, generally disgust-and fear-inducing pictures. *Journal of Psychophysiology*, *22*(1), 5-13.

Schrijvers, D., de Bruijn, E. R., Maas, Y., De Grave, C., Sabbe, B. G., & Hulstijn, W. (2008). Action monitoring in major depressive disorder with psychomotor retardation. *Cortex*, *44*(5), 569-579.

Schrijvers, D., De Bruijn, E. R., Maas, Y. J., Vancoillie, P., Hulstijn, W., & Sabbe, B. G. (2009). Action monitoring and depressive symptom reduction in major depressive disorder. *International Journal of Psychophysiology*, *71*(3), 218-224.

Schroder, H. S., Fisher, M. E., Lin, Y., Lo, S. L., Danovitch, J. H., & Moser, J. S. (2017). Neural evidence for enhanced attention to mistakes among school-aged children with a growth mindset. *Developmental Cognitive Neuroscience*, *24*, 42-50.

Schroder, H. S., Nickels, S., Cardenas, E., Breiger, M., Perlo, S., & Pizzagalli, D. A. (2020). Optimizing assessments of post-error slowing: A neurobehavioral investigation of a flanker task. *Psychophysiology*, *57*(2), e13473.

Schupp, H. T., Junghöfer, M., Weike, A. I., & Hamm, A. O. (2004). The selective processing of briefly presented affective pictures: an ERP analysis. *Psychophysiology*, *41*(3), 441-449.

Schupp, H. T., Flaisch, T., Stockburger, J., & Junghöfer, M. (2006). Emotion and attention: event-related brain potential studies. *Progress in brain research*, *156*, 31-51.

Schultz, W. (2000). Multiple reward signals in the brain. *Nature reviews neuroscience*, *1*(3), 199.

Schultz, W. (2002). Getting formal with dopamine and reward. *Neuron*, *36*(2), 241-263.

Schultz, W. (2007). Multiple dopamine functions at different time courses. *Annu. Rev. Neurosci.*, *30*, 259-288.

Sellbom, M., Ben-Porath, Y. S., & Bagby, R. M. (2008). On the hierarchical structure of mood and anxiety disorders: confirmatory evidence and elaboration of a model of temperament markers. *Journal of Abnormal Psychology*, *117*(3), 576.

Shalgi, S., Barkan, I., & Deouell, L. Y. (2009). On the positive side of error processing: error-awareness positivity revisited. *European Journal of Neuroscience*, *29*(7), 1522-1532.

Shankman, S. A., & Klein, D. N. (2003). The relation between anxiety and depression: an evaluation of the tripartite, approach-withdrawal and valence-arousal models. *Clinical Psychology Review*, *23*(4), 605-637.

Simons, R. F. (2010). The way of our errors: theme and variations. *Psychophysiology*, *47*(1), 1-14.

Slade, T. I. M., & Watson, D. (2006). The structure of common DSM-IV and ICD-10 mental disorders in the Australian general population. *Psychological medicine*, *36*(11), 1593.

Smith, T. J., Levin, D., & Cutting, J. E. (2012). A window on reality: Perceiving edited moving images. *Current Directions in Psychological Science*, *21*(2), 107-113.

Steinhauser, M., & Yeung, N. (2010). Decision processes in human performance monitoring. *Journal of Neuroscience*, *30*(46), 15643-15653.

Sylvester, C. M., Corbetta, M., Raichle, M. E., Rodebaugh, T. L., Schlaggar, B. L., Sheline, Y. I., ... & Lenze, E. J. (2012). Functional network dysfunction in anxiety and anxiety disorders. *Trends in neurosciences*, *35*(9), 527-535.

Treadway, M. T., & Zald, D. H. (2011). Reconsidering anhedonia in depression: lessons from translational neuroscience. *Neuroscience & Biobehavioral Reviews*, *35*(3), 537-555.

Treadway, M. T., Bossaller, N. A., Shelton, R. C., & Zald, D. H. (2012). Effort-based decision-making in major depressive disorder: a translational model of motivational anhedonia. *Journal of abnormal psychology*, *121*(3), 553.

