AVERSIVENESS OF ERRORS IN PERFORMANCE MONITORING AND ERROR-RELATED NEGATIVITY IN OBSESSIVE COMPULSIVE SYMPTOMATOLOGY

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Master's dissertation

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Master's dissertation submitted in partial satisfaction of the requirements for the degree of master’s in psychology by the supervision of Prof. Dr. Rosa Maria Martins de Almeida and adjunct supervision of Prof. Dr. Gustavo Gauer

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"If you shut the door to all errors, truth will be shut out."

Rabindranath Tagore

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ABSTRACT

The error-related negativity is one of the most examined event-related potentials in the study of cognitive control, yet its functional significance has not been fully determined. The present dissertation had the objective to investigate the relationship between error processing and affective states manipulations in non-clinical samples and in OC symptomatology. Two studies constitute this dissertation. In study 1, we conducted a systematic review of studies investigating affective state manipulations, aversiveness of errors and the ERN. This review showed considerable evidence for ERN sensitivity to affect states experimental manipulations. In study 2, we aimed to explore the incidence of the error-related potentials at a gambling-type task (HiLo game) in a sample composed of people with high OCD symptomatology. Although the ERPs of interest were not elicited, we showed that the HiLo game is a promising paradigm to investigate the ERN in upcoming studies. In the general discussion, the results from the two studies are discussed in relation to the literature on error monitoring and affective conceptualizations.

Keywords: Error-related Negativity, ERN, error monitoring, performance monitoring, aversiveness, negative affect, errors, uncertainty, OC symptomatology.

CHAPTER I: INTRODUCTION

Errare humanum est,
sed in errare perseverare diabolicum
Seneca

Presentation

To err is human, but to persevere (in error) is diabolical (Seneca).

Most people know the quote, whether they know the author or know it through shared knowledge. Everyone knows to err is part of the daily experience. All of us commit errors every day. In other words, making mistakes is part of human behavior and a hugely important part of it. It is at the core of learning processes, attention, and other cognitive processes (Miller & Cohen, 2001). Likewise, behavioral adaptation after error commissioning seems to be part of the processing of unsought outcomes. Humans constantly evaluate their actions and errors as a fundamental tool to inform the need for corrective behaviors to adapt to environmental demands (Hoffmann & Beste, 2015).

Great questions related to this topic have emerged through the decades in psychology and neuroscience. Why do we err? What happens in our brains when we err? What is the cognitive nature of errors? Is there any emotional significance of errors? What does error inform us? Some of these questions are considerably investigated, but some are still waiting for a better understanding. This thesis intends to address recent theoretical and empirical questions regarding error and performance monitoring and the role of emotion and affect in cognitive control. This thesis is organized as follows: It begins with a general introduction, presents two studies, and ends with a general discussion that integrates all the findings and indicates its main implications.

The introduction addresses the theoretical paradigm of cognitive control, conflict, and error monitoring. It then exposes the role of emotions and the neurobiological substrate of these processes. Next, we discuss the Error-Related Negativity (ERN), the neurobiology of OCD, the role of uncertainty in OCD symptomatology, and the importance of the studies with abnormal error and response monitoring. Finally, it concludes with the specification of the research objectives, indicating how they will be addressed in each of the studies.

Cognitive control, error monitoring, and emotion

Cognitive control is the ability to engage adaptive goal-directed behavior, and it usually attends several higher processes that help humans, and other animals successfully operate in their environment (Miller, 2000; Zavala et al., 2018). Its principal function is to contain or inhibit prevalent responses among multiple conflicting options to focus on current goals (Koechlin et al., 2003; Miller & Cohen, 2001). To do so, it must involve monitoring actions and ongoing performance and the signaling of final adjustments to behavior and learning (Schiffer et al., 2015; Ullsperger et al., 2014). Convergent evidence from cognitive neuroscience points out that cognitive conflict generates control efforts (Inzlicht et al., 2015). Conflict monitoring theory suggests that the monitoring system is vital in analyzing the actual representations of action tendencies for potential conflicts. Thus, inhibitory mechanisms may be engaged to override the unwanted bias and promote active goal pursuit (Botvinick, 2007; Botvinick et al., 2001; Yeung, 2014).

Akin to conflict monitoring, error monitoring detects and signals an error to optimize behaviors across various tasks and situations (Ullsperger et al., 2014). Error detection is a necessary process for adaptive behavioral adjustments (Moser et al., 2013). An organism can use it to inform behavioral strategies to achieve higher accuracy or preserve the speed in the executed task (Ridderinkhof et al., 2004; Zhou et al., 2019). For instance, error monitoring is correlated with the

number of response alternatives in experimental tasks (Maier et al., 2010) and the difficulty of the chosen task. More complex tasks provoke more errors, and increasing the number of alternative responses decreases the response monitoring mechanisms. That is due to the cognitive overload on the different strategies, neural structures (Prefrontal Cortex, Motor Cortex, Basal Ganglia), and functions (hold and manipulate information) that are involved in error commissioning (Hoffmann & Beste, 2015).

In humans, detecting committed errors is regularly accompanied by negative emotional responses (Hajcak et al., 2004a); these responses inform an affective dimension within performance monitoring that influences future motivated behavior and remedial actions (Ullsperger et al., 2014). On the one hand, in cognitive neuroscience, the cognitive processing aspect of control is relatively well understood (Iannaccone et al., 2015; Koechlin et al., 2003; Yeung et al., 2004; Zavala et al., 2018). On the other hand, emotion has not yet been fully defined with consensus, and there is still theoretical debate on the actual definition of emotion. As a result, different biological and cognitive theoretical theories have been formulated since the past century to better conceptualize emotion (Bradley & Lang, 2007; Cabanac, 2002; Kajić et al., 2019; Suri et al., 2013).

Despite the plurality of theories, emotion can be described as a state/ process with an underlying set of neural circuits and response systems that motivates and organizes cognition and behavior (Suri et al., 2013). Thus, it involves an organic subjective experience, variations in physiological actions, and behavioral expression. The principal function of emotion is to prepare an individual to respond to environmental demands and facilitates homeostatic balance (Bradley & Lang, 2007; Damasio & Carvalho, 2013). That directs the organism to environmental cues that indicate motivationally essential needs and desires (Bradley & Lang, 2007; Cacioppo & Berntson, 1999). In other words, an emotional signal is triggered by an antecedent event that generates

changes in the organism, and those changes motivate the execution of goal-directed behavior (Inzlicht et al., 2015).

