Examination of relationships between worry and rumination on neural indices of emotional processing: An event-related potentials study

Jean Marie Quintero

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Abstract

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The importance of dimensional approaches for conceptualizing and assessing transdiagnostic mechanisms that confer risk for psychopathology has become increasingly recognized within the field of affect science. Worry and rumination are characterized as negative self-referential processes, both of which are underlying mechanisms of distress disorders, however there is disagreement among clinical scientists regarding whether worry and rumination are unitary or distinguishable constructs. The present study sought to examine the transdiagnostic mechanisms of worry and rumination using subjective and biobehavioral assessments of emotional processing with the overarching goal of examining whether electrocortical responses to emotional images indexed by three event-related potentials (N1, EPN, LPP) were moderated by individual differences in trait- and state-levels of worry and rumination. Participants ($N = 99$) were undergraduate students that completed self-report measures assessing trait and state levels of worry and rumination, followed by a passive view task comprised of emotional images (i.e., threat, affiliative, erotic, mutilation), during which their electrocortical activity was recorded. Findings showed that rumination at the trait-level and state-level exhibited a pattern of findings that varied based on the specificity of emotional content, with a significant interaction between trait rumination and emotional image type occurring during early stages of emotional processing (indexed by N1 reactivity), and a significant interaction between state rumination and emotional image type occurring during later stages of emotional processing (indexed by late LPP reactivity). These discriminative patterns on neural markers of emotional reactivity that were

specific to rumination but not worry lend support to conceptualizations of these negative repetitive thinking styles as being distinct constructs, highlighting the importance of capturing nuances in temporal dynamics with subjective and biobehavioral assessments to elucidate the complex underpinnings of these maladaptive processes. Taken together, this study shows promise in contributing to the field by addressing gaps in extant literature considering that there are no studies to date that have incorporated these three ERP components specifically to examine the role of trait worry *and* rumination *as well as* state worry *and* rumination on emotional processing. Future studies that concurrently examine trait-level and state-level worry *and* rumination are needed given the role that these transdiagnostic mechanisms have in the prevention, etiology, and treatment of distress disorders.

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Dedication

"Surround yourself with the dreamers and the doers, the believers and thinkers, but most of all, surround yourself with those who see the greatness within you, even when you don't see it yourself." *– Edmund Lee*

This dissertation is dedicated to my family for providing me with love, strength, hope, resilience, and inspiration throughout every step of my journey as a doctoral student.

Swarley: You were my copilot in life, my best friend, my everything. Thank you for being the light that kept me going even on the darkest of days. You were there for me through it all and I cherish every moment of the 'swonderful' life that we shared together. I wish more than anything that you could be here with me to reach the finish line of this journey together. While you may not be here physically, you are still with me in everything I do, and for that reason, I dedicate this dissertation most of all to you.

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Chapter 1: Introduction

Distress Disorders

Distress disorders (Watson, 2005)—which include generalized anxiety disorder (GAD), major depressive disorder (MDD), and posttraumatic stress disorder (PTSD)—are treatment refractory conditions that pose challenges for effective assessment and treatment, particularly when comorbidity is present (Farabaugh et al., 2010). These challenges may be attributed to the limitations imposed by the traditional categorical classification systems of psychopathology most widely used by mental health professionals—*Diagnostic and Statistical Manual of Mental Disorders* (5th ed.; *DSM-5;* American Psychiatric Association, 2013) and *International Classification of Diseases and Related Health Problems* (11th ed.; *ICD-11*; World Health Organization, 2019)—which have been criticized for a variety of problems that hinder the identification and treatment of these disorders, including but not limited to high rates of comorbidity between diagnoses (e.g., GAD and MDD; Brown & Barlow, 2009; Kessler, Chiu, Demler, & Walters, 2005), heterogeneity within diagnostic categories (e.g., PTSD; Galatzer-Levy & Bryant, 2013), and lack of attention to individuals with subthreshold symptoms experiencing significant distress and/or impairment. In light of the increasingly recognized utility of studying transdiagnostic mechanisms implicated in psychopathology using dimensional approaches (e.g., National Institute of Mental Health's Research Domain and Criteria project [RDoC]: Cuthbert & Insel, 2010; 2013; Hierarchical Taxonomy of Psychopathology [HiTOP]: Kotov et al., 2017), empirical investigations that employ biobehavioral methods in conjunction with self-report measures are essential for advancing the field's understanding of core processes of dysfunction, offering a promising avenue for improving the identification and treatment of mental health disorders – particularly those that are comorbid and treatment refractory (e.g., GAD and MDD). Accordingly, identifying the overlapping and unique features of these disorders by addressing core disruptions as well as delineating mechanisms of action that ally closely with an understanding of basic affective and cognitive processes underlying chronic anxiety and co-occurring depression has merit for improving treatment outcomes. The propensity towards frequent engagement in repetitive negative thinking styles (e.g., worry, rumination) is a commonly endorsed feature reported by individuals with subclinical and clinical levels of anxiety and/or depression (Naragon-Gainey, McMahon, & Chacko, 2017; Stade & Ruscio, 2023). Both worry and rumination purportedly serve the function of emotion regulation, particularly when faced with actual or potential negative, unpleasant experiences (Mennin & Fresco, 2013). Worry and rumination exemplify transdiagnostic processes that appear to be particularly salient in GAD and MDD, yet there is continued debate among researchers as to whether or not these represent distinct cognitive affective processes (e.g., Hur, Heller, Kern, & Berenbaum, 2017; Watkins, Moulds, & Mackintosh, 2005) or are more so two sides of the same coin (e.g., McEvoy, Mahoney, & Moulds, 2010; Ruscio, Seitchik, Gentes, Jones, & Hallion, 2011). Further, there may be differential impacts of chronic use of worry and/or rumination (i.e., trait worry/rumination), as opposed to acute engagement in worry and/or rumination (i.e., state worry/rumination) which is a fairly normative experience if aligned with contextual demands; this underscores the importance of capturing nuances between trait-level versus state-level worry and rumination.

The present study implements subjective, behavioral, and neurophysiological measures of emotion-related constructs to better tease apart individual differences in trait and state emotion dysregulation—specifically worry and rumination—both of which are negative self-referential processes that differentially confer risk for internalizing psychopathology such as anxiety and depressive disorders. Better characterizing trait-level and state-level forms of emotion regulation at various stages in the unfolding of an emotional response using multi-modal indices (i.e., behavioral, physiological, subjective) may help elucidate the functional role of transdiagnostic processes such as worry and rumination, which could provide clinically valuable insight toward more targeted approaches to the assessment and treatment of distress disorders given that heightened emotionality and frequent engagement in repetitive negative thinking are transdiagnostic mechanisms present in both GAD and MDD. The present study offers a step in this direction by seeking to comprehensively examine the commonalities and distinctions between worry and rumination in relation to the shared versus differential impact these cognitive affective processes have on neural reactivity during the temporal unfolding of emotional responses. To this end, this study aims to link the subjective experience of emotion with objective neural measures using event-related potentials associated with emotional processing, with the overarching goal of seeking a better understanding of the connections between emotion and cognition as it relates to trait-level and state-level worry and rumination.

Worry and Rumination as Underlying Mechanisms of Distress Disorders

Worry. Worry is defined as a cognitive process characterized by repetitive thoughts focused on negative aspects of future events (Borkovec, Robinson, Pruzinsky, & DePree, 1983). Some theoretical frameworks underscore the role of emotional avoidance as a core feature underlying GAD by pinpointing shifts in negative affective intensity as the precursor to engaging in various forms of avoidance (e.g., worry, rumination, and self-criticism), so as to exert a sense of control over the somatic arousal in an emotionally charged situation, leading to a pattern of responding in this rigid and inflexible manner irrespective of whether the context is threatening or rewarding (Newman & Llera, 2011). Borkovec's Cognitive Avoidance Theory of Worry

(Borkovec, Alcaine, & Behar, 2004) argues that worry is a secondary response to the distress caused by a tendency toward avoiding threat above all else, implying that worry serves the function of avoidance, which then becomes negatively reinforced by a perceived sense of control over emotional responses. As a result, this form of experiential avoidance can become an implicit maladaptive emotion regulation strategy that perpetuates a vicious cycle whereby engaging in worry offers a means by which distress relief is gained through escaping from a perceived potential threat. This attempt at regulating internal distress (i.e., maladaptive emotion regulation) eventually has the net result of perpetuating a rather constant state of hypervigilance and avoidance when confronted with perceived threats. Consequently, these maladaptive emotion regulation tendencies are implemented in a rigid, automatic fashion and play a role in the inflexibility characterizing this disorder (Roemer & Orsillo, 2002).

Rumination. Rumination is defined as a cognitive process characterized by repetitive thoughts focused on negative aspects of one's past emotional experience (Nolen-Hoeksema, 1991). Many have alluded to the role of cognitive biases in rumination given its association with a tendency to attend to and remember negative information as opposed to positive information (e.g., Joorman, 2004). Research has implicated hypersensitivity to negative stimuli (Silk et al., 2014) as well as blunted responsiveness to reward-related stimuli (Forbes & Dahl, 2012) in adolescent depression as well as among healthy adults characterized by high levels of trait rumination (Schettino et al., 2021). According to the impaired disengagement hypothesis of rumination (Koster, De Lissnyder, Derakshan, & De Raedt, 2011), rumination is characterized by poor attentional disengagement from self-reflective information, thereby leading to a more prolonged state of rumination and subsequently contributing to negative affect and depression.

Similarities and Differences between Worry and Rumination

Whether trait worry and rumination represent independent constructs remains subject to debate given the similarities that have been identified and demonstrated between these forms of repetitive negative thinking (Funk, Takano, Schumm, & Ehring, 2022; McEvoy & Bran, 2013; Segerstrom, Stanton, Alden, & Shortridge, 2003). Although trait worry is widely recognized as a core defining symptom of GAD, trait worry is a common feature present across anxiety and depressive disorders, as demonstrated by a study that found no significant between-group differences in trait worry among GAD versus MDD (McEvoy, Watson, Watkins, & Nathan, 2013). While trait rumination has been linked to increased depressed symptomatology, it is also a significant predictor of mixed anxiety and depressive symptoms (Nolen-Hoeksema, 2000), suggesting that this is a transdiagnostic risk factor for distress disorders such as anxiety and depression (Nolen-Hoeksema & Watkins, 2011).

Negative interpretation biases are central features shared by both of these forms of repetitive negative thinking. Both worry and rumination are associated with cognitive inflexibility and difficulty switching attention from negative stimuli (Davis & Nolen-Hoeksema, 2000). This link between negative interpretation biases with worry and rumination has been demonstrated in the general population as well as among individuals with GAD or depression (Krahé, Whyte, Bridge, Loizou, & Hirsch, 2019), suggesting that this commonality is not specifically driven by diagnostic overlap among distress disorders. Further, both worry and rumination have been shown to be treatment refractory conditions as evidenced by less treatment gains and greater likelihood of relapse (Jones, Siegle, & Thase, 2008). Both rumination and worry are cognitively elaborative verbal linguistic forms of avoidance that inhibit emotional reactivity. This represents an overlap in functional aspects underlying worry and rumination, both of which purportedly serve as compensatory strategies to escape or avoid strongly felt emotional and/or somatic experiences, particularly in the context of perceived threat or negative outcomes (Mennin & Fresco, 2013).

Research using neuroimaging techniques, such as functional magnetic resonance imaging (fMRI), have provided key insight towards some of the structural and functional similarities characterizing these negative self-referential processes (Fresco et al., 2017). Worry and rumination are both associated with neural activation in the default mode network (DMN) and salience network (SN). The DMN is associated with autobiographical, self-monitoring, and social cognitive functions and reflects activity in the medial prefrontal cortex (MPFC; narrative and autobiographical self) and the posterior cingulate cortex (PCC; experiential self-reflection) (Brewer et al., 2011; Qin & Northoff, 2011). Notably, increased activation of DMN is characteristic of GAD (Chen & Etkin, 2013; Wang et al., 2016) and MDD (Hamilton et al., 2011; Hamilton, Chen & Gotlib, 2013), which may help to explain cognitive and emotion regulation deficits. The SN is responsible for integrating sensory, emotional, and cognitive information and thus plays a role in communication, social behavior, and self-awareness by facilitating attention to external and internal information (Menon & Uddin, 2010). Further, worry and rumination have demonstrated a neural pattern characterized by hyperactivitiy within the DMN network, hypoconnectivity within the SN network and frontoparietal control network, and hypoconnectivity between the DMN, frontoparietal control network, and dorsal attention network (Schooler et al., 2011). This pattern of neural activity implicated in worry and rumination underscores the similarities between these processes from a neuroscientific perspective.

Despite the similarities between worry and rumination as repetitive negative thinking styles that appear to be linked to anxiety and/or depression, many researchers recognize these as related yet distinct cognitive processes (Fresco, Frankel, Mennin, Turk, & Heimberg, 2002). According to results obtained using structural equation modeling, there is some evidence to suggest that self-report measures of worry and rumination are indeed statistically distinguishable (albeit related) constructs, supporting a bi-factor factor approach that both captures the common variance as well as separate worry-specific and rumination specific factors (Segerstrom, et al., 2017). Some have underscored that the key difference between worry and rumination is temporal orientation such that worry is more future-focused and rumination is more past-focused (Watkins, 2008). Others have underscored the distinctions in thought content and functional aspects underlying worry and rumination. While worry and rumination both purportedly serve as forms of avoidance, some have argued that the specific nonconscious avoidant functions are different, suggesting that worry is characterized by a nonconscious motive to avoid core negative affect and painful images, whereas rumination is characterized by a nonconscious motive to avoid aversive situations and responsibility to take action leading to withdrawal and inactivity (Nolen-Hoeksema, Wisco, & Lyubomirsky, 2008). In addition, these researchers purport that both processes involve perceptions about uncertainty and uncontrollability of one's environment, with more uncertainty and a greater sense of controllability in worry versus less uncertainty and a reduced sense of controllability in rumination.

Emotion Regulation

Emotion regulation difficulties have increasingly been recognized as a transdiagnostic risk factor of psychopathology (Kring & Sloane, 2009) and is a core disruption in GAD and MDD. To better understand the underlying function served by worry and rumination, models positioning emotion regulation difficulties as central to the pathogenesis of internalizing disorders have provided a useful theoretical framework from which overlapping risk factors for anxiety and depression can be examined (Fresco & Mennin, 2019; Mennin & Fresco, 2013). Emotion regulation is broadly defined as the processes by which individuals modify internal (i.e., thoughts, feelings, physiology) and external (i.e., situations) aspects of their emotional experience so as to dampen, intensify, or maintain emotion (Gross & Thompson, 2007). Flexibility, characterized by a malleable pattern of responding to environmental demands, is often understood as being a marker of adaptive emotion regulation (Bonanno & Burton, 2013; Bonanno, Papa, Lalande, Westphal, & Coifman, 2004). In line with this view underscoring the importance of flexibility in adaptive emotion regulation, the difficulties in emotion regulation characterizing various forms of psychopathology may be distinguished by a chronic pattern of rigid or inflexible responses to environmental demands that can be reflected behaviorally, cognitively, experientially, or physiologically (Dennis, O'Toole, & DeCicco, 2013). Similarly, emotion regulation difficulties are often characterized by the role of emotionality (e.g., negative affect) and maladaptive emotion regulation strategies (e.g., avoidance vis-à-vis worry and/or rumination), both of which play central roles in symptoms present across various forms of psychopathology (e.g., anxiety, depression). Taken together, conceptualizations of anxiety and depression firmly rooted in affective neuroscience offer a means by which cognitive and affective processes (e.g., attentional biases to pleasant/unpleasant stimuli) can be studied within emotionally salient contexts to better understand maladaptive emotion regulation strategies—specifically worry and rumination—that may not be readily observable.