Trimber, E. M., & Luhmann, C. C. (2017). Implicit predictions of future rewards and their electrophysiological correlates. *Behavioural Brain Research*, *333*, 184-191.

Vaidyanathan, U., Nelson, L. D., & Patrick, C. J. (2012). Clarifying domains of internalizing psychopathology using neurophysiology. *Psychological medicine*, *42*(3), 447-459.

Verbruggen, F., & Logan, G. D. (2009). Models of response inhibition in the stop-signal and stop-change paradigms. *Neuroscience & Biobehavioral Reviews*, *33*(5), 647-661.

Veit, R., Flor, H., Erb, M., Hermann, C., Lotze, M., Grodd, W., & Birbaumer, N. (2002). Brain circuits involved in emotional learning in antisocial behavior and social phobia in humans. *Neuroscience letters*, *328*(3), 233-236.

Von Borries, A. K. L., Verkes, R. J., Bulten, B. H., Cools, R., & De Bruijn, E. R. A. (2013). Feedback-related negativity codes outcome valence, but not outcome expectancy, during reversal learning. *Cognitive, Affective, & Behavioral Neuroscience*, *13*(4), 737-746.

Wacker, J., Dillon, D. G., & Pizzagalli, D. A. (2009). The role of the nucleus accumbens and rostral anterior cingulate cortex in anhedonia: integration of resting EEG, fMRI, and volumetric techniques. *Neuroimage*, *46*(1), 327-337.

Watson, D., Clark, L. A., Weber, K., Assenheimer, J. S., Strauss, M. E., & McCormick, R. A. (1995). Testing a tripartite model: II. Exploring the symptom structure of anxiety and depression in student, adult, and patient samples. *Journal of abnormal Psychology*, *104*(1), 15.

Watson, D. (2005). Rethinking the mood and anxiety disorders: a quantitative hierarchical model for DSM-V. *Journal of abnormal psychology*, *114*(4), 522.

Weinberg, A., Olvet, D. M., & Hajcak, G. (2010). Increased error-related brain activity in generalized anxiety disorder. *Biological psychology*, *85*(3), 472-480.

Weinberg, A., & Hajcak, G. (2011a). Electrocortical evidence for vigilance-avoidance in Generalized Anxiety Disorder. *Psychophysiology*, *48*(6), 842-851.

Weinberg, A., & Hajcak, G. (2011b). Longer term test–retest reliability of error-related brain activity. *Psychophysiology*, *48*(10), 1420-1425.

Weinberg, A., Klein, D. N., & Hajcak, G. (2012a). Increased error-related brain activity distinguishes generalized anxiety disorder with and without comorbid major depressive disorder. *Journal of Abnormal Psychology*, *121*(4), 885.

Weinberg, A., Riesel, A., & Hajcak, G. (2012b). 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.

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.

Weinberg, A., Perlman, G., Kotov, R., & Hajcak, G. (2016). Depression and reduced neural response to emotional images: Distinction from anxiety, and importance of symptom dimensions and age of onset. *Journal of abnormal psychology*, *125*(1), 26.

Wessel, J. R., & Aron, A. R. (2013). Unexpected events induce motor slowing via a brain mechanism for action-stopping with global suppressive effects. *Journal of Neuroscience*, *33*(47), 18481-18491.

Wessel, J. R., & Aron, A. R. (2015). It's not too late: The onset of the frontocentral P 3 indexes successful response inhibition in the stop-signal paradigm. *Psychophysiology*, *52*(4), 472-480.

Whitton, A. E., Treadway, M. T., & Pizzagalli, D. A. (2015). Reward processing dysfunction in major depression, bipolar disorder and schizophrenia. *Current opinion in psychiatry*, *28*(1), 7.

World Health Organization. (2017). *Depression and other common mental disorders: global health estimates* (No. WHO/MSD/MER/2017.2). World Health Organization.

Xiao, Z., Wang, J., Zhang, M., Li, H., Tang, Y., Wang, Y., ... & 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.

Yeung, N., Botvinick, M. M., & Cohen, J. D. (2004). The neural basis of error detection: conflict monitoring and the error-related negativity. *Psychological review*, *111*(4), 931.