Instead of comprehending emotion and cognitive control as brain processes that have independent functioning, contemporary authors suggest that these two processes are integrated or interact in the brain in a way that makes the processes almost indistinguishable at preliminary analysis (Okon-Singer et al., 2015; Pessoa, 2008). Some studies examined the effect of emotions in cognitive control (Clayson et al., 2012a; Clayson & Larson, 2019; Song et al., 2017) or the other way around: cognitive control in emotional experience (Ochsner et al., 2012; Ochsner & Gross, 2005). Connections between emotion and cognitive control are well established at the neuro-functional level (Cromheeke & Mueller, 2014; Shackman et al., 2011a). However, it remains unclear at a process level if they are two different processes or if they can be considered two aspects of the same process.

As described above, both emotion and cognitive control direct the organism for goal achievement. Knowing that cognitive control begins with the appearance of conflict, it is also relevant to point out that conflict is not affectively neutral. Instead, conflict represents an aversive event for the organism and includes negative affective states and emotional costs (Dreisbach & Fischer, 2012). Inzlicht et al. (2015) suggested that negative affect is an integral, instantiating aspect of cognitive control. Thus, cognitive control depends on emotion or some of its properties, such as arousal and valence. For the authors, cognitive control begins when goal conflicts provoke negative affect. Negative affect then makes the conflicts outstanding, and goal-directed behavior is engaged to resolve the existing conflict.

In this line of thinking, interesting questions emerged about emotion-cognition interactions regarding cognitive control, conflict, and performance monitoring: How does the affective system influence cognitive control? What is the role of emotions in cognitive control? Do aversive stimuli

influence error processing? Which of these processes are emotionally independent and which are not? These and other theoretical and empirical questions are currently being studied by cognitive and affective neuroscience (Schmeichel & Inzlicht, 2013; Song et al., 2017; Suri et al., 2013).

Nevertheless, throughout psychological and affective neuroscience literature, the concept of *emotion* as a construct tends to be used without distinction from affect, and mood, leading to conceptual confusion in the field (Ekkekakis, 2013). Although the definition of the concept is circumscribed to the theoretical perspective of the researcher, to disentangle the role of emotion and affect in performance monitoring and cognitive control, it is necessary to state clearly what is understood by each construct and how it is experimentally manipulated. An attempt to summarize the distinctions between emotion, affect, and mood from the predominant cognitive theoretical framework in the field can be found in Table 1.

Table 1.

Tentative distinctions between core affect, emotion, and mood

	Core affect	Emotion	Mood
Present When? Duration?	Always Constant	Rarely Short (seconds to minutes)	Much of the time Long (hours or days)
Intensity?	Variable	High	Lower than emotion
Multiple components?	No, elementary ("the most elementary consciously accessible affective feelings")	Yes (core affect, cognitive appraisal, bodily changes, vocal and facial expressions, action tendencies)	Yes, but some components (e.g., peripheral physiology, facial expressions) are not as pronounced or distinct as in emotions
About something?	Not necessarily	Yes	Possibly, although not necessarily about something specific (Could be "about Everything, about the world in general")

	Core affect	Emotion	Mood
Antecedent appraisal?	Not necessary in "free-floating" core affect (but may cooccur with an appraisal in emotion or mood)	Necessary	Necessary
Object of appraisal?	N/A	Specific stimulus, clearly identifiable	Varies but could be larger, "existential" issues or concerns or not easily identifiable
Temporal relation to stimulus?	Direct	Immediate or close	May be distant
Evolutionary origins?	Ancient, primitive	More recent than core affect	More recent than core affect
Cultural influence?	Limited	Presumed strong	Presumed strong
Function?	Approach useful and avoid harmful stimuli, prioritize multiple sensory stimuli, form valenced memories and preferences	Direct attention, coordinate response across multiple channels, communicate	Prepare or caution about what the future might bring, influence cognition, lower threshold for elicitation of congruent emotions
Examples?	Pleasure, displeasure, tension, relaxation, energy, tiredness	Anger, fear, anxiety, jealousy, pride, shame, guilt, love, sadness, grief, disgust	Dysphoria, euphoria, irritation, joyfulness, cheerfulness, grumpiness

Note. Reproduced from (Ekkekakis, 2013 p. 47) The measurement of Affect, Mood, and Emotion. A guide for Health-behavioral Research, with permission from Cambridge University Press publishing.

For further discussion of this topic, see Chapter II: Aversiveness of errors and the error-related negativity (ERN): A systematic review on the affective states' manipulations.

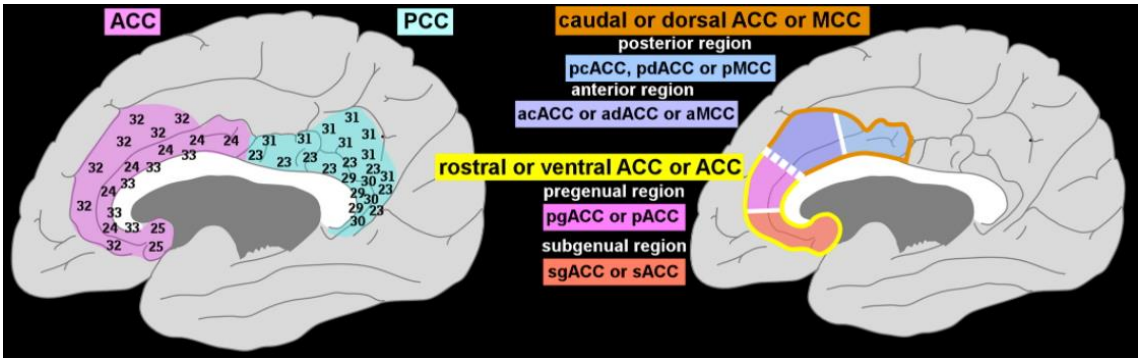
Brain Structures implicated in cognitive control, conflict, and error processing

Convergent evidence from neuroscience has shown that cognitive control correlates with activation in the ventral, lateral, and medial Prefrontal Cortex, Orbitofrontal Cortex, Cingulate Cortex, and the Pre-supplementary motor area (Koechlin et al., 2003; E. K. Miller & Cohen, 2001; Widge et al., 2019; Zavala et al., 2018). The involvement of the Cingulate Cortex has been a focus

of particular interest due to its vital role in cognitive control, goal-oriented behavior, and emotion (Moser et al., 2013; Ridderinkhof et al., 2004; Shackman et al., 2011a). Several mappings of the human cingulate cortex are found in the literature to account for its cytoarchitectural and functional divisions. The most widely used is based on the Broadmann categorization: The anterior cingulate cortex (ACC) and the posterior cingulate cortex (PCC) (see Figure 1). Nevertheless, since the neuroimaging studies have shown a different pattern of activation of the ACC in several processes lead to a new subdivision of the region (see Figure 1): the anterior segment was referred to as rostral ACC and the posterior part as dorsal ACC (Stevens et al., 2011; van Heukelum et al., 2020).

Figure 1.