Psychophysiology of Emotional Regulation

Emotion regulation has predictive utility for adaptive and maladaptive coping across the life span. This critical link is further demonstrated by the profound impact that emotion regulation difficulties have on psychological and physical health problems (Kemp & Quintana, 2013). Indeed, frequent use of maladaptive emotion regulations strategies such as worry and rumination exacerbates the emotional and physiological impact of a stressor (Brosschot, Pieper, & Thayer, 2005). In an effort to understand the role of worry and rumination on physiological activity, the perseverative cognition hypothesis proposes that chronic and sustained activation of perseverative thinking plays a role in increased susceptibility for deleterious physical health problems (Brosschot et al., 2005). Importantly, this theoretical framework posits that frequent engagement in negative perseverative thinking prolongs the physiological stress response as evidenced by a chronic, sustained state of physiological arousal (Brosschot, Gerin, & Thayer, 2006). Research has shown that physiological responses to stress that are chronically over- or underregulated are a significant predictor for future disease onset (Turner et al., 2020).

Theoretical models linking emotion-related processes with autonomic dysregulation have led to important insights on the interplay between psychological and physical health. Porges' polyvagal theory presents a framework that substantiates the link between emotion dysregulation and the parasympathetic branch of the autonomic nervous system via the vagal influences on cardiac responding (Porges, 2007). The neurovisceral integration theory builds upon this by underscoring the role of the central nervous system (CNS) to support an interconnected process involving emotion-regulatory components informed by affective neuroscience (Thayer, Hansen, Saus-Rose, & Johnsen, 2009). Essential to both of these theories is the justification of psychophysiological measures to study emotional responding (Thayer, Åhs, Fredrikson, Sollers,

& Wager, 2012).

Psychophysiological indices of emotion dysregulation have been instrumental for providing another means by which adaptive and maladaptive functioning may be understood according to distinct profiles reflecting flexibility/inflexibility and over- or under- regulation in neural and autonomic functioning. This seems particularly relevant to gleaning insight towards the inflexible patterns of neural and autonomic responses that are exhibited among individuals with anxiety and/or depression. Research on adults with anxiety disorders have consistently exhibited a pattern of low heart rate variability (Friedman, 2007; Thayer, Friedman, & Borkovec, 1996), a pattern which has also been shown in adults with major depression (Kemp & Quintana, 2013) and among nonclinical samples endorsing relatively higher levels of perseverative cognition (Ottaviani, Medea, Lonigro, Tarvainen, & Couyoumdjian, 2015; Ottaviani, Shapiro, & Couyoumdjian, 2013), thereby substantiating that both share an autonomic profile characterized by rigidity or lack of flexibility in response to environmental stressors.

Importance of Timing

Some psychophysiological methods that have been used in prior research (e.g., skin conductance response; Andor, Gerlach, & Rist, 2008) pose certain limitations in the study of emotional responding in that they lack the temporal resolution needed to index rapid cognitive and affective processes that occur in response to a given stimulus. Gross' (1998) process model of emotion regulation identifies different stages within the temporal unfolding of emotional responses spanning across varying degrees of cognitive elaboration from relatively automatic and effortless emotion regulation strategies to more controlled and effortful emotion regulation strategies (Gross, 1998; 2015; Gross & Thompson, 2007), which provides a sound theoretical framework emphasizing that emotion regulation can take place at multiple points along the temporal unfolding of emotional response, thereby further underscoring the importance of timing or temporal dynamics involved in emotion regulation. Considering that emotional reactivity involves a cascade of responses spanning from initial relatively automatic stages of processing to increasingly more elaborative stages of processing, all of which unfold quickly in less than a second, capturing these temporal and functional distinctions is essential for elucidating the complex and dynamic neural underpinnings of emotion regulation. Given the temporal dynamics involved in emotional processing, which occur rapidly in the order of milliseconds, methods that are able to accurately and reliably quantify these responses are essential.

Utility of Event-Related Potentials for Studying Emotional Processing

Event-related potentials (ERPs) are one such metric that has demonstrating utility for characterizing the temporal dynamics of emotional reactivity due to the ability to quantify neural responses to emotional stimuli on a millisecond-by-millisecond basis, thereby justifying this method as being ideally suited for studying cognitive and affective processes that unfold rapidly in time (Weinberg, Ferri, & Hajcak, 2013). In addition to the superior temporal resolution, ERPs are not reliant on an individual's ability to access and report on cognitive-affective processes, which may help overcome limitations imposed by relying purely on self-report measures.

There is ample evidence to support the influence of emotion on the amplitude of an ERP waveform (MacNamara & Hajcak, 2010), thereby providing further justification for the use of this valid and reliable psychophysiological method for examining emotion-related processes. An ERP component is defined as scalp-recorded neural activity that is generated in a given neuroanatomical module when a specific computational operation is performed (Luck & Kappenman, 2012). To date, a variety of ERP components have been utilized for the purpose of studying emotion-related processes, which has led to a consensus that there is an important distinction between ERP components that occur during earlier stages of processing (<300 ms) that reflect initial attention of stimuli versus later (>300 ms) stages of processing that are more specific to the motivational salience of stimuli, the latter of which has shown to be indicative of relatively more elaborative emotional processing (Codispoti, Ferrari, & Bradley, 2007; Olofsson, Nordin, Sequeira, & Polich, 2008).

Three ERP components—N1, early posterior negativity (EPN), late positive potential (LPP)—were specifically chosen given extant literature supporting them as well-established measures of emotional processing. Moreover, each of these components index different aspects of the distinct temporal unfolding of emotional processing, thereby offering a means of elucidating relatively more automatic stages to relatively more elaborative stages of neural responses to emotional stimuli, with the N1 and EPN reflecting earlier attentional processes and the LPP reflecting later more cognitively elaborative cognitive processes (Foti, Hajcak, & Dien, 2009).

N1. The N1 is a centroparietal (Cz, CPz) negative deflection that peaks approximately ~130 ms after stimulus onset and reflects increased early visual processing of emotional content (Keil et al., 2001). It is widely accepted that the N1 represents the earliest component modulated by emotional stimuli and appears to be resistant to habituation (Carretié, Hinojosa, & Mercado, 2003). Extant research has demonstrated that the N1 is sensitive to emotional content of visual stimuli irrespective of valence (Keil et al., 2001). Further, numerous studies have shown that the N1 is particularly salient for highly arousing unpleasant pictures versus pleasant and neutral pictures (Carretié, Hinojosa, López-Martín, & Tapia, 2007), therefore it is plausible that this component is sensitive to both intensity and perhaps uniquely sensitive to negatively valenced stimuli.

EPN. The early posterior negativity (EPN) is an occipital (Iz, P9, P10) relative negativity that occurs between approximately ~200-280/300 ms after stimulus onset and reflects increased visual processing of emotional compared to neutral stimuli (Bradley, Hamby, Löw, & Lang, 2007). Researchers have established that the EPN as being sensitive to perceptual aspects of emotional stimuli indicative of increased selective attention (Luck & Kappenman, 2012).

There is some evidence suggesting that the EPN may be uniquely sensitive to pleasant stimuli content versus unpleasant and neutral stimuli (Schupp, Junghöfer, Weike, & Hamm, 2004). Frank and Sabatinelli (2019) demonstrated that pleasant and unpleasant emotional content evoked larger EPN responses compared to neutral stimuli; moreover, the EPN was significantly greater in response to viewing erotic images compared to mutilation images. In another study, this pattern of findings was similar in that results showed significantly greater modulations of the EPN evoked by erotic content compared to threat, mutilation, and neutral content (Farkas, Oliver, & Sabatinelli, 2020). Whether the EPN is especially sensitive to positively valenced stimuli is still subject to debate given that there have been inconsistent findings across studies (MacNamara, Joyner, & Klawohn, 2022).

LPP. The late posterior positivity (LPP) is a centroparietal (Pz, CPZ, Cz, CP1, CP2) positivity that occurs approximately ~300 ms after stimulus onset, is sustained for as long as 400-2000ms, and reflects sustained attention to emotional content (Cuthbert, Schupp, Bradley, Birbaumer, & Lang, 2000). Indeed, the LPP is perhaps the most well-established neurocognitive index of emotion regulation (Dunning & Hajcak, 2009; Schupp et al., 2000). Given that the LPP is sustained for a relatively long time compared to other ERP components, some researchers have argued that there may be different processes occurring during the earlier portion of the LPP ~400-1000 ms after stimulus onset versus the later portion of the LPP ~1000-1500 ms after stimulus onset (Weinberg & Hajcak, 2010). In a study conducted by Weinberg and Hajcak (2010), erotic images elicited an unusually large LPP during the early portion of the LPP, whereas the later portion of the LPP in response to erotic images was comparable in magnitude to other pleasant image categories. Considering the sustained duration and relatively later temporal onset of the LPP, this ERP component has been featured most prominently in the study of emotion regulation (MacNamara et al., 2022).

There is ample evidence showing that the LPP is larger following the presentation of emotional stimuli versus neutral stimuli irrespective of valence, suggesting that the LPP is more sensitive to arousal rather than valence. In one study (Schupp et al., 2000), enhanced LPP responses were specific to emotional intensity and these larger LPPs occurred irrespective of whether the stimuli were characterized as pleasant or unpleasant, therefore researchers concluded that this ERP component appears to be capturing the degree to which an emotional image reflects intrinsic motivational salience. While the LPP appears to be relatively less sensitive to valence and is resistant to habituation, researchers have shown that the LPP is enhanced by the saliency of emotional content most directly relevant to biological imperatives, such as images characterized by threat, mutilation, and erotic (Schupp et al., 2004; Weinberg & Hajcak, 2010). Similarly, this conclusion was echoed in a recent review of LPP studies (Hajcak & Foti, 2020), such that the LPP appears to be reflecting relatively automatic and sustained engagement with motivationally salient emotional content exhibited by continued activation of cortico-limbic appetitive and defensive systems, lending support to the widely held notion that the LPP appears to be sensitive primarily to arousal/intensity level rather than valence of emotional stimuli.

Taken together, previous research has substantiated that each these three ERP components reflect distinct and unique aspects of emotional processing, with the N1 representing the earliest component modulated by emotional stimuli, followed by the EPN, and the LPP representing the later stages of emotional processing (Foti et al., 2009). This substantiates the use of these three ERP components given that they evidence distinct electrocortical indices of emotional modulation. In addition to reflecting distinct stages of the temporal unfolding an emotional response, the degree to which each of these ERP components is sensitive to the valence (i.e., pleasant, unpleasant) and/or arousal (i.e., intensity) of emotional stimuli is an important distinction, as these may offer insight to functional aspects of emotional processing. This may be especially relevant to the study of worry and rumination considering that some of the prevailing theoretical accounts have implicated the role of cognitive biases towards negative or unpleasant stimuli, while others have implicated a more general avoidance of emotional intensity irrespective of valence.

ERP Research on Individual Differences in Worry, Rumination, and Related Conditions

Researchers have become increasingly aware of the role that individual differences play in differentially modulating emotional responses indexed by these (and other) ERP components. Extant ERP research has often favored using clinical and nonclinical samples endorsing symptoms of anxiety and/or depression as proxies for drawing conclusions about worry and/or rumination, therefore these studies as well as studies that more directly target worry and/or rumination will be reviewed briefly. This is by no means an exhaustive review, particularly considering that many of the studies on worry, rumination, and related constructs (i.e., anxiety, depression) incorporate a variety of ERP components, some of which necessitate task-specific parameters (e.g., error-related negativity [ERN], feedback negativity [FN], reward positivity [RewP]). While a variety of ERP components have been implemented in these studies to index earlier, relatively automatic stages of emotional processing (e.g., P1, N1, N170, P2), the LPP has consistently been utilized across studies to index later, relatively more elaborative stages of emotional processing.

Anxiety. There have been mixed findings on the effect of trait anxiety on LPP amplitudes, with some studies demonstrating anxiety enhances the LPP whereas other studies have shown that anxiety attenuates the LPP. Several studies have found that individuals with GAD demonstrate decreased LPP amplitudes in response to unpleasant emotionally evocative pictures compared to controls (Weinberg & Hajcak, 2011). Similar findings were shown in a study wherein individuals with greater self-reported concerns about the future (as measured by higher levels of intolerance to uncertainty) exhibited a reduced emotional modulation of the LPP in response to negatively valenced stimuli (MacNamara, 2018). In contrast, other studies have revealed increased LPP amplitudes in response to emotional images present among individuals with GAD (MacNamara & Hajcak, 2010; MacNamara & Proudfit, 2014). Similarly, a study by MacNamara, Kotov, and Hajcak (2016) found that symptoms of GAD were associated with increased LPP responses to unpleasant pictures, whereas MDD symptoms reflected the opposite pattern as reflected by blunted LPP response to unpleasant pictures.

In a study by Weinberg and Hajcak (2011), they found that early neural responses to unpleasant images evoked a heightened response (as measured by the P1, a positive deflection occurring ~100 ms after stimulus onset), whereas later neural responses to unpleasant images as measured by the LPP elicited an attenuated LPP. More recently, a similar pattern of results was obtained from a sample of individuals endorsing varying degrees of anxious apprehension (Kausche, Härpfer, Carsten, Kathmann, & Riesel, 2022). In this study, greater levels of anxious apprehension were associated with heightened automatic attention as indexed by increased N1 amplitudes followed by reduced in-depth processing as indexed by attenuated LPP amplitudes in response to threatening pictures. Both of these studies lend support to the argument that anxious individuals experience early hypervigilance to threatening stimuli followed by a disengagement in elaborative processing.

The time course of emotional responding as measured by ERPs suggest important distinctions for disentangling the mixed findings regarding heightened versus attenuated LPP responses among individuals with GAD.

Depression. Prior research has demonstrated that individuals with depression have an attenuated or blunted LPP in response to emotional stimuli compared to healthy controls, an effect that has also been shown among individuals characterized as being at-risk of developing depression (Bylsma, 2021). Further, this attenuated LPP to emotional content (e.g., images) appears to be insensitive to valence, as evidenced by an attenuated LPP in response to both pleasant and unpleasant stimuli (Proudfit, Bress, Foti, Kujawa, & Klein, 2015). In contrast, studies that have implemented a self-referential encoding task (e.g., participants are presented with a list of adjectives and asked to indicate which describe themselves versus others, and then later asked to recall as many of these adjectives as possible) among adults (Shestyuk & Deldin, 2010) and female adolescents (Auerbach, Stanton, Proudfit, & Pizzagalli, 2015) found that individuals with depression exhibited enhanced LPP responses to negative versus positive words compared to healthy controls who demonstrated the opposite pattern of results (i.e., enhanced LPP responses to positive words versus negative words). During the earlier and relatively automatic stages of processing, depression was associated with a heightened neural response (as measured by the P2, a positive deflection occurring ~200 ms after stimulus onset) specific to negative versus positive words, which the authors interpreted as evidence to support the notion of an attentional bias towards negative information (Shestyuk & Deldin, 2010).

Findings from a study comparing a clinical sample of individuals with anxiety and/or unipolar depressive disorders showed a current diagnosis of depression with and without comorbid anxiety significantly predicted an attenuated LPP in response to rewarding pictures (Weinberg, Perlman, Kotov, & Hajcak, 2016), indicating disengagement from emotional stimuli. Interestingly, the presence of an anxiety disorder diagnosis was unrelated to the magnitude of LPP responses to rewarding or threatening pictures. Findings such as these beg the question of whether this blunting effect is specific to depression, anxiety, or characteristic of both distress disorders.

Trait worry. Further, some research has demonstrated that trait worry differentially impacts the LPP response to emotional and neutral images. In one study (Grant, Judah, White, & Mills, 2015), findings reflected different patterns of processing between high versus low worriers such that low worriers evidenced a significantly greater difference in the magnitude of LPP in response to emotional compared to neutral images, whereas high worriers exhibited a smaller difference between LPP responses to emotional and neutral images. These findings were interpreted as either increased processing of neutral content or reduced processing of threatening content among high trait worriers, which lends credence to the notion that worry is used a cognitive avoidance strategy to shift attention away from perceived threat.