Zimmerman, M., & Coryell, W. (1987). The Inventory to Diagnose Depression (IDD): A self-report scale to diagnose major depressive disorder. *Journal of Consulting and Clinical Psychology*, *55*(1), 55.

Zinbarg, R. E., & Barlow, D. H. (1996). Structure of anxiety and the anxiety disorders: a hierarchical model. *Journal of abnormal psychology*, *105*(2), 181.

James E. Glazer

Phone: 517-204-1773
Email: glazerja1@gmail.com
3813 N. Bernard, Apt. 1, Chicago, IL

Education

Ph.D., Northwestern University, expected June 2022
Clinical Psychology (APA-Accredited)
Dissertation: *Symptom Dimensions of Executive Control, Threat-, and Reward-Related Neural Activity*
Advisor: Robin Nusslock, Ph.D.
Committee: Vijay Mittal, Ph.D., Ken Paller, Ph.D.
Qualifying Exam Passed: June 2018
Expected Dissertation Completion: March 2022

M.S., Northwestern University, August 2018
Psychology
Thesis: *Beyond the FRN: Broadening the Time-Course of EEG and ERP Components Implicated in Reward Processing*

B.A., Michigan State University, August 2011
Psychology, Additional Major: Philosophy
Dean's List and membership nomination in Psi Chi Honors in Psychology

Research Grants

2016-2021 National Science Foundation (NSF) Graduate Research Fellowship Program (awarded 2016). "Relationship between reward-related neural activation and delay-discounting tendencies." DGE-201623198 to J.E.G.
Area: Cognitive Neuroscience
Direct Costs: $90,000
Status: Completed

Publications

Glazer, J., Nusslock, R. (under final review). *Stimulus Frequency and Outcome Valence Modulate Electrocortical Activity during Reward and Punishment Feedback Evaluation.* Submitted for publication in *Psychophysiology*.

Glazer, J., Nusslock, R. (in preparation). *Reduced Neural Activity in Anhedonia Across Several Stages of Reward Anticipation and Reward Outcome.*

Glazer, J., King, A., Yoon, C., Liberzon, I., & Kitayama, S. (2020). DRD4 polymorphisms modulate reward positivity and P3a in a gambling task: Exploring a genetic basis for cultural learning. *Psychophysiology*, e13623.

Glazer, J., Kelley, N. J., Pornpattananangkul, N., & Nusslock, R. (2019). Hypomania and depression associated with distinct neural activity for immediate and future rewards. *Psychophysiology*, 56(3), e13301.

Kelley, N. J., **Glazer, J.**, Pornpattananangkul, N., & Nusslock, R. (2019). Reappraisal and suppression emotion-regulation tendencies differentially predict reward-responsivity and psychological well-being. *Biological Psychology*, 140, 35-47.

Damme, K. S., Kelley, N. J., Quinn, M. E., **Glazer, J.**, Chat, I. K. Y., Young, K. S., Nusslock, R., Zinbarg, R., Bookheimer, S., & Craske, M. G. (2019). Emotional content impacts how executive function ability relates to willingness to wait and to work for reward. *Cognitive, Affective, & Behavioral Neuroscience*, 1-16.

Nadig, A., Kelley, N. J., Pornpattananangkul, N., **Glazer, J.**, & Nusslock, R. (2019). Shifts in attentional scope modulate event-related potentials evoked by reward. *Cognitive, Affective, & Behavioral Neuroscience*, 1-14.

Glazer, J., King, A., Yoon, C., Liberzon, I., & Kitayama, S. (2020). DRD4 polymorphisms modulate reward positivity and P3a in a gambling task: Exploring a genetic basis for cultural learning. *Psychophysiology*, *57*(10), e13623.

Nusslock, R., **Glazer, J.**, Ng, T. H., Titone, M. K., & Alloy, L. B. (2019). Reward Hypersensitivity in Bipolar Spectrum Disorders. *The Oxford Handbook of Positive Emotion and Psychopathology*, 161.