Proposed subdivisions of the human cingulate cortex



Note. **Left:** The cingulate cortex (colored areas) lies in the medial wall of each hemisphere, adjacent to the corpus callosum (white). Brodmann divided this area into a precingulate (pink), now called the anterior cingulate cortex (ACC), and a postcingulate (blue), now called the posterior cingulate cortex (PCC). **Right:** The ACC is further subdivided into two major sections. The three most common approaches to naming are illustrated. The dorsal posterior section (outlined in gold) has been called caudal or dorsal ACC. In Vogt's system, it is considered a separate area, the middle cingulate cortex (MCC). The ventral anterior section (outlined in yellow) has been called rostral or ventral ACC. In Vogt's system, it is considered ACC. These major sections are commonly further divided, as illustrated. Reproduced from Stevens et al. (2011) Anterior cingulate cortex: unique role in cognition and emotion. J Neuropsychiatry Clin Neurosci. (2):121-5. with permission from APA publishing.

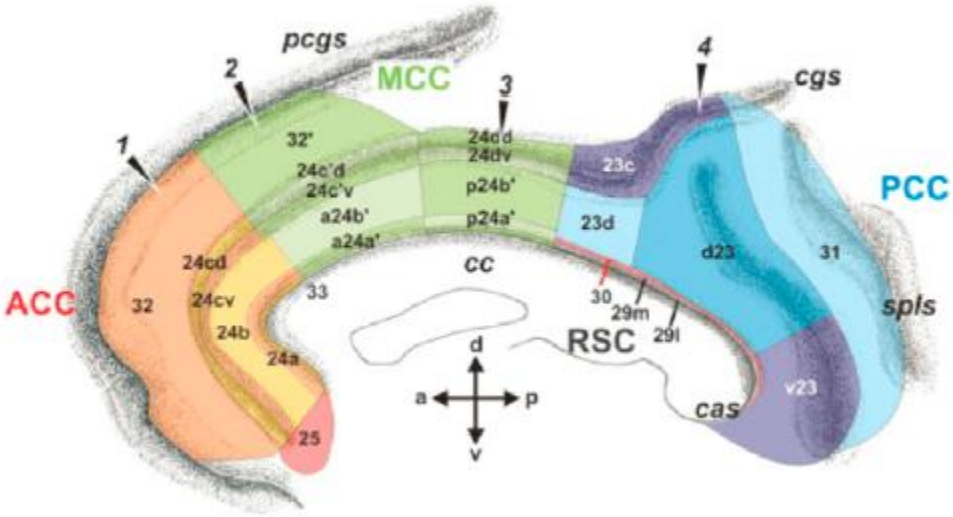
However, an important work emerged regarding the anatomical features of the subdivision proposed. Vogt (1993) stated that the ventral ACC (vACC) should be considered a distinct structure rather than a so-called anterior cingulated structure subdivision. He introduced a nomenclature in which the vACC is referred to as ACC, and the dorsal-caudal ACC is, in fact, part of the

midcingulate cortex (MCC). In a posterior manuscript, Vogt (2016) clarified and distinguished with more detail the structure and functions of the ACC and MCC due to their vague and inaccurate use in recent literature. Human ACC and MCC can be subdivided into several subregions. The ACC comprises the frontal third of the cingulate cortex, bordering the rostral part of the corpus callosum (A24a–c, A25, A32, and A33), while MCC occupies the middle third of the cingulate cortex (A24a′–c′, A32′, and A33′). The ACC and MCC are subdivided into two subregions – pregenual (pACC) and subgenual ACC (sACC), and anterior MCC (aMCC) and posterior MCC (pMCC). The cytoarchitectural divisions of the cingulate cortex in humans, as described by Vogt (2016), are shown in Figure 2.

Coherent use of Cingulate Cortex subdivisions is crucial because those designations represent cortical models with predictive value and directly impact theoretical perspectives (Vogt, 2016). This clear distinction of the regions and subregions has proved beneficial to analyze the cingulate cortex's anatomy, connectivity, and functions (Rolls, 2019; van Heukelum et al., 2020). Neuroimaging evidence suggests that both ACC and MCC have strong connections with the orbitofrontal cortex (OFC), ventromedial prefrontal cortex (vmPFC), and dorsolateral prefrontal cortex (dlPFC) (van Heukelum et al., 2020). However, the connectivity patterns of ACC and MCC differ on functional purposes. For example, ACC strongly connects with the amygdala and vmPFC, nucleus accumbens (NAc), and hypothalamus; regions implicated in process stimulus significance, motivation, and sympathetic activity patterns (Damasio & Carvalho, 2013; Etkin et al., 2011; Kobayashi, 2012). Conversely, MCC connects to dlPFC, sensorimotor and parietal cortex, and motor cortices, areas involved in cognitive control, decision making, and motor functions (Shackman et al., 2011a; van Heukelum et al., 2020).

Figure 2.

Cytoarchitectonic subdivisions of the human medial prefrontal cortex



Note. The color-coding reflects *Vogt et al. (2004)* four-region model. The region referred to as human dACC (typically refers to areas 24a–d and the dorsal extent of area 32) throughout most of the papers in the field is the anterior portion of midcingulate cortex (aMCC), encompassing an area referred to as the rostral cingulate zone (RCZ). Reprinted from Shenhav et al. (2013) The Expected Value of Control: An Integrative Theory of Anterior Cingulate Cortex Function. Neuron 79 (2): 217-240. Copyright (2021), with permission from Elsevier. Reproduced from Palomero-Gallagher et al. (2009) with permission from the authors, and respectively with permission from John Wiley and Sons.

This functional differentiation has been relevant to understanding the role of the cingulate cortex in the interaction of major psychological processes as cognitive control, overall performance monitoring, and emotion. For instance, in their meta-analysis, Shackman et al. (2011) concluded that negative affect, pain, and cognitive control seem to be integrated at the subdivision level in aMCC. In addition, computational models of cognitive control (Shenhav et al., 2013, 2016) address the central role of MCC in conflict and performance processing through event-related potential (ERP) studies that had identified a medial-frontal potential, the error-related negativity (ERN), indexing the monitoring performance, and error commission (Iannaccone et al., 2015; Ridderinkhof et al., 2004). Furthermore, Rainhart & Woodman (2014) demonstrated that manipulating the MCC and the ERN using transcranial direct current stimulation (tDCS) influenced the subject's error detection and other behavioral adaptation measures as reaction times and accuracy.

Nevertheless, along with the Cingulate Cortex, other relevant structures play a fundamental part in error processing and error-behavioral adaptation: the Prefrontal Cortex (PFC), the basal ganglia (BG), and the dopamine system (Hoffmann & Beste, 2015). Although the BG communicates with higher cortical regions through different pathways, it is hypothesized that those pathways support distinct limbic loops (Eisinger et al., 2018); they are also central in action selection mechanisms and are necessary to understand the PFC functioning. Computational models propose that the BG receives convergent input from several cortical structures consisting of stimuli, task sets previously established in the PFC, and a subsequent efference copy (Eisinger et al., 2018; Hoffmann & Beste, 2015). Notably, the modulatory influences of the BG on the task-goal representations (correct and erroneous) will ultimately strengthen at the PFC network level via dopaminergic activity (DA) (van Schouwenburg et al., 2010).