Trait rumination. Researchers have posited that the LPP in the context of negative stimuli may serve as a neural index of one's propensity to ruminate. In one study, Webb and colleagues (2017) implemented a monetary gambling task to a sample of adolescent females and found that higher levels of trait rumination exhibited a larger LPP to losses versus wins. In addition to this finding, higher trait rumination was associated with a significantly larger LPP to losses but not to wins, highlighting that this relationship between rumination and enhanced LPP responses was specific to negative/unpleasant outcomes.

State worry. In a study that examined the role of trait worry and state worry on covert selective attention and working memory suppression, White and colleagues (2021) found that for individuals with high trait worry, state worry (as measured by the ERP CDAp amplitude) was associated with working memory suppression of threatening information and that the interaction between trait and state worry influenced covert attention (as measured by the N2pc) to both threatening as well as neutral stimuli. However, it should be noted that this study was the first study to observe the CDAp waveform in the context of acute worry, thereby making it hard to generalize some of these findings given that this particular ERP component is novel and requires further study to establish it as a valid, reliable index of working memory.

State rumination. In one study (Lewis, Taubitz, Duke, Steuer, & Larson, 2015), undergraduate participants completed an experimental induction task of rumination prior to viewing pleasant and unpleasant emotional images, which resulted in an enhanced LPP in response to unpleasant images. Despite the role of state rumination on LPP responses to unpleasant images specifically, there was not an association detected between a measure of trait rumination and the enhanced LPP to unpleasant images, thereby bringing into question whether state and trait rumination are distinguishable constructs with regards to the impact on psychophysiological reactivity. This could, however, be a result of different modalities utilized to capture state and trait rumination, in that state rumination was experimentally induced via behavioral paradigm whereas trait rumination was measured via self-report. Similarly, studies that include trait and state worry tend to use different modalities to measure these constructs such that trait worry is measured via self-report and state worry is manipulated using an experimental induction. Alternatively, it could also suggest that state-level measures of worry and/or rumination may be more directly related to psychophysiological reactivity.

In summary, while some of these findings are mixed or inconclusive, much of the research suggests that individuals characterized by high levels of anxiety, depression, worry, rumination appear to exhibit heightened/increased attention to emotionally evocative stimuli at earlier stages of processing followed by quicker disengagement from emotionally evocative stimuli at more elaborative stages of processing. It is possible that some of the inconsistent findings regarding the later stages of processing as indexed by the LPP may be due to methodological differences between studies. It is plausible that variability in the types of emotion-eliciting behavioral paradigms used (e.g., pictures, words), differences in scoring ERP components (e.g., pooling of electrodes used to generate the ERP, timing parameters used to generate the ERP, mean amplitude calculations based on a specific condition versus difference scores between conditions), sampling characteristics (e.g., age, gender, clinical vs. nonclinical), and operationalization of measures used for a given construct may all be such indicators of methodological differences among studies. Despite the extant literature that has shown significant differences in neural responses present in distinct stages of emotional processing among individuals high in trait-level and state-level worry and rumination compared to healthy controls, the relationship between these constructs remains an area of investigation warranting further study. Trait worry and trait rumination have received far less attention compared to anxiety and depression, despite various studies using anxiety and depression related measures as a proxy to make inferences about worry and/or rumination. To date, there has only been one study that simultaneous examined trait worry and trait rumination (Tanovic, Hajcak, & Sainslow, 2017) albeit doing so with a different ERP component (i.e., error-related negativity [ERN] and error positivity [Pe]), thereby warranting future research that incorporates worry and rumination simultaneously within the same study. Similarly, no ERP studies to date have concurrently investigated state worry and state rumination. Further, the ERP literature is somewhat sparse in terms of measuring state worry and/or state rumination, although there are a few behavioral induction tasks that have been used as a proxy for measuring state negative self-referential processes (e.g., self-referential encoding task) as noted above, thereby necessitating future studies using ERPs to investigate the role of state worry and state rumination. Furthermore, while there have been studies to utilize all three of the selected ERP components to study emotion-related processes (e.g., Foti et al., 2009; Liu, Wang, & Li, 2018; Müller-Bardorff et al., 2016), no study to date has used these three indices in the context of examining trait-level or state-level worry and rumination.

The Current Study

The present study sought to identify the shared and distinct effects of trait as well as state worry and rumination on neurocognitive processing of emotional information with three unique but related event-related potential (ERP) components (i.e., N1, EPN, LPP) characterizing various stages in the temporal unfolding of an emotional response elicited during a lab-based behavioral paradigm. These three ERP components selected for the present study—N1, EPN, LPP—appear to be capturing unique aspects of emotional processing, yet further research is needed to elucidate whether the time-course of such indices can be useful for differentiating specific aspects of emotional processing (Speed & Hajcak, 2020) and emotion regulation. After completing self-report measures assessing trait and state levels of worry and rumination, participants completed a passive view task comprised of emotional (i.e., threat, affiliative, erotic, mutilation) and neutral images, during which their electrocortical activity was recorded.

The central goal of the present study is to examine whether neural responses to emotional images are moderated by individual differences in trait worry and rumination as well as state worry and rumination by measuring distinct stages of emotional processing as indexed by the N1, EPN, LPP. While previous studies have examined trait worry and rumination independently (or related constructs such as trait anxiety and/or depression) or state worry and rumination independently, there are no studies to date that have incorporated these three ERP components specifically to examine the role of trait worry *and* rumination *as well as* state worry *and* rumination on emotional processing. To address this gap in the extant literature, worry *and* rumination—both of which are underlying mechanisms of distress disorders and are forms of avoidance—will be tested simultaneously to offer a means of investigating how these negative perseverative thinking styles impact responsivity to emotional stimuli at both the trait-level *and* state-level respectively. Examining the relative contribution of worry and rumination on emotion reactivity simultaneously serves the purpose of elucidating if one is more important than the other or whether they are comparable. Further, testing worry and rumination at the trait-level and state-level offers a means of understanding whether the trait versus state distinction yields a different pattern of findings. Given the overlap between worry and rumination, this study aims to provide insight into shared and unique aspects of the relationships within and between these constructs in differentiating the temporal unfolding of electrocortical responses to emotional pictures comprised of varying levels of valence (i.e., pleasant [affiliative, erotic] and unpleasant [threat, mutilation]) and arousal/intensity (i.e., high [erotic, mutilation] and low [threat, affiliative]).

Aims and Hypotheses

The overarching aim of the present study seeks to address the question of how varying levels of worry and rumination at the trait-level and at the state-level influence emotional reactivity at different stages of processing. In doing so, this study endeavors to investigate trait-level and state-level worry and rumination as differential predictors of emotional reactivity at different stages (early [N1], intermediate [EPN], late [early LPP, late LPP]) of the response to emotionally evocative images. The main hypotheses that will be tested are informed by theoretical and empirical accounts that suggest individuals characterized by high levels of worry or rumination exhibit heightened/increased attention to emotionally evocative stimuli at earlier stages of processing followed by quicker disengagement from emotionally evocative stimuli at more elaborative stages of processing. These hypotheses rest on the overarching assumption that worry and rumination are more similar than different, hence the predictions are suggestive of comparable effects, which will be tested by including worry and rumination within the same statistical models to tease apart whether these constructs are unique or distinguishable in relation to their predictive utility on neurocognitive indices of emotional reactivity. Further, this study endeavors to examine whether the condition type of the emotional images moderates the effects of trait worry vs. trait rumination and state worry vs. state rumination. This is largely an exploratory research question in so far as lacking specific hypotheses about *how* these specific emotional image types would demonstrate a moderating role between worry and/or rumination on emotional reactivity, whether this moderating effect would be present at the trait-level and/or the state-level, or whether this moderator would differentially impact certain stages of processing as opposed to being present throughout. While there are no a priori expectations about *which* specific conditions would play a moderating role in the relationship between worry and/or rumination on emotional responding at various stages of processing per se, there is value in exploring these nuances given that previous ERP studies have often yielded mixed findings about how various characteristics of emotional stimuli (e.g., valence, intensity) modulate emotional reactivity indexed by ERP components and how these impact the ability of ERPs to distinguish clinically relevant groups.

Aim #1. To examine the role of trait worry and trait rumination on temporal dynamics of emotional reactivity and whether the condition type of the emotional images moderates these effects. It is predicted that trait worry and trait rumination will yield comparable patterns of findings. At earlier and intermediate stages of processing, it is expected that individuals endorsing higher levels of trait worry or trait rumination would exhibit increased reactivity as reflected by greater N1 and EPN mean amplitudes relative to individuals endorsing lower trait worry and trait rumination, which would be reflected by a significant negative relationship between worry and rumination in relation to ERP mean amplitudes**.** During the later stages of processing, it is expected that there will be a significant negative relationship between worry and rumination, respectively, in relation to ERP mean amplitude of the LPP [early LPP, late LPP], as reflected by a blunting effect for those that are higher in trait worry and trait rumination such that these individuals would have relatively lower LPP mean amplitudes compared to those who are lower in trait worry or trait rumination who would have relatively higher LPP mean amplitudes. It is predicted that condition (i.e., type of emotional image) will moderate the effect of trait worry and trait rumination on emotional reactivity.

Aim #2. To examine the role of state worry and state rumination on temporal dynamics of emotional reactivity and whether the condition type of the emotional images moderates these effects. A different pattern of results outlined in *Aim #1* are expected for state worry and state rumination in terms of the expected direction of significant relationships between these state-level indices with ERP mean amplitudes. It is predicted that higher levels of state worry and/or state rumination will differentially correspond with enhanced ERP amplitudes throughout *all* temporal stages of the emotional response, demonstrating a negative relationship with earlier (N1) and intermediate (EPN) ERP components and a positive relationship with later ERPs (LPP [early LPP and late LPP]). Accordingly, all stages of emotional processing would be expected to be impacted by state-level worry and/or state rumination such that higher levels state worry and/or state rumination would exhibit greater reactivity demonstrated by increases in ERP mean amplitudes. If these patterns of findings are shown, it would suggest that ERP amplitudes vary based on the degree of state worry and/or state rumination and that the direction of this association would be consistent throughout earlier, intermediate, and later stages of emotional processing as reflected by relatively greater N1, EPN, and LPP amplitudes for those reporting more state worry and/or state rumination and relatively lower N1, EPN, and LPP amplitudes for those endorsing less state worry and/or state rumination. It is predicted that condition (i.e., type of emotional image) will moderate the effect of state worry and state rumination on emotional reactivity.

Chapter 2: Method

Participants

This study is based on a secondary analysis from a data collection that has not yet been published. Participants in the proposed study are from an undergraduate college student sample comprised of men and women between the ages of 18-60 years, all of whom were currently enrolled in Introduction to Psychology undergraduate course. Students at Hunter College were recruited through the Psychology Department's SONA research participation pool, which is an online system that offers students enrolled in Introduction to Psychology courses credits in exchange for their participation in research studies. All participants were required to be over 18 years old, to be fluent in English, and to have normal or corrected-to-normal vision. A total of 128 individuals enrolled in this study, however 20 of these participants were automatically excluded from the present study due to: solely completing the self-report questionnaires ($n = 6$); not completing the passive view task ($n = 4$); not having EEG data collected during the passive view task ($n = 9$); reporting significant history of TBI that caused damage to right temporal area of brain and prevented ability to use 60% of frontal lobe ($n = 1$). Additional participants were excluded from all analyses for the present study due to EEG-related data issues identified while processing these data, including: poor quality of EEG recording resulting in loss of all ERP data ($n = 3$); inability to process EEG data due to requiring interpolation of >4 electrodes ($n = 4$); excessive artifacts present in EEG recording operationally defined as having less than 10 usable trials for each condition ($n = 2$). The final sample therefore consisted of data collected from 99 individuals.

Participants in the present study ($N = 99$) were adults (63.5% female) between the ages of 18-36 years ($M_{age} = 21.33$, $SD = 4.617$). The racial and ethnic composition of the sample was as follows: 41.7% Caucasian (*n* = 40), 21.9% Asian (*n* = 21), 20.8% Hispanic (*n* = 20), 4.2% African American (*n* = 4), and 11.5% Other (*n* = 11).

Materials

In the present study, a battery of self-report questionnaires will provide subjective measures of trait emotion regulation. Electroencephalogram (EEG) data were collected to measure emotional processing elicited by a well-established lab-based paradigm utilizing a passive view task comprised of pleasant, unpleasant, and neutral images from a standardized stimuli set. In addition to the abovementioned battery of self-report questionnaires, a brief packet comprised of subjective measures of state-level emotion regulation was administered prior to and immediately following the passive view task.

Self-report assessments. A battery of self-report measures comprised of sociodemographic questions (e.g., age, gender) and the specific questionnaires described in detail below.

Trait Worry. The Penn State Worry Questionnaire (PSWQ; Meyer, Miller, Metzger, & Borkovec, 1990) is a 16-item questionnaire that is widely regarded as the gold standard measure of pathological worry. Participants are asked to respond using a Likert-type scale ranging from 1 (*not at all typical of me*) to 5 (*very typical of me*). Each item is summed to yield a composite index of trait worry based on a total score ranging from 16-80, with higher scores indicating greater levels of trait worry. This scale showed excellent internal consistency in the present study (α = .92).

Trait Rumination. The Brooding subscale from the Rumination Scale (RS; Treynor, Gonzalez, & Nolen-Hoeksema, 2003) is a 5-item questionnaire that measures rumination. Participants are asked to respond using a Likert-type scale ranging from 1 (*never*) to 4 (*almost* *always*). Each item is summed to yield a composite index of trait rumination based on a total score ranging from 5-20, with higher scores reflecting greater levels of trait rumination. Internal consistency for this scale was acceptable in the present study ($\alpha = .75$).

State Worry. The Worry Visual Analog Scale (WVAS; Wichelns, Renna, & Mennin, 2016) is a brief self-report assessment of state worry. Worry is defined on the WVAS as "talking a lot to ourselves about things that we are concerned about happening in the future". This measure contains two sheets: an anchor sheet and a score sheet. On the top of each sheet is a line representing 0 to 100. The anchor sheet asks a participant to describe five situations, personal to them, that represent differing degrees of worry. The score sheet asks a participant to refer to their anchor sheet and give themselves a score between 0 and 100 according to how much worry they are experiencing "right now". Using their anchor sheet as a guide, the participant rapidly provides a score at baseline and immediately after completing the passive view task, with higher scores reflecting greater levels of state worry. Previous research has demonstrated that the WVAS as a reliable measure of state-level worry has shown acceptable levels of convergent and discriminant validity among unselected undergraduate and clinical samples (Wichelns et. al, 2016).

State Rumination. The Rumination Visual Analog Scale (RVAS; Wichelns et al., 2016) is a brief self-report assessment of state rumination. Rumination is defined on the RVAS as "mulling things over in our heads about things that have happened to us". This measure contains two sheets: an anchor sheet and a score sheet. On the top of each sheet is a line representing 0 to 100. The anchor sheet asks a participant to describe five situations, personal to them, that represent differing degrees of rumination. The score sheet asks a participant to refer to their anchor sheet and give themselves a score between 0 and 100 according to how much rumination they are experiencing “right now”. Using their anchor sheet as a guide, the participant rapidly provides a score at baseline and immediately after coming the passive view task, with higher scores reflecting greater levels of state rumination. Previous research has demonstrated that the RVAS as a reliable measure of state-level rumination has shown acceptable levels of convergent and discriminant validity among unselected undergraduate and clinical samples (Wichelns et. al, 2016).