Glazer, J., Kelley, N. J., Pornpattananangkul, N., Mittal, V. A., & Nusslock, R. (2018). Beyond the FRN: Broadening the time-course of EEG and ERP components implicated in reward processing. *International Journal of Psychophysiology*, 132, 184-202.

Schroder, H. S., **Glazer, J.**, Bennett, K. P., Moran, T. P., & Moser, J. S. (2017). Suppression of error-preceding brain activity explains exaggerated error monitoring in females with worry. *Biological psychology, 122,* 33-41.

Hitokoto, H., **Glazer, J.**, & Kitayama, S. (2016). Cultural shaping of neural responses: Feedback-related potentials vary with self-construal and face priming. *Psychophysiology, 53*(1), 52-63.

Presentations at Scientific Meetings

Glazer, J., Gaumond, J., Liebman, E. Syed, S., & Nusslock, R. (2021). *Anhedonia associated with attenuated reward-related neural activity during cue-evaluation and motor-preparation.* Poster accepted for presentation at the 75th annual meeting of the Society of Biological Psychiatry Conference (Virtual Presentation).

Glazer, J., Nusslock, R. (2020). *Stimulus Frequency and Outcome Valence Modulate Reward-Positivity during Reward and Punishment Feedback Evaluation.* Poster presented at the 60th Annual Meeting of the Society for Research in Psychophysiology (Virtual Presentation).

Glazer, J., Kelley, N., Chat, I. K. Y., Young, K., Zinbarg, R., Craske, M., Nusslock, R. (2019). *Anhedonia is uniquely associated with blunted reward-related neural activity during cue-evaluation.* Poster presented at the 33rd Annual Meeting of the Society for Research in Psychopathology in Buffalo, NY.

Glazer, J., Bennett, K.P., Schroder, H.S. Moran, T.P., & Moser, J.S. (2013). *Error-Preceding Brain Activity is Reduced Among Worriers.* Poster presented at the 25th Annual Convention of the Association for Psychological Science in Washington, D.C.

Glazer, J., Hitokoto, H., Wasserman, E., Kitayama, S. (2015). *Cultural Self-Salience Modulates Feedback-Related P300.* Poster presented at the 16th Annual Meeting of the Society for Personality and Social Psychology in Long Beach, California.

Hitokoto, H., **Glazer, J.,** Du, M., Kitayama, S. (2015). *Culture Moderates the Face-Priming Effect on FRN.* Poster presented at the 16th Annual Meeting of the Society for Personality and Social Psychology in Long Beach, California.

Kelley, N., **Glazer, J.,** Pornpattananangkul, N., Nusslock, R. (2016). *Individual Differences in Emotion Suppression Predict Reward Anticipation: Evidence from the Stimulus-Preceding Negativity.* Poster presented at the 56th Annual Meeting of the Society for Psychophysiological Research in Minneapolis, Minnesota.

Nadig, A., Pornpattananangkul, N., Kelley, N., **Glazer, J.,** Nusslock, R. (2016). *Attentional Scope Differentially Impacts Anticipatory Versus Consummatory Reward-Related Neural Activity.* Poster presented at the 56th Annual Meeting of the Society for Psychophysiological Research in Minneapolis, Minnesota.

Glazer, J., Pornpattananangkul, N., Kelley, N., Singh, B., O'Brien, M., Kittleson, A., Nusslock, R. (2016). *Opposite Profiles of Reward Sensitivity: Hypomania Enhances Immediate Rewards while Depression Enhances Immediate Losses.* Poster presented at the 56th Annual Meeting of the Society for Psychophysiological Research in Minneapolis, Minnesota.

Glazer, J., Pornpattananangkul, N., Kelley, N., Singh, B., O'Brien, M., Kittleson, A., Nusslock, R. (2016). *Depression Attenuates the Reward Positivity for Immediate but not Delayed Rewards.* Poster presented at the 30th Annual Meeting of the Society for Research in Psychopathology in Baltimore, Maryland.

Kelley, N., Quinn, M., **Glazer, J.,** Pornpattananangkul, N., Grogans, S., Nadig, A., Nusslock, R. (2016). *Executive Control for Positive Information Mediates the Relationship Between Self-Reported Behavioral Approach Sensitivity and Reward Related Neural Activation.* Poster presented at the 30th Annual Meeting of the Society for Research in Psychopathology in Baltimore, Maryland.