In this regard, it has been suggested that the dopaminergic system has different cognitive effects on the BG and the PFC; in the first one, DA facilitates the dynamic changes or cognitive switching between high and selectivity states (Gilbertson & Steele, 2021) and in the PFC by providing cognitive stability respectively (van Schouwenburg et al., 2010). The DA in both the BG and PFC regulates the stability and flexibility in action selection and learning processes (Gilbertson & Steele, 2021). In the reinforcement learning context, this assumption has served as the origin of theoretical explanations. The error is coded in dopamine neurons, and the error signal is transmitted to the MCC, signaling the need to implement control (Holroyd & Coles, 2002). Consequently, the interactions between MCC, lateral PFC, BG, and other relevant structures in their networks (i.e., thalamus, insula) are necessary for adequate performance monitoring and error processing.

In the next section, brain responses and measures in cortical potentials linked with error processing and cognitive control are reviewed.

Error-related Negativity (ERN): Definition and theoretical frameworks

The Error Related Negativity (ERN) is a component of event-related potentials (ERPs) that reaches maximum negative amplitude in frontocentral regions about 100ms after an error has occurred in simple reaction time tasks. This measure demonstrates the moment when the brain realizes that an error was committed. It is detected by the midcingulate cortex (MCC) and allows the adaptation of the individual to continue the task. With converging evidence coming from fMRI, EGG source modeling, and brain lesion research (Hajcak, 2012a; Hajcak et al., 2012; Moser et al., 2013), it has been identified as a valuable and reliable measure of partial or total detection of errors in healthy participants and individuals with various mental disorders (Zambrano-Vazquez & Allen, 2014).

Several studies have shown that simple cognitive tasks with the most experimental reaction time/inhibitory control paradigms evoke the ERN (Riesel et al., 2013). Although the other paradigms are adequate, the Flanker task has effectively elicited the ERN component. The study conducted by Riesel and colleagues (2013) evaluated the ERN potential in a group of participants through three experimental tasks of different reaction times, all recognized in the literature for assessing inhibitory control, namely: Flanker task, Stroop task, and a Go/No-Go task. The study's objective was to evaluate the most appropriate task to measure the ERN, considering that different tasks can promote different results on error processing. The results pointed to the Flanker task as the most valid due to its moderate difficulty level (Riesel et al., 2013).

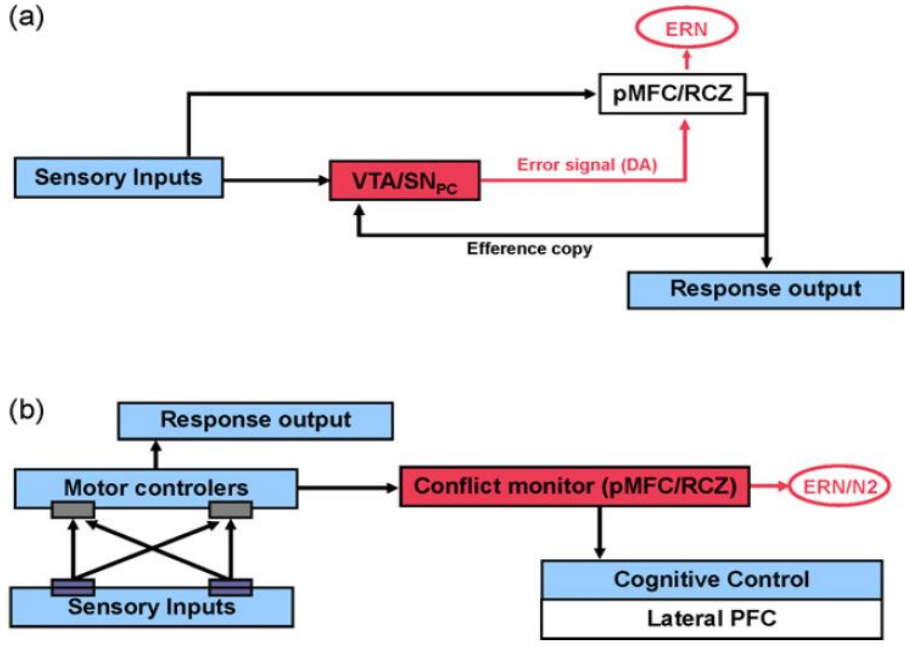
Moreover, there is currently some discussion within the field about what the ERN reflects. Some researchers claim that the ERN is generated during error responses in reaction time tasks, but it is a specific measure of detecting errors (Coles et al., 2001). Others suggest that the conflict monitoring system originates it, not specific to errors (Botvinick et al., 2001; Burle et al., 2008).

All these cognitive theories of ERN have been implemented in computational models of conflict or error processing in task performance (Yeung et al., 2004).

Still, how does the cognitive system detect and represent errors? How do performance monitoring and error processing emerge in the brain? Proponents of the most influential theories of error processing, as the reinforcement learning hypothesis (see Figure 3a) and the conflict monitoring theory (see Figure 3b), have debated the origin of the error signal (reflected in the ERN), the response representations, and how the underlying neural mechanisms works (Jocham & Ullsperger, 2009). Most of the authors in the field used the terminology "ACC" in their original papers for referring to different areas (i.e., dACC, rACC) implicated in conflict and error processing. However, in this dissertation, it is followed the nomenclature subdivision proposed by Vogt (2016) while reviewing the theoretical frameworks of the ERN.

Figure 3.

Illustration of the reinforcement learning theory



Note. (a) and the conflict monitoring theory (b) of performance monitoring and the generation of the error-related negativity (ERN). Common to both theories is that the ERN is assumed to be generated in the pMFC. Sensorimotor or cognitive processes are represented by blue boxes, neuroanatomical structures by empty (white) boxes. The brain area

where conflict or error is thought to be detected is indicated by a red box. Abbreviations: ACC, anterior cingulate cortex; DA, dopamine; ERN, error-related negativity; PFC, prefrontal cortex; pMFC, posterior medial frontal cortex; SNPC, substantia nigra pars compacta; VTA, ventral tegmental area. Reprinted from Jocham, M. Ullsperger (2009) Neuropharmacology of performance monitoring. Neuroscience and Biobehavioral Reviews 33: 48-60. Copyright (2021), with permission from Elsevier.