Positive Affect and Negative Affect. The Positive and Negative Affect Scales (PANAS; Watson, Clark, & Tellegen, 1988) is a 20-item self-report questionnaire that can be used as a trait-level and/or state-level assessment of positive affectivity and negative affectivity. Participants are instructed to respond using a Likert-type scale ranging from 1 (very slightly or not at all) to 5 (extremely) based on the degree to which the individual relates to a variety of adjectives used to describe a range of feelings and emotions. Each item is summed to yield two subscale scores: Positive Affect (PA) and Negative Affect (NA). Total scores on each scale range from 10 to 50, with higher scored being indicative of greater levels of current positive affect or negative affect, respectively. In the present study, state-level changes in positive and negative affect were measured directly before and after completing the passive view task. Internal consistency in the present study was slightly higher for the Positive Affect scale (α = .84) than Negative Affect scale (α = .75).

Emotion elicitation task. The passive view task served as an emotion induction paradigm. Participants were instructed to passively view emotional and neutral images, which were presented in a randomized order.

Stimuli. The stimuli used in this passive view task included 125 images that were selected from the International Affective Picture System (IAPS; Lang, Bradley, & Cuthbert, 2008), a widely used standardized stimuli set comprised of emotional and neutral images. The specific images included this study were categorized as follows: 25 neutral[1], 25 affiliative[2], 25 erotic[3], 25 threat[4], 25 mutilation[5]. These stimuli incorporate varying levels of valence (positive valence: affiliative, erotic; negative valence: threat, mutilation) and arousal/intensity (high arousal/intensity: erotic, mutilation; low arousal/intensity: affiliative, threat) to elicit a range of emotional responses.

Electrophysiological recording and data reduction. Continuous EEG activity was recorded by the ActiveTwo BioSemi system (BioSemi; Amsterdam, NL). 64 Ag/AgCl scalp electrodes were placed into an elasticized nylon cap and arranged in accordance with the international 10/20 system. Additionally, two electrodes were places on the left and right mastoids. Eye movement was monitored by electrooculogram (EOG) signals recorded by four electrodes: two electrodes placed 1 cm above and below the left eye (to measure vertical eye movements) and two electrodes placed 1 cm on the outer edge of each eye (to measure horizontal eye movements). The EEG signal was pre-amplified at each electrode to improve the signal-to-noise ratio. During data acquisition, EEG was recorded at a sampling rate of 512 Hz and amplified by a band pass of 0.16-100 Hz. The Common Mode Sense (CMS) active electrode and the Driven Right Leg (DRL) passive electrode were used to form the ground electrodes. The voltage from each of the 64 electrodes from which data was collected was referenced online with

[1] Neutral images: 2026, 2102, 2190, 2211, 2220, 2377, 2385, 2487, 2495, 2512, 2570, 2635, 2840, 2850, 5510, 7000, 7003, 7004, 7012, 7019, 7034, 7041, 7090, 7100, 7550

[2] Affiliative images: 1440, 1463, 1510, 1540, 1601, 1610, 1620, 1650, 1660, 1710, 1720, 1722, 1750, 1920, 2002, 2005, 2018, 2019, 2030, 2040, 2070, 2080, 2150, 2156, 2165

[3] Erotic images: 4007, 4180, 4537, 4538, 4559, 4604, 4605, 4617, 4643, 4650, 4651, 4653, 4656, 4659, 4660, 4664, 4666, 4669, 4670, 4676, 4677, 4690, 4694, 4698, 4800

[4] Threat images: 1301, 2692, 2717, 3022, 3550, 5972, 6212, 6213, 6230, 6241, 6244, 6263, 6312, 6315, 6350, 6370, 6520, 6561, 6570, 6821, 9120, 9163, 9403, 9425

[5] Mutilation images: 2750, 2800, 3001, 3010, 3015, 3016, 3030, 3051, 3059, 3062, 3063, 3068, 3080, 3100, 3102, 3103, 3120, 3170, 3185, 3261, 8231, 9075, 9253, 9400, 9432

respect to the CMS active electrode, a procedure that produces a monopolar (nondifferential) channel.

Offline analyses of EEG data were performed using BrainVision Analyzer software (Version 2.2, Brain Products GmbH, Gilching, Germany). All data was re-referenced offline to an average reference (i.e., average of the left and right mastoids) and filtered with a high pass frequency of .1 Hz and a low pass frequency of 30 Hz. For each trial, data was segmented into epochs starting at 200 ms prior to stimulus onset and continuing for 2,000 ms after stimulus onset. Baseline correction used the 200 ms portion of segmented data prior to stimulus onset. Ocular correction was conducted using the Gratton, Coles, and Donchin (1983) method to correct for blinks and eye movements present in the raw data. Artifacts present in the raw data were identified using a semi-automatic procedure and removed from analysis based on the following criteria: data with voltage steps greater than 50 μV, changes within a given segment greater than 300 μV, and activity lower than .5 μV per 100 ms. In addition to using this semi-automatic identification of artifacts, trials were visually inspected to detect and remove any additional artifacts on a trial-by-trial basis. If a participant had less than ten artifact-free segments for a condition, the participant was excluded from averaging (Moran, Jendrusina, & Moser, 2013).

Stimulus-locked ERPs extracted from these EEG data were quantified by mean amplitude and used to calculate three ERP components for each condition separately. The specific ERP time windows and pooling electrodes parameters used were consistent with previous studies employing similar emotion-eliciting paradigms (e.g., Weinberg & Hajcak, 2010). The N1 was identified and quantified as the mean amplitude from 100 to 150 ms over Cz and CPz . The EPN was identified and quantified as the mean amplitude from 200 to 280 ms over Iz, P9, and P10.

The early LPP was identified and quantified as the mean amplitude from 400 to 1000 ms over Pz, CPz, Cz, CP1, and CP2 and the late LPP was quantified as the mean amplitudes from 1000 to 1500 ms using this same pooling of electrodes.

Procedures

Institutional Review Boards approved all study procedures. Eligible participants received detailed information regarding study involvement and all provided written informed consent for their involvement. Participants spent approximately three hours in the laboratory. After obtaining written informed consent, participants were instructed to complete a battery of self-report questionnaires administered electronically using an online survey software (SurveyMonkey, San Mateo, California, USA). Next, participants were prepped for EEG data collection with the guidance of research assistants ensuring careful placement of a fitted elasticized nylon cap and proper application of electrodes. After attaching the EEG equipment and before starting the passive view task, participants were asked to complete a short packet of subjective questionnaires to obtain state-level ratings of positive affect, negative affect, worry, and rumination. Participants were seated in a dimly lit room and told to remain as still as possible during the task. At the beginning of the passive view task, the following instructions were presented on a computer screen: “Your job will be to view sets of highly emotional images. When we say ‘highly emotional’ we mean images that tend to bring out strong positive or negative emotions. This experiment will involve images that are negative, positive, or neutral.” After the instructions were presented, each trial consisted of a centrally presented white fixation cross lasting 1000 ms, followed by the display of each IAPS image lasting 2000 ms. A period of 2000 ms was inserted between the offset of each image and the presentation of the next trial. Images were presented in a randomized order. Stimuli were presented in color using E-Prime software (Psychology Software Tools; Sharpsburg, PA) on a PC computer. Upon finishing the passive view task, participants were instructed to complete the same packet of subjective questionnaires, which served as a tool for measuring state-level changes in positive affect and negative affect.

Data Analysis Plan

All statistical analyses were conducted using SPSS (Version 21) software. Considering that psychophysiological data is particularly susceptible to skewness, all ERP data were examined for normality prior to use in analyses. If normality tests reflect that the data is not normally distributed in the sample, additional procedures (e.g., examining effect of outliers, applying a log-10 transformation) were considered and applied as needed in an effort to normalize the skew of the data so as to prevent violating assumption of normality prior to running main analyses.

Preliminary analyses.

Bivariate correlations were run to test the associations between and among all of the main study variables.

Amplitudes of each of the ERP components (N1, EPN, LPP [early LPP and LPP]) were examined by comparing responses to neutral images versus each emotional image type. This preliminary analysis was conducted by running a series of paired t-tests comparing neutral to each emotional condition. Presumably, significant differences will be found such that emotional images will demonstrate enhanced N1, EPN, and LPP mean amplitudes in response to emotional pictures versus neutral pictures.

Manipulation check. As a manipulation check of whether the passive view task was an emotion-eliciting paradigm in the present study, subjective changes in state levels of positive affect and negative affect were examined by comparing the self-reported levels of positive and negative affect at baseline versus directly after completing the passive view task. To do so, paired t-tests were conducted comparing changes in state positive affect and state negative affect at each of the two timepoints (baseline versus after completing passive view task) using subjective ratings provided via the PANAS. Significant results would be consistent with the notion that there were subjective changes in positive and negative affect that would lend credence to the assumption that the passive view paradigm did indeed elicit positive and emotions.

Examining age and gender as potential covariates. Given that age and gender often produce differential effects on self-report and physiological indices of emotion, these suspected covariates were examined prior to conducting main analyses. Analyses were conducted using bivariate correlations for age and independent t-tests for gender with all predictor (self-report measures of trait worry, trait rumination, state worry, state rumination) and outcome variables (mean amplitudes of N1, EPN, LPP [early LPP, late LPP] across all four emotion conditions [erotic, mutilation, threat, affiliative]) to determine if covariates of age and gender were present. If/when significant effects of age and/or gender were found, this was controlled for by including age and/or gender as covariates when appropriate to do so subsequently in the main analyses.

Main analyses. Mixed linear models (MLMs) were utilized to test all primary and exploratory aims of the study. This statistical modeling approach accounts for the non-independence in participants' data (i.e., correlation between an individual's ERP scores on the same variable over time) and maximizes the use of existing data by including all participants in these analyses regardless of missing data points (Brauer & Curtin, 2018).

The mixed models used maximum likelihood estimation, and a subject-specific random intercept captured the within-subject correlation. Given that this statistical approach is limited to the inclusion of one dependent variable per model, each ERP component was tested separately. This statistical approach offered a means of examining the relative contribution of worry and rumination on emotion reactivity thereby making it possible to determine if one is more important than the other or whether they are comparable. Further, testing worry and rumination at the trait-level and state-level respectively in two separate sets of models provided insight towards a nuanced understanding of whether the trait versus state distinction yields a different pattern of findings.

For *Aim #1,* four models were used to test trait-level measures of worry and rumination on each of the ERP components separately. Each of the models included two continuous predictors (trait worry, trait rumination), one four-level categorical predictor (condition type: threat, mutilation, affiliative, erotic), and three two-way interaction predictor variables (trait worry*trait rumination, trait worry*condition, trait rumination*condition). Additional covariates (e.g., age and gender) were added to the models if/when deemed appropriate.

For *Aim #2*, four models were used to test state-level measures of worry and rumination on each of the ERP components separately. Each of the models included two continuous predictors (state worry, state rumination), one four-level categorical predictor (condition type: threat, mutilation, affiliative, erotic), and three two-way interaction predictor variables (state worry*state rumination, state worry*condition, state rumination*condition). Additional covariates (e.g., age and gender) were added to the models if/when deemed appropriate.

To test the primary aims and hypotheses of the study, the main effects of trait-level worry and rumination (*Aim #1*) as well as state-level worry and rumination (*Aim #2*) were examined at different temporal stages of the response to emotionally evocative images. If the primary hypotheses of the study are supported, significant relationships between worry as well as rumination with emotional reactivity would emerge such that negative effects would be demonstrated under the estimate of fixed effects for the main effects of trait-level worry and trait-level rumination on early and intermediate stages of processing as indexed by N1 and EPN respectively (*Aim #1*). A similar pattern of findings is hypothesized for state-level measures of worry and state-level rumination such that significant relationships with emotional reactivity would emerge in the same direction in that negative effects would be demonstrated under the estimate of fixed effects for the main effects of state-level worry and state-level rumination on early and intermediate stages of processing as indexed by N1 and EPN (*Aim #2*). During later stages of processing, it is expected that a significant relationship between worry and rumination with emotional reactivity would emerge such that a significant negative effect would be demonstrated under the estimate of fixed effects for the main effect of trait worry and trait rumination (*Aim #1*) and a significant positive effect would be demonstrated under the estimate of fixed effects for the main effect of state worry and state rumination (*Aim #2*) on later stages of processing as indexed by LPP (early LPP, late LPP).

To test the secondary part of these two aims, the interaction between the emotional condition of the images with worry and rumination were examined to determine whether the effects of trait worry vs. trait rumination and state worry vs. state rumination on emotional reactivity are moderated by the emotional condition of the images. Significant interactions found between trait worry*condition, trait rumination*condition, state worry*condition, state rumination*condition would lend support for this hypothesis that condition (i.e., type of emotional image) has a moderating role on the relationships between trait-level and state-level worry and rumination with emotional reactivity. Any significant interactions identified were probed post-hoc for further examination by graphing estimated marginal means +/-1 SD of modeled predictors to better understand which specific conditions were likely driving the moderating effects. If no significant interactions are obtained, then this portion of each of the two hypotheses would not be supported, suggesting that condition type does not differentially impact the relationship between worry and/or rumination on emotional responding neither at the trait-level (*Aim #1*) nor at the state-level (*Aim #2*) at any stage of processing.

Chapter 3: Results

Descriptive Statistics

Means, standard deviations, and ranges for all study variables are summarized in Table 1. Grand averaged waveforms for N1, EPN, and LPP reactivity to each emotional condition are presented in Figure 1, Figure 2, and Figure 3.

Normality. To ensure that all predictor and outcome variables were normally distributed prior to running preliminary or main analyses, skew and kurtosis was carefully examined with visual inspection and statistical normality tests. Based on results yielded from Shapiro Wilk normality test statistics (all p's $< .05$), EPN mean amplitudes for several conditions (erotic, neutral, mutilation, threat), early LPP mean amplitudes for several conditions (affiliative, erotic, neutral, threat), and late LPP mean amplitudes for neutral and erotic conditions were non-normal. Exclusion of outliers from each of these respective conditions was done to determine whether outliers in each of the abovementioned conditions impacted the normality of the data. This resulted in removing outliers as follows: EPN (erotic: $n = 1$; neutral: $n = 3$; mutilation: $n = 3$; threat: $n = 1$); early LPP (affiliative: $n = 1$; erotic: $n = 1$; neutral: $n = 2$; threat: $n = 1$); late LPP (erotic: $n = 2$; neutral: $n = 1$). Given that MLM maximizes the use of existing data by including all participants in these analyses regardless of missing data points, no participants were removed from the study as a result of these procedures. Upon removal of these outliers from each of the respective conditions noted above, all variables were normally distributed as indicated by the Shapiro Wilk statistic (all p's $> .05$), therefore no further transformations were made to these data.

Preliminary Analyses

Bivariate correlations were run to test the associations between and among the main study variables: self-report measures (trait worry, trait rumination, state worry, state rumination) and ERP components (N1, EPN, LPP [early LPP, late LPP]) across all four emotion conditions (erotic, mutilation, threat, affiliative).

Associations between worry and rumination. Results yielded from these bivariate correlational analyses between all predictor variables are presented in Table 2. Preliminary bivariate correlations between trait worry and trait rumination were conducted. Results yielded a significant moderate relationship between trait worry and trait rumination: $r(99) = .395$, $p < .001$. Similarly, bivariate correlations between state worry and state rumination were examined. Results yielded a significant moderate relationship between state worry and state rumination: $r(96) = .631$, $p < .001$. Examination of bivariate correlations between trait and state-level indices of worry and rumination, respectively, demonstrated a significant moderate relationship between trait worry and state worry [$r(97) = .431$, $p < .001$] and a significant small to moderate relationship between trait rumination and state rumination [$r(97) = .314$, $p < .01$].

Associations between ERP components. Bivariate correlations were run between ERP components (N1, EPN, LPP [early LPP, late LPP]) across all four emotion conditions (erotic, mutilation, threat, affiliative). All results yielded from these correlational analyses are presented in Table 3.