Vanderlind, M., Pornpattananangkul, N., **Glazer, J.,** Baskin-Sommers, A., Nusslock, R., Joormann, J. (2016). *Keep Your Eye on the Prize: The Relation Between Biased Attention and Reward Processing Among Dysphoric Individuals.* Poster presented at the 30th Annual Meeting of the Society for Research in Psychopathology in Baltimore, Maryland.

Glazer, J., Hentschel, C., Becker, S., Shanker, E., Knott, H., Lisser, N., Nusslock, R. (2017). *Enhanced Neural Activity to Both Immediate and Delayed Rewards is Associated with Proneness to Hypomania.* Poster presented at the 31st Annual Meeting of the Society for Research in Psychopathology in Denver, Colorado.

Kelley, N., **Glazer, J.**, Pornpattananangkul, N., Nusslock, R. (2017). *Elevated Emotion Suppression Associated with Blunted Reward Sensitivity.* Poster presented at the 31st Annual Meeting of the Society for Research in Psychopathology in Denver, Colorado.

Glazer, J., Kelley, N., Fada, E., Sandozi, A., Nusslock, R. (2018). *Depressive and Hypomanic Symptoms are Related to Opposite Profiles of Reward-Related Neural Activity Only Following Immediate Rewards.* Poster presented at the 32nd Annual Meeting of the Society for Research in Psychopathology in Indianapolis, Indiana.

Symposia and Workshops

Glazer, J., Kelley, N.J., & Nusslock, R. (2018). Distinct and Opposite Profiles of Reward-Related Neural Activation in depression and mania. In N.J. Kelley & **Glazer, J.E. (co-Chairs),** *Broadening the time-course of ERP components implicated in reward processing: Implications for emotion, cognition, and psychopathology.* Symposium conducted at the 58th Annual Meeting of the Society for Psychophysiological Research, Quebec City, Quebec, Canada.

Glazer, J. (2016, 2019). *Processing Event-Related-Potentials using MatLab: eeglab/erplab Workshop.* Workshop presented to graduate students and faculty at Michigan State University (2016) and Northwestern University (2019).

Glazer, J. (2017). *Excel Tips, Tricks, Logic, Pivot Tables, and Automation: Introduction to Visual Basic and Macro Programming.* Workshop presented to Northwestern graduate students through the Ares Workshop Series.

Glazer, J. (2019). *Introduction to Psychophysiology: How to Measure and Analyze Human Biological Processes and Critically Evaluate their Strengths and Weaknesses.* Workshop presented to 50+ post-doctoral fellows and untenured faculty from research-focused Universities through the Summer Institute in Biological and Social Sciences (SIBASS), supported by the Russell Sage Foundation (RSF), Northwestern University.

Research Experience

Jul.2021-Present — *Clinical Psychology Intern,*
Lab: Affective Clinical and Neuroscience Lab
Location: University of Illinois at Chicago
Department: Psychiatry
Advisors: Drs. Tara Mehta, Heide Klumpp, Olusola Ajilore, and Katie Burkhouse.
Description: Processed and analyzed very large amounts of EEG data for several ongoing projects. Conducted psychotherapy in the Mood and Anxiety Clinic and as part of ongoing research to examine CBT interventions for social anxiety and major depression disorders. Currently receiving training in fMRI data processing, computational models of EEG/fMRI, and neurobiological models of psychopharmacology.

Aug.2015-Present — *Graduate Student,*
Lab: Affective Clinical and Neuroscience Lab
Location: Northwestern University
Department: Clinical Psychology
Advisor: Dr. Robin Nusslock, Ph.D.
Description: Managed electrophysiology lab used across multiple departmental labs with high-volume continuous data collection for five years. Supervised and mentored 25+ research assistant undergraduates and four honors theses. Of these, four secured post-bac positions at NIMH, two went on to enroll in dual M.D./Ph.D programs, and most matriculated to medical school. Designed and administered 10+ EEG experiments and directed a simultaneous EEG/fMRI experiment.