The reinforcement learning theory (Holroyd et al., 2005; Holroyd & Coles, 2002) suggests that errors are coded at the dopamine neurons from the BG (at the VTA) and alert the daMCC that outcomes of responses are worse than expected. The ERN is conceptualized as a reinforcement learning signal that trains the daMCC and the motor system. The role of the daMCC is to use the signal to adapt the response selection process for future better outcomes, acting as a control motor filter (Holroyd & Coles, 2002). In contrast, the conflict monitoring theory (Botvinick et al., 2001; Yeung et al., 2004) suggests that when a task requires selection among a set of responses, conflict emerges when overlapping pre-activated (task representations) response sets exist. Thus, the daMCC reflects a signal of response conflict between correct and incorrect response processes. The response conflict signal (ERN) informs the Prefrontal Cortex of the need to increase cognitive control.

Another neurocognitive model of the ERN is proposed by Alexander & Brown (2011), called Prediction of Response-Outcome (PRO). According to them, the Prefrontal Cortex predicts the probability of several possible outcomes of an action. It also compares the current versus expected results, generating signals when a discrepancy occurs (Alexander & Brown, 2010). The PRO model focuses on the role of the daMCC response–outcome based on models of reinforcement learning and their findings, where the planned responses activate learned response–outcome predictions. These predicted outcome signals can provide feedback to planned action. Once an action is generated, the actual outcome is compared to the expected result, and any discrepancy leads to an update of the learned response–outcome predictions (Alexander & Brown, 2010). The PRO model aims to explain various processes that include a more significant predicted activity for

error, conflict, error likelihood, and unexpected outcomes in general. In addition, the theory explains unexpectedly positive and negative results, which are especially important to the organism to direct its behavior.

However, other exciting models suggest that the ERN reflects the motivational meaning or the motivational salience and aversiveness of errors (Hajcak et al., 2005; Hajcak & Foti, 2008; Weinberg, Klein, et al., 2012). This perspective is consistent with findings linking errors and the ERN to autonomic arousal (Hajcak et al., 2003a, 2004a) and results that observed increased ERN amplitudes in participants who are more sensitive to negative affect (Olvet & Hajcak, 2012; Proudfit et al., 2013; Weinberg, Klein, et al., 2012, 2012). Furthermore, integration between cognitive and affective theories of the functional significance of the ERN states that conflict is part of affective and motivational processing (Hajcak et al., 2005; Inzlicht et al., 2015), and when the monitoring processes evaluate error commissioning, those processes generate a signal, the ERN. Thus, the ERN would indicate the activation of the monitoring system that is sensitive to the motivational significance and value of errors (Hajcak et al., 2005). In that sense, an affective conceptualization of ERN is possible because it could not be dissociable from the affective or motivational influences (Hobson et al., 2014; Inzlicht & Al-Khindi, 2012a; Larson et al., 2011).

Obsessive-Compulsive Disorder: Definition and Neurobiology

Obsessive-Compulsive Disorder (OCD) is a prevalent and disabling disorder (Goodman et al., 2021; Ting & Feng, 2011). It is characterized by distinctive signs and symptoms from which it takes its name: obsessions and compulsions. Obsessions are unwanted and persistent thoughts that repeat continuously; compulsions involve ritualistic repetition and stereotyped behaviors or mental acts (American Psychiatric Association, 2013). A typical feature of these obsessions and compulsions is the awareness of the symptomatology yet a difficulty to control it (Pereira de Souza,

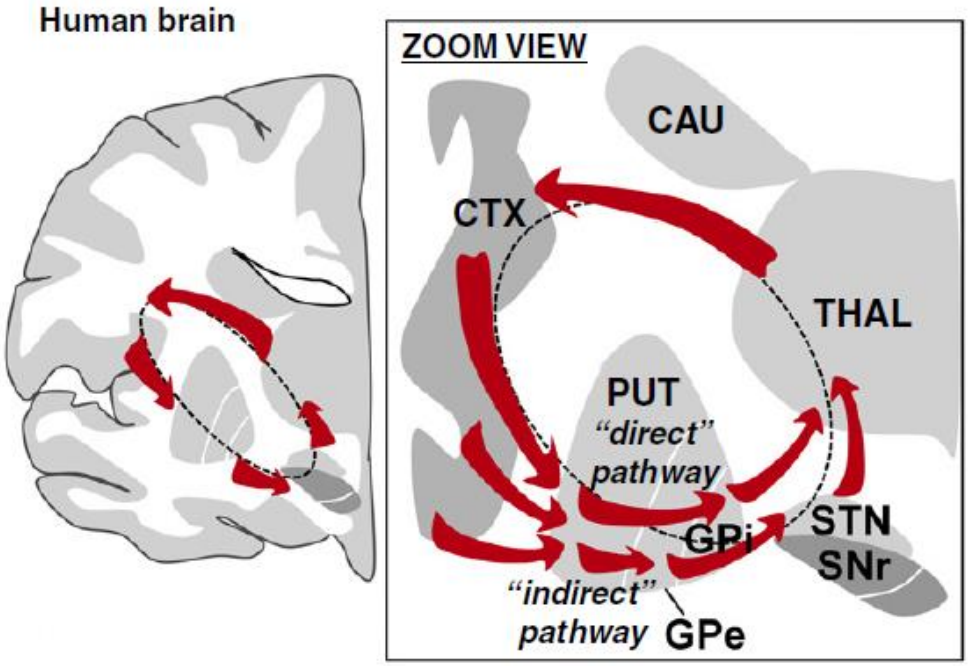
2021), usually accompanied by high levels of anxiety; thus, OCD could be express as a cognitive-affective disorder or an executive-behavioral disorder (Graybiel & Rauch, 2000).

Although the specific etiology and neurobiology of OCD are not yet fully elucidated, multiple lines of evidence support the connection between dysfunctional corticostriatal-thalamocortical (CSTC) circuitry and OCD pathogenesis (Burguière et al., 2015; Pena-Garijo et al., 2010; Ting & Feng, 2011). Several theories have emerged from structural and functional neuroimaging studies in humans and animal models to explain this connection (Ahmari et al., 2013; Pena-Garijo et al., 2010). Based on these studies, knowledge of the anatomical projections reaching the caudate nucleus from the OFC and aMCC is well established (Ahmari & Dougherty, 2015; Manning & Ahmari, 2018; Szechtman et al., 2017). In a regulated circuit function, the caudate nucleus sends inhibitory fibers to the globus pallidus, which is assumed to be a way out of the information processed in the BG. Finally, this fundamentally inhibitory information that leaves the globus pallidus and reaches the thalamus is projected back into the cortex, thus closing the circuit (Burguière et al., 2015; Pena-Garijo et al., 2010).

It is thought that an imbalance of the activity of the direct and indirect BG pathways (see Figure 4) could lead to general disinhibition and therefore causes the abnormal patterns of activation in CSTC loops that underlies the manifestation of OCD symptoms (Burguière et al., 2015; Ting & Feng, 2011). On the other hand, another method used in understanding the neurobiology of OCD is studies examining neural correlates with ERPs. In addition, EEG studies using cognitive activation paradigms have shown hyperactivity of the aMCC in OCD patients during tasks involving error/conflict monitoring (Endrass & Ullsperger, 2014; Riesel et al., 2014, 2017), suggesting possible impairments in aMCC function and other connected regions. However, the precise role of the aMCC in OCD symptomology is still unclear.