Comparison between ERP amplitudes in response to neutral and emotional conditions. There were significant differences in mean N1 amplitudes elicited in response to neutral images versus threatening [$t(96) = -3.83$, $p < .001$] and mutilation [$t(96) = -2.12$, $p < .05$] images, however no significant differences emerged when comparing mean N1 amplitudes elicited in response to neutral versus affiliative [$t(96) = -1.34$, $p = .183$] or erotic [$t(95) = -1.54$, $p = .127$] images. Significant differences were demonstrated between mean EPN amplitudes elicited in response to neutral versus erotic [$t(94) = 4.52$, $p < .001$] and threatening [$t(94) = -2.46$, $p < .05$] images, but not between neutral versus affiliative [$t(93) = 1.45$, $p = .152$] or mutilation [$t(94) = -1.07$, $p = .287$] images. When examining early LPP reactivity, mean LPP amplitudes elicited in response to neutral images were significantly different across all emotional images: affiliative [$t(91) = -13.18$, $p < .001$]; erotic [$t(90) = -15.80$, $p < .001$]; mutilation [$t(97) = -7.00$, $p < .001$]; threat [$t(91) = -10.80$, $p < .001$]. Similarly, late LPP reactivity was significantly different when comparing mean amplitudes in response to neutral images to all emotional images: affiliative [$t(93) = -9.48$, $p < .001$]; erotic [$t(91) = -9.92$, $p < .001$]; mutilation [$t(93) = -11.68$, $p < .001$]; threat [$t(93) = -7.37$ $p < .001$].

Manipulation check for emotion-elicitation task. As anticipated, paired t-tests were run and yielded results demonstrating that there were significant changes in both state positive affect [$t(98) = 11.20$, $p < .001$] and negative affect [$t(98) = -5.52$, $p < .001$] when comparing subjective ratings completed before versus after participants completed the passive view task. Taken together, these preliminary analyses are indicative of the passive view task exerting some degree of change in subjective emotional responses, thus substantiating its use as an emotion-elicitation task.

Effects of age and gender.

Age. To explore whether there were any age differences on and of the predictor or outcome variables, bivariate correlations were conducted. Greater age was related to significantly greater EPN mean amplitudes in response to affiliative ($r = -.275$, $p = .013$), mutilation ($r = -.297$, $p = .007$), and threatening ($r = -.312$, $p = .005$) images. Older participants also demonstrated a significant relationship between age and reduced early LPP mean amplitudes in response to affiliative (r = -.235, p = .032) and erotic (r = -.255 p = .022) images. Lastly, older age was related to significantly reduced LPP amplitudes in response to affiliative images (r = -.263, p = .016). No other correlations with age reached significance for trait-level and state-level indices of worry or rumination nor for any of the remaining ERP outcome variables.

Gender. Gender differences were investigated in all of these same primary variables using independent samples *t*-tests. Since gender groups were uneven, equal variances were not assumed for these analyses in accordance with the Welch-Satterthwaite approximation (Ruxton, 2006; Satterthwaite, 1946; Welch, 1938, 1947). Compared to female participants, male participants demonstrated significantly greater mean EPN amplitudes in response all categories of emotional images: affiliative (M = 4.06, SD = 3.31 vs. M = 2.88, SD = 2.16), t(91.07) = -2.09, p = .039; erotic (M = 3.56, SD = 2.83 vs. M = 1.62, SD = 2.30), t(80.81) = -3.61, p = .001; mutilation (M = 4.72, SD = 2.74 vs. M = 2.87, SD = 1.95), t(86.83) = -3.80, p = .000; threat (M = 45.11, SD = 3.05 vs. M = 3.32, SD = 2.37), t(85.34) = -3.18, p = .002. No other gender differences reached significance for trait-level and state-level indices of worry or rumination nor for any of the remaining ERP outcome variables (N1, LPP [early LPP, late LPP]) across all emotional conditions.

To control for the effects these variables may have on subsequent analyses, age and gender were included as covariates for analyses with the EPN outcome variable, and age was included as a covariate for analyses with the LPP (early LPP and late LPP) outcome variables.

Main Analyses

Multilevel linear models were used to test the central aims of the study. This statistical approach offers a means of examining the relative contribution of worry and rumination on emotion reactivity thereby making it possible to determine if one is more important than the other or whether they are comparable. Further, testing worry and rumination at the trait-level and state-level separately would provide insight to understand whether the trait versus state distinction yields a different pattern of findings. To this end, four models were constructed to test *Aim #1* and four models were constructed to test *Aim #2*. Each of these models were constructed to included two continuous predictors, one four-level categorical predictor, three interaction predictors, and covariates if/when appropriate (e.g., age and gender for EPN, age for LPP [early LPP and late LPP]).

Aim #1: To examine the role of trait worry and trait rumination on temporal dynamics of emotional reactivity and whether the condition type of the emotional images moderates these effects.

N1. Trait worry [F(1, 98.46) = .00, p = .990], trait rumination [F(1, 98.70) = .38, p = .539], and the interaction between trait worry and trait rumination [F(1, 98.49 = .13, p = .723] were non-significant predictors of N1 reactivity.

During early stages of emotional processing, the interaction of trait rumination and condition significantly predicted N1 reactivity, F(3, 115.19) = 3.00, p = 033*. Figure 4 displays a visual illustration of this significant interaction on N1 reactivity based on estimated marginal means +/-1 SD to provide insight on the differential impact of high versus low trait rumination within each emotional condition. Accordingly, it is evident that there is a negative relationship between trait rumination on N1 reactivity such that higher trait rumination is associated with greater N1 mean amplitudes, and that this effect is most prominent in response to affiliative images. Although the main effect of trait rumination was not significant given that the impact of trait rumination on N1 reactivity varies as a function of emotional condition, the estimate of fixed effects for the main effect of trait rumination reflects a negative relationship, *b* = -.24, *t*(102.08) = -.58, *p* = 563. The interaction between trait worry and condition did not significantly predict N1 reactivity [*F*(3, 114.31) = .47, *p* = .705].

EPN. During intermediate stages of emotional processing, trait worry [*F*(1, 78.61) = .44, *p* = .510], trait rumination [*F*(1, 78.65) = .36, *p* = .551], and the interaction between trait worry and trait rumination [*F*(1, 78.56) = .54, *p* = .464] did not significantly predict EPN reactivity.

Neither the interaction between trait worry and condition [*F*(3, 98.06) = 1.17, *p* = .325] nor the interaction between trait rumination and condition [*F*(3, 97.45) = .42, *p* = .741] significantly predicted EPN reactivity.

LPP. During later stages of emotional processing, trait worry [*F*(1, 78.53) = .01, *p* = .936], trait rumination [*F*(1, 78.47) = .89, *p* = .347], and the interaction between trait worry and trait rumination [*F*(1, 78.26) = .62, *p* = .432] did not significantly predict early LPP reactivity.

A similar pattern emerged when examining the effects of these predictors on late LPP reactivity such that trait worry [*F*(1, 80.12) = .00, *p* = .971], trait rumination, [*F*(1, 80.18) = .14, *p* = .713], and the interaction between trait worry and trait rumination [*F*(1, 80.11) = .10, *p* = .750] were not significant predictors of late LPP reactivity.

Further, the interaction between trait worry and condition [*F*(3, 98.73) = .51, *p* = .680] and the interaction between trait rumination and condition [*F*(3, 98.68) = .1.15, *p* = .333] did not significantly predict early LPP reactivity. Similarly, neither the interaction between trait worry and condition [*F*(3, 104.88) = .24, *p* = .867] nor the interaction between trait rumination and condition [*F*(3, 104.77) = .34, *p* = .794] exhibited significant effects on late LPP reactivity.

Aim #2: To examine the role of state worry and state rumination on temporal dynamics of emotional reactivity and whether the condition type of the emotional images moderates these effects.

N1. During early stages of emotional processing, state worry [$F(1, 95.32) = .20$, $p = .658$], state rumination [$F(1, 95.25) = .51$, $p = .477$], and the interaction between state worry and state rumination [$F(1, 95.14 = .28$ $p = .596$] were not significant predictors of N1 reactivity.

The interaction between state worry and condition [$F(3, 110.20) = .62$, $p = .605$] and the interaction between state rumination and condition [$F(3, 110.19) = .83$, $p = .480$] did not significantly predict N1 reactivity.

EPN. During intermediate stages of emotional processing, state worry [$F(1, 78.24) = .21$, $p = .649$], state rumination [$F(1, 78.06) = .68$, $p = .412$], and the interaction between state worry and state rumination did not significantly predict EPN reactivity [$F(1, 78.16) = .29$, $p = .592$].

Both the interaction between state worry and condition [$F(3, 95.85) = 1.83$, $p = .147$] and the interaction between state rumination and condition [$F(3, 96.89) = .18$, $p = .908$] were non-significant predictors of EPN reactivity.

LPP. There was a marginally significant main effect of state rumination on predicting early LPP reactivity [$F(1, 77.45) = 3.87$, $p = .053^{\dagger}$]. Estimates of fixed effects for the main effect yielded a positive significant relationship between state rumination and early LPP reactivity [$b = .11$, $t(88.85) = 2.11$, $p = .038^{*}$], thereby indicating that higher state rumination was associated with greater mean amplitudes for early LPP reactivity. State worry [$F(1, 78.71) = .29$, $p = .593$] and the interaction between state worry and state rumination [$F(1, 77.39) = 2.46$, $p = .121$] did not significantly predict early LPP reactivity.

Examination of the late LPP demonstrated that the marginally significant main effect of state rumination on LPP reactivity was sustained in predicting late LPP reactivity [$F(1, 79.05) = 3.29$, $p = .074^{\dagger}$]. Neither the effect of state worry [$F(1, 79.67) = .24$, $p = .624$] nor the interaction between state worry and state rumination [$F(1, 79.38) = 2.21$, $p = .141$] were significant predictors of late LPP reactivity.

During late stages of emotional processing, the interaction between state rumination and condition was a significant predictor of late LPP reactivity [$F(3, 103.87) = 3.10$, $p = .030^{*}$]. Figure 5 provides a visual illustration of this significant interaction between state rumination and condition on late LPP reactivity based on estimated marginal means +/-1 SD offering further insight on the differential impact of high versus low state rumination within each emotional condition. Accordingly, there is a positive relationship that emerges between the interaction of state rumination and condition and late LPP reactivity such that higher state rumination is associated with greater late LPP mean amplitudes, with this difference being particularly salient in response to erotic and threatening images. Similarly, the direction of the main effect of state rumination exhibited a positive significant relationship based on the estimates of fixed effects [$b = .10$, $t(103.32) = 2.00$, $p = .048^{*}$], further suggesting that higher levels of state rumination was associated with greater mean amplitudes for late LPP reactivity. Given that the main effect of state rumination was marginally significant in the overall model, whereas the interaction between state rumination and condition was significant, the degree to which state rumination influences late LPP reactivity varies as a function of emotional condition. The interaction between state worry and condition did not significantly predict late LPP reactivity [$F(3, 102.21) = 1.26$, $p = .293$].

The abovementioned interaction effect appears to be specific to relatively later stages of processing given that the interaction of state rumination and condition did not significantly predict early LPP reactivity [$F(3, 97.43) = .67$, $p = .572$]. Similar to the pattern that emerged for late LPP reactivity, the interaction between state worry and condition was a non-significant predictor of early LPP reactivity [$F(3, 96.32) = .75$, $p = .526$].

Chapter 4: Discussion

The present study sought to elucidate how varying levels of worry and rumination at the trait-level and at the state-level influence the temporal dynamics of emotional reactivity. This multimodal investigation used subjective, behavioral, and neural measures to capture the shared and distinct underpinnings of worry and rumination. To this end, trait and state indices of worry and rumination were examined as differential predictors of neural reactivity captured at stages of processing (early [N1], intermediate [EPN], late [early LPP, late LPP]) in response to emotionally evocative images.

Summary of Findings

Aim #1. Trait worry, trait rumination, and the interaction of trait worry with trait rumination did not significantly predict emotional reactivity during early stages of processing indexed by N1, intermediate stages of processing indexed by EPN, or later stages of processing indexed by the early LPP and late LPP. During early states of processing, there was a significant interaction between trait rumination and condition, suggesting a moderating role of condition between trait rumination on N1 reactivity. This interaction effect of trait rumination with condition on late N1 reactivity appeared to be most pronounced in response to affiliative images. Condition did not moderate the effect of trait rumination or trait worry on emotional reactivity during intermediate (EPN) or later stages of processing (early LPP, late LPP).

Aim #2. During later stages of processing, there was a significant moderating effect of condition interacting with state rumination on late LPP reactivity. This interaction effect of state rumination with condition on late LPP reactivity appeared to be most pronounced in response to threatening and erotic images. In addition to this significant interaction, there was a marginally significant effect of state rumination on both early LPP reactivity and late LPP reactivity. No other significant findings emerged between state rumination or the interaction between state rumination and condition on emotional reactivity during early (N1) or intermediate (EPN) stages of processing. No significant findings emerged with state worry, the interaction between state worry and state rumination, or the interaction between state worry and condition as significant predictors of emotional reactivity at any stage of processing.

Interpretation of Study Findings and Integration with Past Literature

At early stages of processing as indexed by the N1, trait rumination had a significant impact on emotional reactivity, however this effect was contingent upon the moderating role of condition. Based on this finding, there does not appear to be a generalized effect of trait rumination on emotional reactivity, but rather this effect is a function of responses to specific type(s) of emotional stimuli.

The significant interaction between trait rumination on N1 reactivity was consistent with the hypothesis that trait rumination would have a negative association in relation to early stages of processing. While there was not a statistically significant main effect of trait rumination, which is contrary to the hypothesis that there would be an generalized influence of trait rumination on N1 reactivity, the direction of the association between trait rumination and N1 reactivity was consistent with the prediction that trait rumination would have a negative relationship on N1 mean amplitudes, whereby enhanced N1 amplitudes were displayed across all of the emotional conditions among individuals endorsing higher levels of trait rumination. Moreover, the moderating effect of emotional condition suggests that the impact of trait rumination on N1 reactivity varied as a function of the type of emotional content. While the specific nature of this condition effect was not statistically analyzed, preliminary examination of graphs for estimated marginal means +/-1 SD differentiating high versus low trait rumination (see Figure 4) pointed to this effect being most salient in response to affiliative emotional images.

Previous research has shown that the N1 is an ERP that is uniquely sensitive to early visual processing of emotional content, however the degree to which the N1 is specific to valence is debatable, as some studies have shown that the N1 is elicited to emotional content irrespective of valence and others have demonstrated that the N1 is generally more pronounced in response to unpleasant stimuli (e.g., Keil et al., 2001) versus pleasant or neutral stimuli (e.g., Carretié et al., 2007). Furthermore, prior research with nonclinical populations has commonly shown that valence typically exerts a more predominant influence in relatively early stages of processing, as opposed to emotional arousal, which typically exerts a more pronounced effect in relatively later stages of processing (Olofsson et al., 2008). Despite the breadth of research supporting that the N1 is a marker of emotional processing, no studies to date have implemented N1 in the context of studying trait rumination, specifically. In a previous study, enhanced N1 amplitudes in response to threatening emotional images was found for those reporting higher levels of trait worry (Kausche et al., 2022). A similar pattern of findings emerged in a study examining the role of trait and state anxiety, wherein higher levels of trait and state anxiety elicited enhanced N1 reactivity to threatening images (Yang et al., 2020). Interpretation of the results in the present study regarding trait rumination could be framed within the scope of research that has exhibited strong associations between rumination with anxiety and depression (e.g., Hughes, Alloy, & Cogswell, 2008), thereby substantiating the finding in this study of enhanced N1 reactivity to emotional images for those reporting higher levels of trait rumination. However, neither of these abovementioned previous studies incorporated pleasant stimuli given their focus on substantiating the role of a negativity bias in worry and anxiety, thus limiting the ability to extrapolate how this extant research converges or diverges with the finding in the present study implicating a particularly pronounced effect of trait rumination in response to affiliative images. Notwithstanding the relatively scant existence of studies incorporating positively valenced stimuli to study rumination and related constructs (e.g., worry, anxiety, depression), a prior study utilizing early ERP components indexing initial stages of emotion processing found that individuals with elevated levels of anxiety showed enhanced P1 amplitudes in response to pleasant stimuli, indicating preferential attention towards pleasant stimuli (Sass et al., 2010). Other studies have substantiated the finding of enhanced P1 amplitudes in response to pleasant and aversive stimuli discriminating anxious populations from healthy controls (e.g., Kolassa, Musial, Kolassa, & Miltner), lending support to anxiety being characterized by generalized hypervigilance for threatening *and* mildly pleasant stimuli. This generalized hypervigilance conceptualization is in juxtaposition with the attentional threat bias conceptualization of anxiety by suggesting that elevated anxiety is characterized by a pattern of heightened emotional reactivity to pleasant stimuli and unpleasant stimuli as opposed to being specifically limited to threatening or aversive stimuli. Given the overlap between rumination and anxiety, it is plausible that similar conclusions can be drawn from findings in the present study. Nevertheless, this interpretation merits some caution given that the present study relied on a different ERP component to index early attentional processes, and the recognition that despite the strong relationship between trait rumination and anxiety, these are distinct as opposed to unitary constructs.