Jul.2013-Jul.2015 — *Research Technician Associate*
Location: University of Michigan
Lab: Culture & Cognition Lab, Culture Neuroscience
Department: Social Psychology

Principal Investigator: Dr. Shinobu Kitayama, Ph.D.
Description: Full time lab management: design and implementation of studies at multiple levels. Technical support for EEG implementation, processing, and data analysis. Coordinating projects, data management and analysis, and participant recruitment.

Jun.2012-Jul.2013 *Research Assistant*
Lab: Clinical Psychophysiology Lab
Location: Michigan State University
Department: Clinical Psychology
Principal Investigator: Dr. Jason Moser, Ph.D.
Description: Proficient MatLab scripting (EEGLAB and ERPLAB) including raw data to SPSS. Extensive experience with BioSemi systems and EEG recording hardware/software. Knowledge of proper EEG set up, cleaning, and running EEG experiments.

Feb.2011-Mar.2012 *Research Assistant*
Lab: Michigan State Twin Registry
Location: Michigan State University
Department: Clinical Psychology
Principal Investigator: Dr. Kelly Klump, Ph.D.
Description: Conducted in-person interviews with same-sex female twins across Michigan. Sole researcher responsible for organizing and maintaining 4+ years of confidential data. Other duties: scheduling, recruitment, payment, and managing relevant IRB information.

Feb.2011-Mar.2012 *Research Assistant*
Lab: Michigan State Twin Registry
Location: Michigan State University
Department: Clinical Psychology
Principal Investigator: Performed data analysis and statistical testing using Excel and SPSS. Coded video interactions between caregivers and their children. Collected, entered, and analyzed large amounts of data.

Work Experience

Sep.2011-July.2013 *Lead Instructor*
Program: Upward Bound
Location: Michigan State University
Description: Worked as the leader of a team of tutors and mentors to manage and organize class time to meet academic needs of Upward Bound high school students. Supervised up to three tutors and up to five mentors in addition to teaching classes. Created, designed, and taught Physics and Mathematics courses during 8-week summer program.

Technical Skills

1. Python: Advanced python programming with expertise in digital signal processing, machine learning, and preprocessing and analysis of physiological data.

2. Matlab: Advanced Octave programming experience focusing on electrophysiological data analysis and automated scripting (proficient in eeglab, erplab, fsl, eptoolbox, bcilab, and mobilab among others).

3. SPSS and R: Advanced SPSS syntax and R scripting including data processing, statistical analysis, and visualization.

4. Microsoft Excel: Advanced visual basic coding and macro scripting.

5. E-Prime and Psychopy: Advanced experience designing, modifying, and troubleshooting experiments.

6. Tensorflow: Proficient machine learning expertise with extensive experience in convolutional neural networks, linear discriminant analysis, brain-computer interface, and neurofeedback.

7. Visual Studio: Intermediate coding skills using C++/C#.

8. Brain Vision Analyzer: Advanced EEG/ERP processing.

9. Virtual Reality: Experience with Oculus and Unity development software, especially integration with simultaneous neural and physiological recording.

10. Motion/Eye Tracking: Advanced knowledge of several Tobii eye-tracking systems, Polhemus motion tracking, and integration with other multi-modal data using Lab Streaming Layer (LSL).

11. EEG Hardware Experience: Transcranial Direct-Current Stimulation, BioSemi, Neuroscan, Muse, OpenBCI, and Emotiv.

12. Functional Resonance Magnetic Imaging (fMRI): Intermediate experience setting-up and collecting simultaneous EEG/fMRI data.

Achievements & Awards

1. National Science Foundation (NSF) Fellowship.
2. Membership in Society of Biological Psychiatry.
3. Student membership in Society for Research in Psychopathology.
4. Student membership in Psychophysiological Research and position on student board.
5. National Merit Scholar Semifinalist.
6. Nominated for the National Society of Collegiate Scholar.
7. Member of Northwestern University Talent Development Program.
8. Nominated for membership in Psi Chi, the National Honor Society in Psychology.
9. Coursera Certificate in Python, Learn to Program: The Fundamentals (University of Toronto).