Figure 4.

Central role of the CSTC circuitry in obsessive-compulsive disorder in humans



Note. Diagram of a human brain section (coronal) illustrating a simplified CSTC loop. Right panel, zoom view of the CSTC loop illustrating the intermingled but functionally distinct 'direct' and 'indirect' projection pathways of the basal ganglia that are thought to exert opposing control over selection of motor behaviors. Reprinted from Ting & Feng (2011) Neurobiology of obsessive-compulsive disorder: insights into neural circuitry dysfunction through mouse genetics. Current opinion in Neurobiology 21(6): 842–848. Copyright (2021), with permission from Elsevier.

Dysfunctions in attention, flexibility and working memory also have been identified in OCD symptomatology (Martínez-Esparza et al., 2021; Nakao et al., 2014). Therefore, one of the most significant challenges for neuroanatomical and electrophysiological studies is to unveil which of these impaired executive functions are rooted within the neural circuits. Moreover, it is relevant to characterize transdiagnostic biomarkers or endophenotypes of OCD and related disorders.

Error-related negativity and evaluation of threat in OCD symptomatology

Over the past few decades, electrophysiological data have provided evidence about the underlying mechanisms of OCD. Since Pitman (1987) suggested that OCD symptoms originate from hyperactive error signals, EEG research has extensively explored one of the central neural

brain activities associated with error detection: error-related negativity (ERN). In addition, some studies suggest that the ERN is sensitive to traits due to the strong evidence for the association between this error signal and several mental disorders (Moser et al., 2013; Olvet & Hajcak, 2009).

Based on these findings, it has been hypothesized that the ERN is an evaluative signal influenced by contextual and individual factors, making it sensitive to affective and motivational variables (Hajcak et al., 2004a; Weinberg et al., 2016). In this perspective, errors are evaluated as threatening and mobilize defensive systems and cognitive processing in the organism (Hajcak & Foti, 2008; Weinberg, Riesel, et al., 2012b). Moreover, errors are conceptualized as an endogenous threat that is experienced as aversive events, so the degree of sensitivity to errors becomes relevant because variations in the ERN magnitude would be related to stable individual traits and high sensitivity to threat, error commissioning, and negative affect (Hajcak, 2012a; Weinberg et al., 2016).

Evidence from studies with individuals with high trait levels of anxiety, perfectionism, and high negative affect (Olvet & Hajcak, 2012; Proudfit et al., 2013; Weinberg, Klein, et al., 2012) supports this view. Likewise, error-specific processing and general monitoring are overactive during cognitive tasks in OCD (Klawohn et al., 2014; Riesel et al., 2017), and increased ERN amplitudes are recurrently found in the literature with OCD patients (Perera et al., 2019). Furthermore, ERN amplitudes appear to remain enhanced regardless of symptom manifestation or intensity (Riesel et al., 2014). They are also found in unaffected relatives of OCD patients (Riesel et al., 2019), which has led to considering the ERN as a potential candidate endophenotype suggesting vulnerability for this disorder (Riesel, 2019b; Riesel et al., 2019).

However, it is essential to note that increased ERN amplitudes are not restricted to OCD but are also observed in different (not all) anxiety disorders (Weinberg, Riesel, et al., 2012a). Multiples studies in children (Meyer, 2017; Meyer et al., 2015), adolescents (Carrasco et al., 2013;

Hanna et al., 2018), and adults (Klawohn et al., 2014; Weinberg et al., 2015a) that exhibit clinical features of the abovementioned disorders found hyperactive neural error signals. Accordingly, increased neural error signals could represent a transdiagnostic marker indicating shared vulnerability for OCD and some anxiety disorders (Meyer, 2017; Riesel, 2019b).

Although the hypothesis of a vulnerability endophenotype has growing and substantial evidence, a recent investigation (Seow et al., 2020) conducted with a larger sample (n=196) found no association between the ERN magnitude and the three transdiagnostic dimensions studied: anxious-depression, compulsive behavior, and intrusive thought, and social withdrawn). Nonetheless, individuals with higher scores for OCD symptomatology had larger ERNs. The authors attributed their results to their manipulations of the task parameters, the possible dependency on the symptom severity, and the likelihood that the association between the ERN and psychopathology could be smaller than it has been assumed to date (Seow et al., 2020).

The specific ERN enhancement in obsessive-compulsive symptomatology and the underlying pathophysiology of OCD requires further investigation. Novel studies might help extend the understanding of the disease (Perera et al., 2019) and the validity and replicability of the hypothesis surrounding the ERN (Seow et al., 2020).

Increased intolerance to uncertainty in individuals with OCD symptomatology

Uncertainty is a concept that we as humans experiment phenomenologically in our everyday routine. Unknown information or varying degrees of uncertainty about the future is part of the living and is unescapable; for instance, consider whether or the course of an illness. Uncertainty is characterized by three components: 1. Feeling that the situation cannot be controlled, 2. Feeling and worrying about possible negative consequences in the future, and 3. Perceiving the situation as a threat (Güney, 2021). Lack of predictability about any situation can cause worry or

even fear, and human beings try to minimize it; however, not everyone copes with it in the same way. Uncertainty increases threat sensibility, and individuals with a high intolerance to it tend to experience it as particularly aversive (Gentes & Ruscio, 2011).

Intolerance to Uncertainty (IU) is a construct that has been revised several times through the years (Carleton et al., 2012; Shihata et al., 2016). Still, it can be defined as the person's tendency to consider as unacceptable and threatening the occurrence of an adverse event, regardless of its probability of occurrence (Carleton et al., 2007). Likewise, one of the distinctive aspects of IU is the focus on future events, where situations or stimuli are viewed as threatening because of their possible negative consequences (Carleton et al., 2012). In this sense, IU could profoundly affect perceptions and desires for predictability and controllability, where efforts to increase certainty and control of context are expected (Carleton, 2016).

The experience of uncertainty as vastly distressing or aversive leads to several symptom expressions. Those include anxiety, frustration, and certainty-seeking behaviors. Thus, individuals with high IU tend to present maladaptive cognitive, emotional, and behavioral responses (Carleton, 2016; Fourtounas & Thomas, 2016). Previous research suggested that IU is associated with worry (Boswell et al., 2013; White et al., 2018), OC like symptoms in non-clinical samples (Dugas et al., 2001), generalized anxiety disorder (GAD) (Boswell et al., 2013; McEvoy & Mahoney, 2012), and OCD (Pinciotti et al., 2021). However, Prospective IU had been consistently associated with GAD and OCD. Individuals with that symptomatology tend to have a particular anticipatory fear of future uncertainty. In turn, that would hinder their ability to tolerate unpredictability (Holaway et al., 2006; Tolin et al., 2003; Wheaton & Ward, 2020).