At later stages of processing as indexed by the LPP, state rumination was a significant predictor of emotional reactivity and similarly this effect was moderated by condition, however it reached statistical significance only at the latest stages of processing as indexed by the late LPP (as opposed to the early LPP). It is notable, however, that this pattern of findings appeared to start emerging in early LPP reactivity, albeit these effects being marginally significant. Unlike the findings with trait rumination on emotional reactivity, which were specific to the early stages of processing (N1), state rumination had a specific impact on the later stages of processing. This lends support to the notion that trait versus state distinctions are important for differentiating the role of rumination on the temporal dynamics of emotional reactivity.

Consistent with the hypothesis that state rumination would exhibit a significant positive relationship with LPP amplitudes, findings from the present study reflected that state rumination was indeed positively related to emotional reactivity, as exhibited by enhanced LPP mean amplitudes in response to emotional content. This finding is indicative of increased engagement with and sustained attention to emotional stimuli when state rumination is heightened. Importantly, the significant interaction between condition and state rumination that emerged in the present study suggests that this effect varies as a function of specific types of emotional stimuli. Examination of graphs of the estimated marginal means +/-1 SD differentiating high versus low state rumination (see Figure 5) illustrated that responses to the erotic and threat conditions were likely driving this interaction effect, however this was not statistically analyzed, and thus is a preliminary conclusion requiring further testing.

Findings from the present study are in alignment with cognitive models of internalizing disorders positing greater sustained attention and increased responsivity to emotional stimuli (e.g., Joorman & Wanderlind, 2014), particularly in situations perceived as threatening or aversive. The moderating effect of condition type is consistent with the notion that the robustness of this effect varies based on the specificity of emotional contexts. The results from the present study demonstrated that the effect of rumination appeared noticeably distinguishable in response to threatening and erotic emotional images, rather than being specific to negatively valenced emotional conditions. In the context of depression, many previous studies have shown a blunted LPP to positive stimuli (e.g., Weinberg et al., 2016), however the differential impact of depression in response to negative stimuli has yielded somewhat heterogenous results (Kujawa & Burkhouse, 2017), with some studies finding attenuated LPP responses (e.g., Proudfit et al., 2015) and others finding enhanced LPP responses (e.g., Auerbach et al., 2015; Speed, Nelson, Auerbach, Klein, & Hajcak, 2016) to negative or threatening stimuli. In a prospective study of college undergraduate students examining the impact of COVID-19 pandemic-related stress on internalizing symptoms (Dickey, West, Pegg, Green, & Kujawa, 2021), attenuated LPP reactivity in response to positive stimuli predicted increased depressive symptoms whereas enhanced LPP reactivity in response to threatening stimuli predicted traumatic intrusion symptoms. Conceptually, there are similarities between the process of rumination and traumatic intrusions, in that they are both forms of negative self-referential thinking styles that are oriented towards the past. While purely speculative, it is possible that this conceptual overlap offers a potential interpretation of the findings from the present study with respect to an enhanced LPP in response to threatening images. In a prospective study of at-risk youth exposed to financial stressors, enhanced LPP responses to negative self-referential stimuli significantly predicted increased anxiety symptoms but was not a significant predictor of depression symptoms (Feurer, Granros, Calentino, Suor, & Burkhouse, 2022). When controlling for anxiety, prior research has found a heighted LPP response to positive and negative stimuli (Burkhouse et al., 2017) distinguishing adolescents with current and remitted depression from healthy controls. Similarly, prior research has found an enhanced LPP response to aversive images exhibited by individuals with GAD (MacNamara & Hajcak, 2010). This underscores the importance of simultaneously examining related constructs. In the present study, the impact of state rumination on LPP was examined controlling for the effects of state worry, and in doing so may help explain why the LPP amplitudes were enhanced (as opposed to blunted) in response to certain emotional conditions (e.g., erotic, threatening) without a clear valence-specific effect being evidenced by these findings.

The differential effect of rumination on late LPP reactivity was expected for both trait-level and state-level indices, however contrary to these hypotheses, these findings reflect that the effect was specific to state rumination. This finding does provide some converging evidence with the only ERP study that has simultaneously examined trait and state rumination (Lewis et al., 2015), wherein an enhanced LPP was elicited in response to negative emotional images presented during an experimental induction task of state rumination, yet no such effect was not detected by trait rumination as measured by self-report. The present study provides incremental support for the unique role of state rumination on LPP reactivity that is not mimicked by self-reported trait rumination, reflected by showing a comparable pattern of results, yet state rumination in the present study was captured by self-report measures of this construct (as opposed to a behavioral measure of state rumination as in the previous study).

In the present study, the hypothesized relationship between trait rumination and later stages of emotional processing indexed by the LPP was not supported given that these results were not statistically or marginally significant. It is quite plausible that state rumination (as opposed to trait rumination) would predict late LPP reactivity given that subjectively endorsing current rumination would presumably be a more reliable indicator of an individual's cognitive emotional state whereas subjectively endorsing trait rumination implies a more general tendency to engage in this cognitive emotional process that may not necessarily have been activated while completing the emotion elicitation task. This presumption is indeed consistent with previous literature that has found trait self-report measures to be far more susceptible to biased responses, including metacognitive appraisals and retrospective recall biases, in comparison to state self-report measures of the same construct (e.g., Mathersul & Ruscio, 2020; Wells, 2013)

Interpreting the divergence in these findings with trait rumination as a predictor of early stages of emotional processing (N1) and state rumination as a predictor of late stages of emotional processing (late LPP) could also be framed within the broader scope of extant research that has characterized rumination as a highly heterogeneous construct (e.g., Siegle, Moore, & Thase, 2004; Stade & Ruscio, 2023).

Taken together, these findings underscore the importance of considering temporal dynamics in elucidating the role of worry and rumination, respectively, on emotional reactivity. Timing offered a distinction between trait and state indices of rumination such that trait rumination emerged solely in early stages of emotional processing (N1 reactivity) whereas the effects of state rumination were specific to later stages of emotional processing (LPP reactivity). Further, examining the temporal dynamics highlighted the importance of later stages of emotionally processing—most notably demonstrated by late LPP reactivity—for state-level indices of rumination.

Affective chronometry, a term that has been used to describe the temporal dynamics of emotional responsivity (Davidson, 1998), offers utility in better understanding the connections between emotion and cognition. This study employed a design that aimed to link the subjective experience of emotion with the objective neural measures associated with emotional processing. Theoretical frameworks of emotional regulation (Gross, 1998; 2015; Gross & Thompson, 2007) have highlighted the importance of temporal dynamics by positing the existence of different stages of an emotional response on a continuum from relatively automatic and effortless emotion regulation strategies (e.g., attentional regulation) to more effortful, cognitively elaborative emotion regulation strategies (e.g., metacognitive regulation). ERPs are ideally suited to provide empirical support to substantiate this theoretical framework given their superior temporal resolution. In the present study, trait rumination and state rumination predicted divergent outcomes on ERP reactivity. Based on theoretical frameworks and empirical studies using ERPs to substantiate the concept of dissociable temporal and functional aspects of emotional reactivity (e.g., Shafir, Schwartz, Blechert, & Sheppes, 2015; Sheppes & Gross, 2011), it is reasonable to suggest that the findings indicate trait rumination was predictive of initial attentional processes whereas state rumination was predictive of relatively more cognitively elaborative processes.

The LPP is a functionally distinct marker of elaborative processing and sustained engagement in response to emotional content (Dennis & Hajcak, 2009; Schupp et al., 2000). Prior studies have identified two distinct temporal and functional phases within the LPP, with the early LPP (<1,000 ms) reflecting initial attention allocation toward emotional stimuli and the late LPP (>1,000 ms) reflecting sensitivity to processing the meaning of emotional stimuli (Foti & Hajcak, 2008). Further, there is evidence to substantiate that the late LPP has a greater capacity to distinguish various clinical groups (Hajcak, Weinberg, MacNamara, & Foti, 2012). Prior research distinguishing the early LPP from the late LPP has offered insight on the early LPP indexing less cognitively elaborative forms of emotional regulation such as distraction and the late LPP indexing more cognitively elaborative forms of emotion regulation such as reappraisal (e.g., Shafir & Sheppes, 2018; Thiruchselvam, Blechert, Sheppes, Rydstrom, & Gross, 2011). These distinctions may offer insight towards why the findings with state rumination were statistically significant for predicting late LPP reactivity and marginally significant for predicting early LPP reactivity.

There were no significant findings with regard to the impact of worry, rumination, or the interaction between worry and/or rumination with condition at the trait-level nor state-level on intermediate stages of emotional processing indexed by EPN reactivity. It is possible that the relatively small size of picture sets (i.e., 25 images per condition) may have suppressed the effects on EPN reactivity. Indeed, previous research (Wiens, Sand, & Olofsson, 2011) has found that small picture sets tend to underestimate the true relationship between emotion and EPN, leading to suppressing the effect on EPN, whereas other ERP components are not as susceptible to this problem (e.g., LPP can be elicited by a relatively small number of trials). Other methodological considerations that may be worth noting include the decision to use a mastoid reference as opposed to an average reference for the EPN implemented in the present study. Indeed, prior research has been inconsistent in that some have used a mastoid reference and others an average reference to calculate the EPN, and there is some evidence to suggest that the affective modulation of the EPN is considerably more prominent when an average reference is used (Hajcak et al., 2012). This decision may potentially account for the lack of expected findings in this study and more broadly explain the lack of convergence across other studies with the EPN. Notwithstanding these potential methodological issues, it is noteworthy that research using the EPN to examine worry and/or rumination is relatively sparse. To date, the majority of studies examining related constructs have focused on differentiating high vs. low trait anxiety using the EPN (Frenkel & Bar-Haim, 2011; Holmes, Nielson, & Green, 2008; Liu et al., 2018). In a case control study of adults diagnosed with GAD, the EPN did not significantly differ between GAD and healthy controls (Denefrio, Myruski, Mennin, & Dennis-Tiwary, 2019). Case control studies of other internalizing disorders have had mixed findings regarding the sensitivity of the EPN in being able to differentiate clinical groups from healthy controls: the EPN did not distinguish adolescents with PTSD from healthy controls (Klein et al., 2019), but studies have shown that the EPN reactivity discriminates individuals with social anxiety disorder versus healthy controls (Mühlberger et al., 2009; Wabnitz, Martens, & Neuner, 2016). Future studies using the EPN are needed to disentangle the predictive utility of this ERP component with trait-level and state-level subjective indices of worry and rumination.

More notably, contrary to the findings for trait rumination and state rumination, there were no significant findings detected for trait worry or state worry predicting emotional reactivity during any stage of emotional processing indexed by N1, EPN, and LPP reactivity. It is somewhat surprising that a similar pattern did not emerge with worry compared to rumination when examining these constructs together using trait-level measures (*Aim #1*) and state-level measures (*Aim #2*), respectively, thus the hypotheses that the effects of worry would be comparable to those of rumination were not supported. The sampling characteristics is one potential factor that may have precluded the ability to detect effects of trait worry and/or state worry. According to a meta-analysis of 60 studies examining psychophysiological measures of worry and rumination, a common problem encountered by samples comprised of nonclinical populations is that trait and state worry may not be elevated enough to yield clear effects on psychological activation (Ottaviani et al., 2016). Future investigations would benefit from sampling techniques ensuring that levels of worry are captured ranging from nonclinical, subclinical, and clinical. Relatedly, previous ERP investigations utilizing any of these three specific ERP components to examine worry have largely been based on case-control studies examining distinguishable effects between individuals with GAD versus healthy controls (e.g., MacNamara & Proudfit, 2014; MacNamara, Ferri, & Hajcak, 2011; Weinberg & Hajcak, 2011). It is also worth noting that many previous ERP studies have utilized related constructs to make inferences about worry, such as intolerance of uncertainty (e.g., Correa, Li, Nelson, & Shankman, 2022; MacNamara, 2018; Tanovic, Pruessner, & Joormann, 2018) and trait/state anxiety (e.g., MacNamara et al., 2011). Further, the inclusion of trait and state worry measures is rarely done in studies using ERP components. To date, the only studies that have incorporated both trait and state worry have focused on other ERP components that were not used in the present study (e.g., ERN & CRN: Härpfer, Carsten, Löwisch, Westermann, & Riesel, 2022; N2pc & CDAp: White et al., 2021). Another important distinction that may be pertinent to the lack of divergence with extant literature is that the relative contribution of worry *and* rumination were tested simultaneously, as opposed to the vast majority of other ERP studies that have examined these constructs independently. Tanovic and colleagues (2017) conducted the only other ERP study to date that has simultaneously examined the effects of trait worry and trait rumination, however they did so with different behavioral paradigms (i.e., flankers task) and ERP components (i.e., ERN, CRN, Pe), with the aim of targeting the influence of trait rumination specifically in the context of error processing while controlling for trait worry, anxiety, and depression. Nevertheless, their conclusions aligned with the unique role of trait rumination, which underscores the importance of disentangling these constructs rather than focusing on them independently and/or combining them into a unitary construct of perseverating negative thinking.

In the present study, findings supported that rumination had a more robust effect on emotional reactivity relative to worry, therefore it is possible that testing worry and rumination together may have suppressed the effects of worry that may have otherwise been detected had worry been tested independently. These findings contradicted the overarching theme of predictions across both aims in that worry and rumination did not appear to exhibit comparable patterns with one another whether examined at the trait-level (*Aim #1*) or state-level (*Aim #2*). The specific hypotheses rested on the underlying assumption that worry and rumination would likely be more similar than different, however these results lend support to the differential effects of worry and rumination broadly speaking, as well as the differential effects of trait worry vs. trait rumination and state worry vs. state rumination, respectively.

General Implications of Study Findings

For the past two decades, the commonalities and distinctions between worry and rumination have remained subject to debate among clinical scientists, evidenced by a lack of consensus about whether these repetitive thinking styles represent a unitary construct or distinct constructs (see Stade & Ruscio, 2023, for a recent meta-analysis).

Unique, distinct features of worry and rumination include temporal orientation, differential impacts on affect, and content-specific features. Temporal orientation is one such distinguishing feature, with worry being future-oriented and rumination being past-oriented (McLaughlin, Borkovec, & Sibrava, 2007; Watkins et al., 2005). The temporal distinction between worry and rumination may have differential effects on affect. In a study investigating the predictive role of self-generated thoughts on negative affect, past-oriented thoughts were associated with subsequent negative mood whereas future-oriented thoughts were associated with subsequent improvements in mood, and these effects were irrespective of whether thought content was positively or negatively valenced (Ruby, Smallwood, Engen, & Singer, 2013). An experience sampling study comprised of women with GAD and MDD demonstrated that in addition to the temporal distinction, self-focus was unique to rumination, whereas situational uncertainty, verbal-linguistic focus, and concreteness were unique to worry (Kircanski, Thompson, Sorenson, Sherdell, & Gotlib, 2015). In a subsequent study of individuals with GAD and MDD, differential effects of worry and rumination were identified using ecological momentary assessment, such that rumination predicted decreases in positive affect and increases in negative affect (Kircanski, Thompson, Sorenson, Sherdell, & Gotlib, 2018). These researchers interpreted this finding as being indicative of rumination being more susceptible to everyday effects and stronger affective changes compared to worry. Findings from the present study, which were significant for rumination but not for worry, may be understood with a similar line of reasoning.