The role of intolerance of uncertainty as a transdiagnostic factor is of great importance in the etiology and maintenance of OCD symptoms. It has proven to be related to OCD doubting and checking (Fourtounas & Thomas, 2016; Holaway et al., 2006), where doubting seems to give rise

to IU, while checking may function as an effort to reduce the distress associated with that uncertainty (Holaway et al., 2006). A recent meta-analysis (Strauss et al., 2020) of perceptual vs. decision-making task studies in threatening and neutral conditions found that checking behaviors were associated with distrust of sensory modalities and interference with automatic processes. However, the overall effects of checking were similar in neutral and threatening conditions, showing that excessive checking may be a risk factor for pathological checking since people with OCD may interpret neutral stimuli as anxiogenic (Strauss et al., 2020).

Knowing that OCD individuals find uncertain situations inherently threatening raises questions on the influence of unpredictable threats on sensitivity to error commissioning because making mistakes is deeply aversive to them. It has been postulated that errors are unpredictable events (Jackson et al., 2016) that represent a type of threat (Jackson et al., 2015) and could place an individual in jeopardy (Hajcak, 2012; Proudfit et al., 2013). Evidence supports the hypothesis that uncertainty is associated with sensitivity to threat (Shihata et al., 2016) and an unpredictable threatening stimulus (Nelson et al., 2016). Moreover, unpredictable contexts may increase the value of errors and potentiate error processing (Jackson et al., 2015).

Nevertheless, most of the research on neural correlates of IU has been with non-clinical samples, so the mechanisms involved in the maintenance of pathological symptoms and the precise influence of uncertainty and IU on error processing and cognitive control impairments remain unclear. However, as literature has indicated, it is expected that individuals with OCD present an enhanced neural error brain activity and high intolerance of uncertainty measures (Agam et al., 2014; McEvoy & Mahoney, 2012; Pinciotti et al., 2021; Weinberg et al., 2015).

Even though the importance of uncertainty in OCD conceptualization and prediction of symptomatology has been evidenced in research, numerous issues remain unresolved. Further inquiry is needed regarding its nature and the possibility of determining if experimental

manipulations of uncertainty would impact underlying features of OCD symptoms (Pinciotti et al., 2021) and neural error processing (White et al., 2018).

Objectives

Due to mixed results on the effect of affect state manipulations and understanding that errors are inherently aversive, especially for people with high sensitivity to threat, the following objectives are proposed to this research:

1. To contribute to a synthesis of studies' results that tested the role of state affect in cognitive control and the ERN generation.
2. To establish the incidence of the ERN and ΔERN components of error responses at a gambling-type task that manipulates uncertainty (the HiLo game) in a sample composed of people with high OCD symptomatology.

General view of the dissertation

This dissertation consists of two studies. Study 1 is a systematic review that aims to review the empirical studies from the 2010-2020 decade that examined the error-related negativity (ERN) associated with those states' affect manipulations as opposed to a trait measurement. The qualitative review pretends to investigate whether those studies' results conclude that the ERN is sensitive to state affect manipulations.

Study 2 is an exploratory study investigating the differences and similarities of the error-related brain activity in two different experimental tasks (Flanker task and HiLo game) in a sample with high OCD symptomatology.

The studies that compel the dissertation are presented below.

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CHAPTER II: AVERSIVENESS OF ERRORS AND THE ERROR-RELATED NEGATIVITY (ERN): A SYSTEMATIC REVIEW ON THE AFFECTIVE STATES' MANIPULATIONS

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Abstract

Error-related negativity (ERN) has been used to investigate neural mechanisms underlying error processing and conflict monitoring. Recent evidence highlights that the ERN is modulated by negative affect and that aversiveness of errors plays a vital role in error monitoring. Therefore, our primary objective was to systematically evaluate and describe papers that found Aversiveness and ERN relationships (Databases). A total of thirty-nine publications identified from PsyInfo,

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Pubmed, and PsyArticles databases were included following the Prisma procedures for systematic reviews. Papers were analyzed in terms of sample attributes, psychological paradigms, and states manipulations. Overall results suggest that the ERN component has recurrently shown to be sensitive to manipulations of affective states in the reviewed literature. Although the physiological measures are convergent, inconsistent definitions of *mood, emotion, and affect* across current studies might have hindered conclusive psychophysiological inference. Common taxonomies at the operational and theoretical levels are needed for the soundness of future research on the error-aversiveness link.

Keywords: Error-related negativity, ERN, aversiveness, affect, negative affect.

Introduction

Emotional and motivational role of errors in conflict and error monitoring

Cognitive control is the mental process that allows adaptive goal-directed behavior, and its principal function is to contain or inhibit prevalent responses to maintain focus on current goals (Inzlicht & Al-Khindi, 2012a; Koechlin et al., 2003; Miller & Cohen, 2001). Convergent evidence from cognitive neuroscience points out that mental conflict generates control efforts (Inzlicht et al., 2015; Schiffer et al., 2015). Conflict monitoring theory suggests that the monitoring system is vital in analyzing the actual representations of action tendencies for potential conflicts. Thus, inhibitory mechanisms may be engaged to override the unwanted bias and promote active goal pursuit (Botvinick, 2007; Shenhav et al., 2016; Yeung, 2014).

Knowing that cognitive control begins with the appearance of conflict, it is also relevant to point out that conflict is not affectively neutral. Conflict represents an aversive event for the organism and includes negative affective states and emotional costs (Dreisbach & Fischer, 2012). Consistent with this view, Inzlicht et al. (2015) suggested that negative affect is an integral,

instantiating aspect of cognitive control. Therefore, it states that cognitive control depends on emotion or its properties, such as arousal and valence.

Akin to conflict monitoring, error monitoring detects and signals an error to optimize behaviors across various tasks and situations. Error detection is a necessary process for adaptive behavioral adjustments (Moser et al., 2013). An organism can use it to inform behavioral strategies to achieve higher accuracy or preserve the executed task speed (Ridderinkhof et al., 2004; Zhou et al., 2019). For instance, error monitoring is correlated with the number of response alternatives in experimental tasks (Maier et al., 2010) and the difficulty of the chosen task. More complicated tasks provoke more errors (Riesel et al., 2013), and increasing the number of alternative responses in such tasks decreases the response monitoring mechanisms (Riesel et al., 2013). That is due to the cognitive overload on the different strategies, neural structures (Prefrontal Cortex, Motor Cortex, Basal Ganglia), and functions (hold and manipulate information) that are involved in error commissioning (Hoffmann & Beste, 2015).