Shared, overlapping features of worry and rumination have been highlighted by psychometric validation studies for measuring a unitary construct of repetitive negative thinking (e.g., Ehring et al., 2011; Magson et al., 2019; McEvoy et al., 2010; Szkodny & Newman, 2019) as well as studies demonstrating a lack of specificity of these processes to particularly relevant diagnostic categories (e.g., Ruscio et al., 2011). In a case-control study of adults meeting criteria for GAD, MDD, comorbid GAD and MDD, and healthy controls, the findings provided evidence to suggest worry and rumination represent a more broadly defined, higher order factor of negative repetitive thinking constituting a common risk process shared by GAD and MDD (Ruscio et al., 2011). The analyses used in that study were based on a single composite variable that was calculated by combining the self-report measures of worry and rumination to capture the unified construct of repetitive thinking, hampering the ability to detect unique relationships of worry versus rumination. Despite the traditional notion that worry is specific to anxiety and rumination is specific to depression, there is skepticism as to whether this may be a somewhat arbitrary distinction, as worry and rumination have exhibited strong associations with both anxiety and depression (e.g., Hughes et al., 2008).

Based on findings from a recent meta-analysis of 233 studies (Stade & Ruscio, 2023), worry and rumination demonstrated common *and* distinct features, therefore it was strongly recommended that researchers study both of these constructs together when possible in the future. The present study aligns with those recommendations by examining the shared and unique features of these constructs simultaneously to elucidate the relative contribution of worry and rumination on neural indices of emotional reactivity. In the present study, there appeared to be meaningful variation when examining trait worry vs. trait rumination and state worry vs. state rumination. In light of the inconsistencies among clinical scientists about whether lumping versus splitting these constructs is best practice, these findings strengthen the argument for conceptualizing worry and rumination as separate (albeit related) entities.

Factor analytic studies of worry and rumination have yielded mixed findings, with some studies delineating two separate factors (e.g., Fresco et al., 2002), some studies identifying one unitary higher-order factor (e.g., McEvoy et al., 2010), and some studies identifying common as well as distinct factors (e.g., Hur et al., 2007). This further obscures the debate as to whether worry and rumination are best conceptualized as unitary or distinct constructs. In light of this, multi-model studies of these constructs may serve as a viable step for overcoming some of limitations imposed by relying solely on self-report measures.

The present study implemented subjective, behavioral, and neuropsychological measures to examine the role of worry and rumination on emotional responding. This represents a growing trend in the field by shifting from categorical towards dimensional approaches to conceptualizing and assessing psychopathology by identifying empirically-derived dimensional phenotypes (e.g., Hierarchical Taxonomy of Psychopathology [HiTOP]: DeYoung et al., 2023; Kotov et al., 2017; National Institute of Mental Health's Research Domain and Criteria project [RDoC]: Cuthbert & Insel, 2010; 2013). One of the premises of dimensional approaches rests on the assumption that there is a shared mechanism that is present along a spectrum from normative, subclinical, and clinical (Cicchetti & Toth, 2009). This is exemplified by HiTOP (Kotov et al., 2017), an empirically-derived dimensional classification system that seeks to address some of the limitations imposed by categorical approaches by understanding mental health on a continuum between psychopathology and normality, offering a graded approach to recognize syndromes, their subcomponents, and the covariation of related symptoms (see DeYoung et al., 2023, for a recent review). This is closely aligned with the growing multidisciplinary field of intervention science and with initiatives set forth by the RDoC project, which seeks to elucidate biobehavioral markers that are reliably dissociable in patient subgroups as compared to healthy controls, with the goal of being able to identify pre-symptomatic dysfunction and develop early prevention efforts accordingly in the context of quantified measures (Cuthbert & Insel, 2010, 2013). Consistent with both of these dimensional approaches, the present study sought to examine the transdiagnostic mechanisms of worry and rumination using biobehavioral markers of emotional processing.

Anxiety and depressive disorders are extremely prevalent and highly comorbid forms of psychopathology (Kessler, Chiu, et al., 2005; Kessler & Wang, 2008). The widespread prevalence of anxiety and depression has increased in recent years, particularly during and following the COVID-19 pandemic (Kessler et al., 2022; Kujawa, Green, Compas, Dickey, & Pegg, 2020), further underscoring the need for studying risk factors that may help reduce the individual and societal burden posed by these mental health conditions. Extant literature has established that worry and rumination confer increased risk for developing anxiety disorders and depressive disorders (McEvoy et al., 2013; Nolen-Hoeksema & Watkins, 2011), thereby suggesting that these constructs represent identifiable pre-symptomatic dysfunctional processes and thus offer hope in prevention efforts for disorders associated with these repetitive negative thinking patterns, such as anxiety and depressive disorders. Prior research has substantiated that ruminative processes is a proximal mechanism that poses cognitive vulnerabilities that contribute to depression (e.g., Spasojevic & Alloy, 2001; Wisco, Gilbert, & Marroquín, 2014), underscoring the role that rumination plays in the susceptibility to depression as well as the onset, severity, and duration of major depressive episodes (e.g., Nolen-Hoeksema et al., 2008). Furthermore, rumination has been shown to have a strong association with both anxiety and depression (e.g., Hughes et al., 2008), underscoring that this construct is likely best conceptualized as a transdiagnostic mechanism underlying distress disorders more broadly.

Biobehavioral measures, such as EEG, provide a more comprehensive approach to understanding transdiagnostic mechanisms that may not otherwise be elucidated by limiting the scope of research to subjective and/or behavioral measures. Further, the incremental validity of neural risk markers is substantiated by extant research demonstrating that neural risk markers are more sensitive than behavioral measures and that neural indices may capture unique aspects of risk not readily identifiable through behavioral indices alone for various forms of psychopathology (e.g., Manoach & Agam, 2013), including internalizing disorders such as anxiety and depression (e.g., Dickey, Politte-Corn, & Kujawa, 2021). Studies that have implemented neural markers of cognitive-affective processing have prospectively predicted the onset of internalizing symptoms (e.g., Dickey, West, et al., 2021; Feurer et al., 2022; Levinson, Speed, & Hajcak, 2019).

In addition to the potential utility offered by establishing valid, reliable neural indices with ERPs that capture worry and rumination to identify individuals at-risk of developing anxiety and/or depressive disorders, there are clinical applications for treatments that directly target these maladaptive cognitive affective processes. Emotion regulation therapy is one such example of a psychosocial treatment informed by affective science that directly targets negative self-referential processes (i.e., worry, rumination, self-criticism) and has demonstrated efficacy for the treatment of distress disorders (Mennin, Fresco, O'Toole, & Heimberg, 2018; Renna et al., 2023). While replication studies are needed to determine the generalizability of these findings to clinical and treatment-seeking populations, implementation of a similar study design incorporating subjective and neural indices of worry and rumination may be a fruitful avenue of research to understand how these processes change over the course of treatment.

Limitations

There are several limitations of the present study that warrant discussion. First, the cross-sectional study design precludes the ability to draw conclusions about causality. In addition, sampling characteristics and methodological issues regarding the experimental design of the study may limit the generalizability of the present study, both of which are discussed in further detail below.

The present study is based on an unselected sample that largely consisted of individuals endorsing normative and subclinical levels of worry and/or rumination, which can be taken as a strength and a weakness. On the one hand, the need for dimensional spectrums spanning from normative to pathological states has become increasingly recognized by the field as reflected by initiatives such as RDoC and HiTOP. On the other hand, the generalizability of these findings to individuals endorsing clinical thresholds of worry and/or rumination often present in anxiety and/or depressive disorders meeting diagnostic criteria for GAD and/or MDD may be somewhat limited given that this was a non-clinical sample. An important extension of the present study would involve employing a similar study design with a stratified sample comprised of individuals with pathological levels of worry and rumination to better understand the clinical utility and practical applications offered by this line of research.

Considering that participants in this study were young adults, the age range of this sample may pose another potential limitation to the generalizability of these findings to individuals in other developmental stages across the lifespan (e.g., childhood, earlier stages of adolescence, older adulthood). At the same time, epidemiological studies show that late adolescence and emerging adulthood is marked as a high-risk period for the emergence of mood and anxiety disorders (Kessler, Berglund, et al., 2005; Kessler, Merikangas, & Wang, 2007), thereby substantiating the importance for studies that focus on this specific developmental period of life.

The experimental paradigm used in the present study was a passive view task comprised of emotional pictures selected from a standardized stimuli set (IAPS; Lang et al., 2008), however there were a relatively small number of images for each emotional condition. Most notably, this may have posed significant challenges to the EPN findings (or lack thereof) and it is quite possible that the small number of trials per condition may have suppressed the EPN effects, as this is a problem that has been recognized as an important consideration by other researchers using this specific ERP component (Weins et al, 2011). It is unlikely that this would have negatively impacted the validity or reliability of the LPP considering that prior psychometric studies have established that mean amplitudes of the LPP are highly stable within ~8 trials (Moran et al., 2013).

There are strengths and limitations inherent to the decision to utilize a passive viewing behavioral assessment. The decision to implement one of the most commonly used emotion elicitation paradigms, which is a valid and reliable experimental induction of emotion, strengthens the internal validity of the study by more readily being able to identify sources of convergence and divergence from previous research studies that have implemented similar or identical behavioral paradigms. Nevertheless, future research may consider using ideographic stimuli to elicit heightened responses that may be more conducive to the emotional processing evoked by personally relevant stimuli. In doing so, the ecological validity of this behavioral paradigm may be strengthened by an experimental induction using ideographic stimuli that would be more conducive to in-vivo inductions of worry and rumination. Relatedly, the present study relied on self-report measures of state worry and state rumination, which may be contaminated by response biases inherent to subjective assessments. More commonly, state measures of worry and rumination are gleaned using behavioral paradigms that directly manipulate worry and rumination using experimental induction tasks (e.g., imaginal exposure to worry: Fisher & Newman, 2013; imaginal exposure to rumination: Nolen-Hoeksema & Morrow, 1993; self-referential encoding task: Shestyuk & Deldin, 2010). Future research would likely benefit from a combined approach utilizing behavioral and self-report measures to offer a more comprehensive examination of state-level indices of worry and rumination.

Chapter 5: Conclusion

Despite these limitations, this study shows promise in offering valuable contributions to the field's understanding of how worry and rumination differentially predict dynamic aspects of emotional reactivity utilizing three distinct neural indices selected for their sensitivity to emotional stimuli and ability to capture discrete temporal stages of emotional processing. To date, no study has simultaneously incorporated *all three* of the selected ERP components (N1, EPN, LPP [early LPP, late LPP]) to examine the relative contribution of trait-level (trait worry vs. trait rumination) *and* state-level (state worry vs. state rumination) indices of worry and rumination on these neural markers of emotional responsivity. Within the scope of ERP literature, no previous studies have used trait *and* state self-report measures of worry *and* rumination, nor have *all three* of these ERP components been simultaneously examined with worry *or* rumination. The present study showed that rumination at the trait-level and state-level exhibited a pattern of findings that varied based on the specificity of emotional content, with a significant interaction between trait rumination and condition occurring during early stages of emotional processing (N1 reactivity) and a significant interaction between state rumination and condition significantly occurring during later stages of emotional processing (late LPP reactivity). This study also contributes to the ongoing debate among clinical scientists regarding whether worry and rumination are unitary or distinguishable constructs. These findings lend support to them being distinct constructs based on the discriminative patterns on neural markers of emotional reactivity that were specific to rumination but not worry. Lastly, this study highlights the importance of capturing nuances in temporal dynamics with subjective and biobehavioral assessments to elucidate the complex underpinnings of these maladaptive processes. This point is underscored by findings that trait rumination and state rumination uniquely predicted early (N1) and later (LPP) stages of emotional processing respectively, implying an element of temporal specificity underlying the role of rumination on emotional processing that would not have otherwise been detected without incorporating these subjective and neural measures that offer a means of capturing these subtle temporal distinctions. The application of multimodal indices of emotion-related constructs is in accordance with initiatives to advance the field of affect science through dimensional (as opposed to categorical) approaches to examine transdiagnostic processes that confer risk for psychopathology. More specifically, this study aligns with these initiatives insofar as worry and rumination being transdiagnostic mechanisms involved in distress disorders, most notably GAD and MDD. There is indeed merit in future research that concurrently examines trait-level and state-level worry *and* rumination given the role these transdiagnostic mechanisms have in predicting the increased susceptibility towards developing an anxiety and/or depressive disorder(s) as well as the predictive utility for the severity and duration of these diagnostic entities. As such, this underscores that this as a promising avenue of research with clinical applications in the prevention, etiology, and treatment of anxiety and depression disorders (e.g., GAD, MDD, comorbid GAD and MDD). To this end, longitudinal studies of trait-level and state-level worry *and* rumination in conjunction with these three ERPs ideally suited for discriminating temporal and functional distinctions of emotional processing are needed to more readily address the prospective relationship between these mechanisms and subsequent development of internalizing disorders. Future research implementing the same measures used in this study with clinical populations is needed to elucidate the practical applications gleaned by further examination of the dynamic relationships and differential aspects of trait-level and state-level worry and rumination on emotional reactivity.

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Appendix

Table 1

Descriptive Statistics with Mean, Standard Deviation, and Range of Predictor and Outcomes Variables

	M	*SD*	*Min.*	*Max.*
Worry and Rumination				
Trait-level Indices				
PSWQ	48.80	13.16	23.00	79.00
RS	10.83	3.25	5.00	20.00
State-level Indices				
WVAS	34.72	25.40	0.00	100.00
RVAS	24.28	22.94	0.00	100.00
ERP Amplitudes				
N1				
Affiliative	-4.31	3.97	-13.92	5.42
Erotic	-4.17	3.94	-13.90	3.04
Mutilation	-4.06	4.15	-13.88	4.85
Threat	-3.53	3.75	-13.68	6.40
Neutral	-4.84	3.87	-16.27	5.11
EPN				
Affiliative	3.64	2.99	-2.05	11.48
Erotic	2.90	2.80	-2.69	10.12
Mutilation	4.05	2.65	-0.93	10.88
Threat	4.46	2.94	-2.43	11.95
Neutral	3.74	2.35	-0.84	9.57
Early LPP				
Affiliative	3.68	4.33	-5.75	13.53
Erotic	7.33	5.56	-6.47	22.59
Mutilation	6.68	6.05	-4.94	21.81
Threat	3.56	4.70	-10.28	17.13
Neutral	-1.50	3.94	-13.17	8.72
Late LPP				
Affiliative	3.75	4.69	-8.73	13.60
Erotic	4.44	4.54	-5.92	17.79
Mutilation	5.79	5.16	-7.24	18.81
Threat	2.99	4.64	-10.03	13.84
Neutral	-0.84	3.38	-10.47	7.02

Note. PSWQ = Penn State Worry Questionnaire; RS = Rumination Scale, Brooding subscale; WVAS = Worry Visual Analogue Scale; RVAS = Rumination Visual Analogue Scale; ERP = event related potential; EPN = early posterior negativity; LPP = late positive potential.

Table 2

Correlation Matrix for Predictor Variables

	1	2	3	4
1. PSWQ	—	.395***	.431***	.293**
2. RS		—	.266**	.314**
3. WVAS			—	.631***
4. RVAS				—

Note. * $p < .05$, ** $p < .01$, *** $p < .001$. PSWQ = Penn State Worry Questionnaire; RS = Rumination Scale, Brooding subscale; WVAS = Worry Visual Analogue Scale; RVAS = Rumination Visual Analogue Scale.

Table 3

Correlation Matrix for Outcome Variables

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
1. N1: A	—	.69**	.78**	.74**	.16	.08	.11	.09	.41**	.28**	.36**	.34**	.30**	.20†	.32**	.19†
2. N1: E		—	.69**	.70**	.00	.09	.02	.08	.26*	.35**	.32**	.33**	.21*	.31**	.29**	.17†
3. N1: M			—	.71**	.04	.10	.14	.12	.26*	.17	.35**	.37**	.15	.09	.32**	.22*
4. N1: T				—	-.00	.13	.02	.07	.27**	.27**	.29**	.42**	.19†	.25*	.23*	.30**
5. EPN: A					—	.67**	.70**	.70**	.16	.17†	.01	.09	.12	.04	-.01	-.01
6. EPN: E						—	.69**	.72**	-.04	.20†	-.06	.10	.02	.14	-.08	.10
7. EPN: M							—	.73**	.18†	.36**	.25*	.21*	.11	.19†	.18†	.08
8. EPN: T								—	.19	.23*	.15	.27**	.15	.07	.14	.22*
9. Early LPP: A									—	.61**	.71**	.63**	.72**	.52**	.47**	.36**
10. Early LPP: E										—	.69**	.67**	.45**	.85**	.53**	.41**
11. Early LPP: M											—	.71**	.54**	.51**	.80**	.41**
12. Early LPP: T												—	.38**	.51**	.57**	.71**
13. Late LPP: A													—	.48**	.63**	.50**
14. Late LPP: E														—	.48**	.48**
15. Late LPP: M															—	.51**
16. Late LPP: T																—

Note. $^{\dagger}p < .10$, $^{*}p < .05$, $^{**}p < .01$. A = affiliative images presented during passive view task; E = erotic images presented during passive view task; M = mutilation images presented during passive view task; T = threat images presented during passive view task EPN = early posterior negativity; LPP = late positive potential.

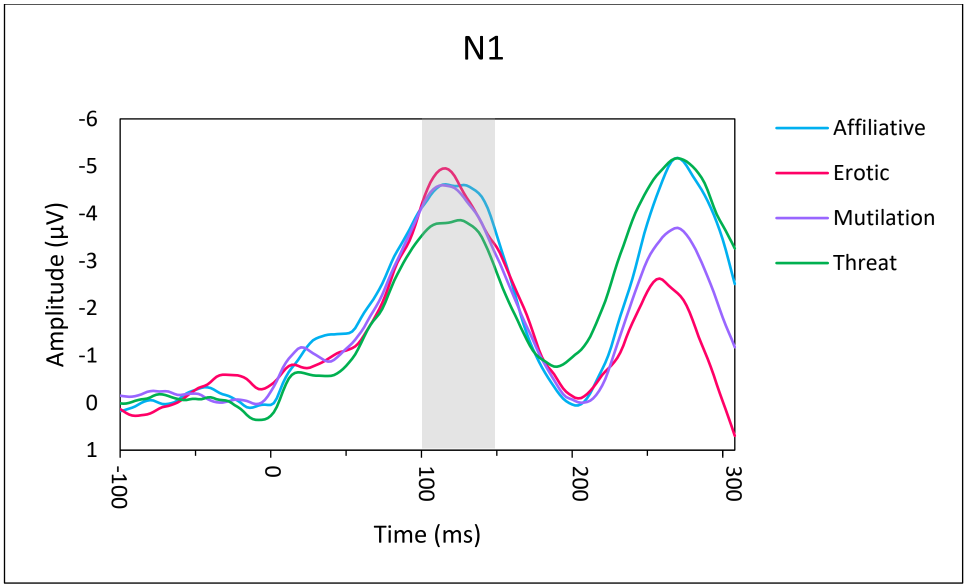

Figure 1. Grand average ERP waveforms depicting N1 responses to emotional images (affiliative, erotic, mutilation, threat) during passive view task based on mean activation (in µV) at Cz and CPz electrodes between 100-150 ms following picture onset.

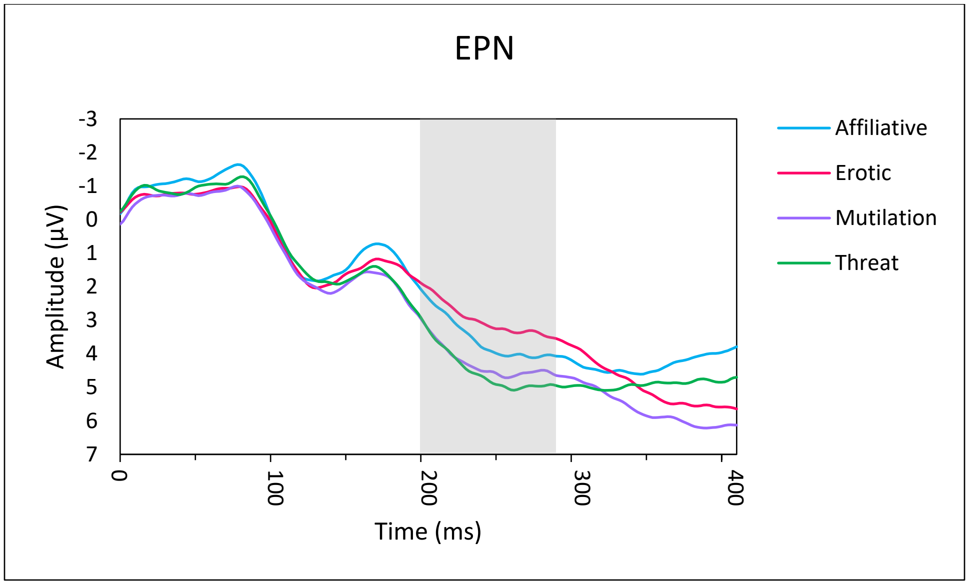

Figure 2. Grand average ERP waveforms depicting EPN responses to emotional images (affiliative, erotic, mutilation, threat) during passive view task based on mean activation (in µV) at Iz, P9, P10 electrodes between 200-280 ms following picture onset.

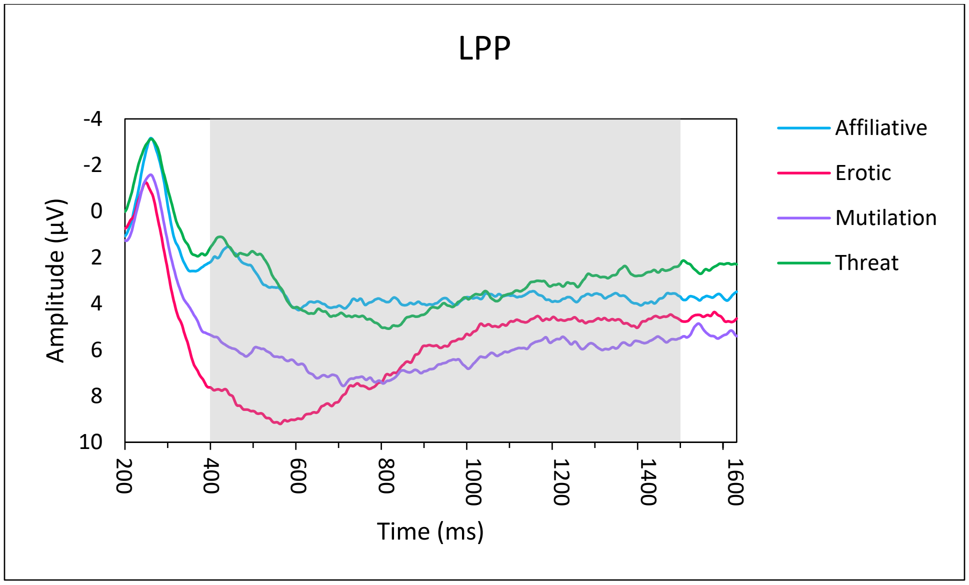

Figure 3. Grand average ERP waveforms depicting LPP responses to emotional images (affiliative, erotic, mutilation, threat) during passive view task based on mean activation (in µV) at Pz, Cz, CPz, CP1, CP2 electrodes with early LPP between 400-1000 ms and late LPP between 1000-1500 ms following picture onset.

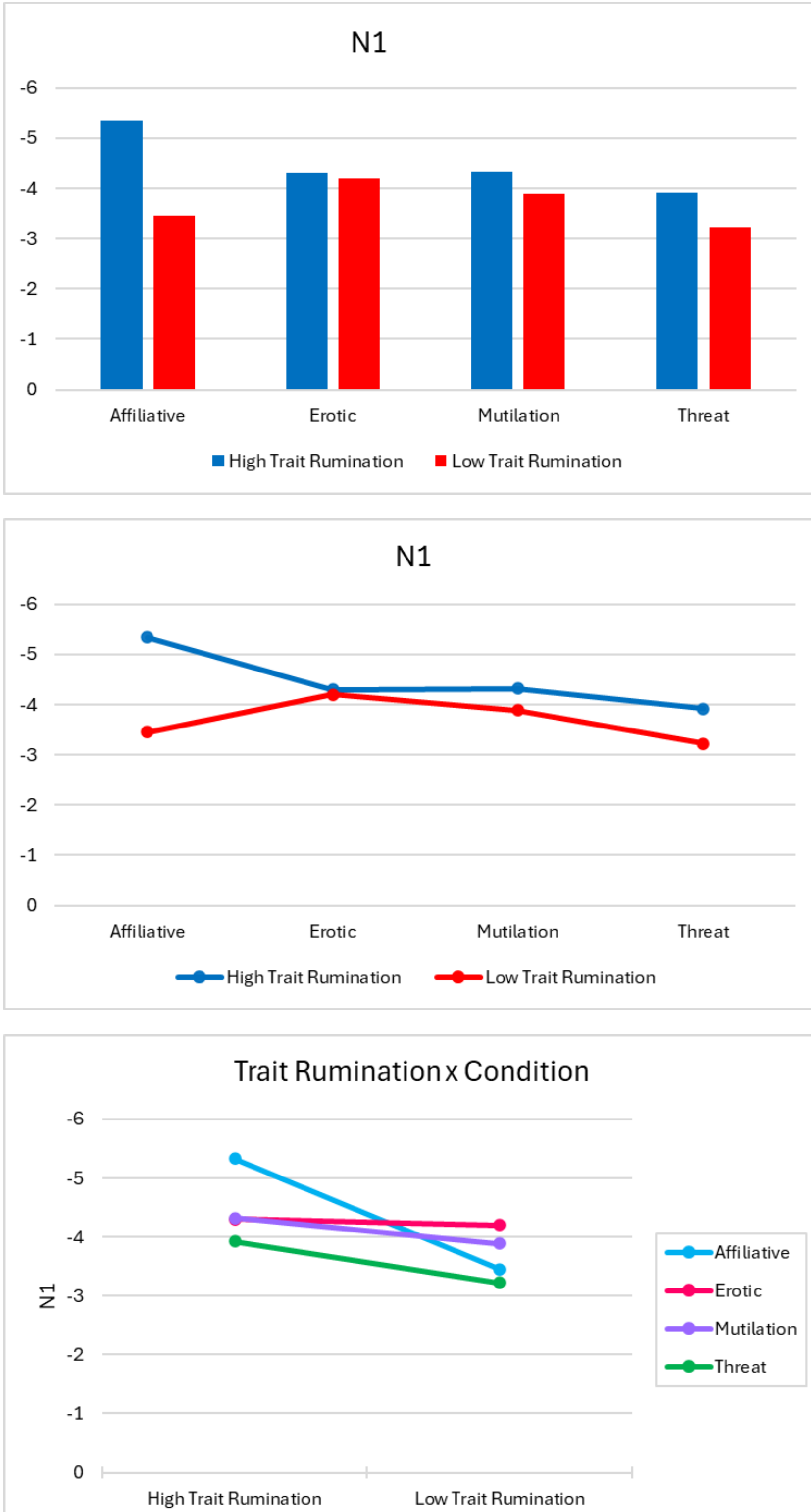

Figure 4. Estimated marginal means for significant interaction between RS and condition on N1 reactivity.

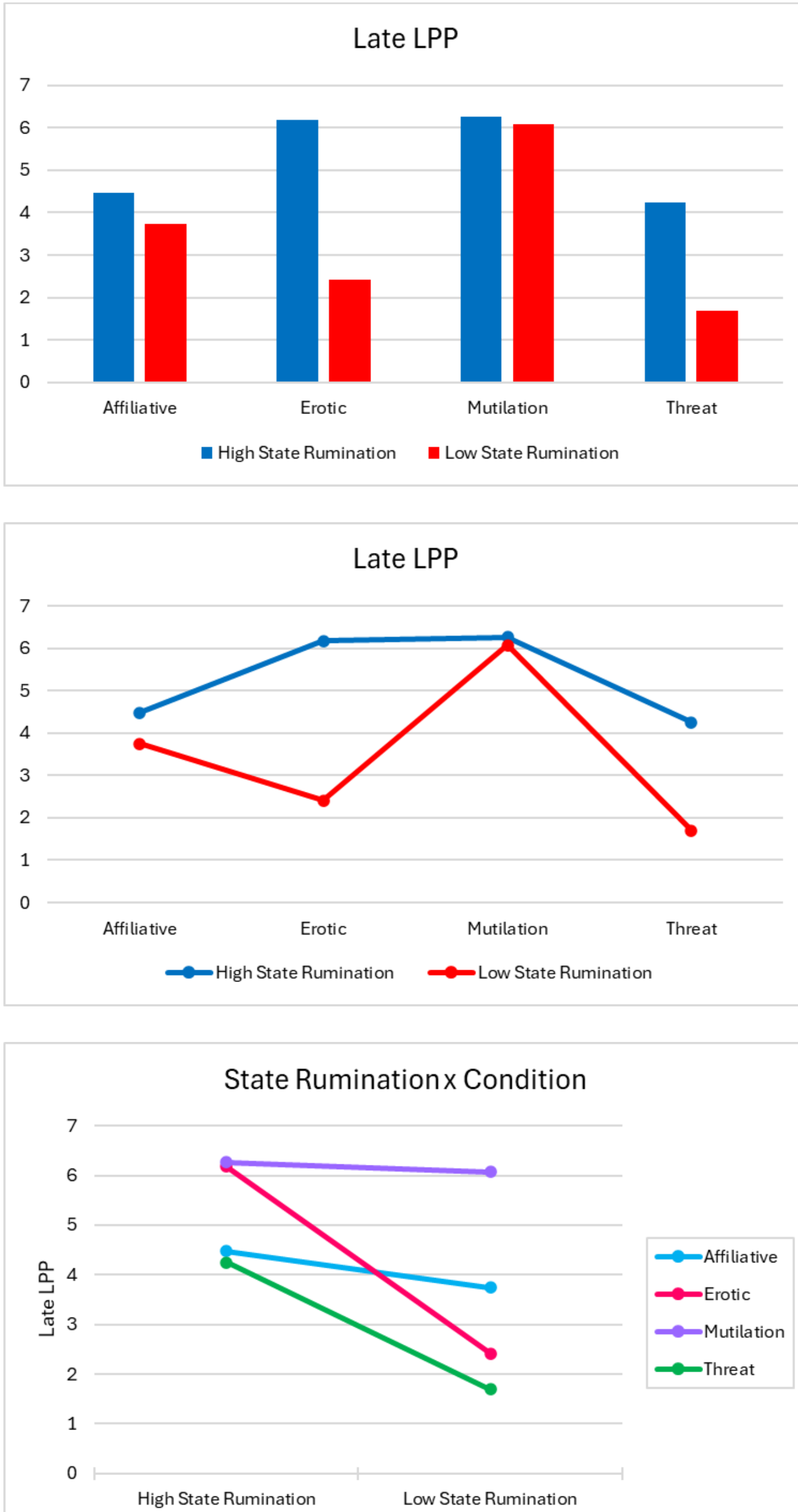

Figure 5. Estimated marginal means for significant interaction between RVAS and condition on late LPP reactivity.