As in conflict, the detection of committed errors is regularly accompanied by some negative emotional response (Hajcak et al., 2004b; Spunt et al., 2012). Errors are unexpected and aversive endogenous events threatening the organism (Hajcak et al., 2012) and engage cognitive control to correct behavior and avoid more error commissioning. This threatening nature of errors suggests motivational salience and aversive properties (Jackson et al., 2015a; Weinberg, Riesel, et al., 2012a). Therefore, error commissioning could not be dissociated from negative affect states and the experience of aversiveness (Shackman et al., 2011b). This perspective is consistent with findings linking errors to psychophysiological changes as Heart Rate Variability (Mackersie & Calderon-Moultrie, 2016), Skin Conductance (Hajcak et al., 2003b), and Electromyographic Activity (Dignath et al., 2019; Elkins-Brown et al., 2018; Hajcak & Foti, 2008).

Theoretical Frameworks of ERN

The Error Related Negativity (ERN) is a component of event-related potentials (ERPs) that reaches maximum negative amplitude in frontocentral regions about 100ms after an error has occurred in simple tasks of reaction time (Falkenstein et al., 1991; Gehring et al., 1993; Nieuwenhuis et al., 2001). The component marks the moment the brain indicates a motor error was committed, thus allowing the individual to adapt their responses and continue the task. Converging evidence from fMRI, EEG source modeling, and brain lesion research points to the dorsal portion of the anterior cingulate cortex as its site (Hajcak et al., 2012; Moser et al., 2013). The ERN has been identified as a valuable and reliable measure of partial or total detection of errors in healthy participants and individuals with various mental disorders (Riesel et al., 2019; Zambrano-Vazquez & Allen, 2014).

Several cognitive and computational perspectives have attempted to explain the processing of errors and their neural signal, the ERN. According to mismatch theory, the error signal reflects a process that compares the neural representations of goal and actual responses (Bernstein et al., 1995; Coles et al., 2001; Falkenstein et al., 1991). From this perspective, the more significant the mismatch, the larger the ERN amplitude (Bernstein et al., 1995; Falkenstein et al., 1995). The reinforcement learning hypothesis (RFL; Holroyd et al., 2005; Holroyd & Coles, 2002) suggests that errors are coded at the dopamine neurons from the basal ganglia (at the Ventral Tegmental Area) and alert the daMCC that outcomes of responses are worse than expected. The ERN is thus conceptualized as a reinforcement learning signal that trains the daMCC and the motor system. The role of the daMCC is to use the signal to adapt the response selection process for future better outcomes, acting as a control motor filter (Holroyd & Coles, 2002).

Another computational model, the conflict monitoring theory (Botvinick et al., 2001; Yeung et al., 2004), focuses on *conflict* detection rather than error detection, the ERN signals conflict. When a task requires selection among a set of responses, conflict emerges when overlapping pre-activated (task representations) response sets exist. The daMCC reflects a signal of response conflict between correct and incorrect response processes. The response conflict signal (ERN) informs the Prefrontal Cortex of the need to increase cognitive control.

An additional, prominent model within the cognitive conceptualization of error processing is the predicted response- outcome model (PRO; Alexander & Brown, 2010). The PRO is a probabilistic model and focuses on the role of the Anterior Cingulate Cortex response–outcome based on models of reinforcement learning and their findings. The PRO model aims to explain various processes that include a more significant predicted activity for error, conflict, and error likelihood, and unexpected outcomes in general (positive and negative results). Once an action is generated, the actual outcome is compared to the expected result, and any discrepancy leads to an update of the learned response–outcome predictions (Alexander & Brown, 2010).

Nonetheless, other exciting models suggest that the ERN reflects the motivational meaning or the motivational salience and aversiveness of errors (Hajcak, 2012b; Hajcak & Foti, 2008; Jackson et al., 2015b; Weinberg, Riesel, et al., 2012a). The following section will account for its implications in recent literature regarding early error-detection processes.

The ERN and the aversiveness of the stimuli

An integration between cognitive and affective theories of the functional significance of the ERN states that conflict is part of affective and motivational processing (Inzlicht et al., 2015). When the monitoring processes evaluate error commissioning, those processes generate a signal, the ERN. Thus, the ERN would indicate the activation of the monitoring system that is sensitive to

the motivational significance and value of errors (Hajcak et al., 2005). Consequently, an affective conceptualization of the ERN is possible because it could not be entirely dissociable from the affective or motivational influences (Hobson et al., 2014; Inzlicht & Al-Khindi, 2012a; Jackson et al., 2015a).

Within this framework, the commission of errors is a distressing experience; it is perceived as threatening (Spunt et al., 2012) and engages a defensive motivational response (Hajcak, 2012b; Weinberg et al., 2016). The ERN could be sensitive to affective and motivational influences (Larson et al., 2011; Unger, Heintz, et al., 2012), and these influences may be a critical point in the path of understanding within and between subjects' variations of the ERN (Proudfit et al., 2013; Weinberg, Klein, et al., 2012). Two lines of research have emerged to unveil the relationships between affect and error-related negativity: manipulations with state affect and measurement of levels of trait affect. If the ERN is sensitive to state affect manipulations, its amplitudes will reflect responses to emotional context (Inzlicht & Al-Khindi, 2012; Tullett et al., 2015; Wiswede et al., 2009a), while measures of more stable levels of trait affect would determine the ERN generation (Hajcak, 2012b; Riesel et al., 2019; Weinberg & Hajcak, 2011).

Moreover, the ERN is extensively reported in the literature as stable and related to trait vulnerability. Trait affective measures of personality like perfectionism, neuroticism, and high anxiety sensitivity are significantly associated with increased error detection processes (Olvet & Hajcak, 2012; Weinberg, Riesel, et al., 2012). The considerable evidence of the state-independent characteristics of the ERN has even pointed it out to be considered as a reliable psychiatric endophenotype (G. A. Miller & Rockstroh, 2013; Weinberg, Riesel, et al., 2012; Weinberg & Hajcak, 2011; de Souza et al., 2018).

However, the connection between the ERN and affective state inductions has mixed and inconclusive data. There is growing evidence that stimuli with emotional significance can modulate

the ERN (Dreisbach & Fischer, 2012; Senderecka, 2018). Studies with experimental manipulations such as evaluation of performance (Masaki et al., 2017), disapproval in a social context (Boksem et al., 2011), the unpredictability of the stimuli (Jackson et al., 2015a), and the administration of reward and punishment (Stürmer et al., 2011) have shown that experimental manipulations of negative affect states impact the ERN indicating an increasing threat value of errors (Aarts et al., 2013a). In contrast, other authors have found an unaltered ERN by inducing negative affect states (Elkins-Brown et al., 2018; Larson et al., 2013; Olvet & Hajcak, 2012).

Insight into the role of affect in cognitive conflict and the ERN generation is critical to address theoretical questions and to define the nature of error processing. To contribute to a synthesis of the results in this area, in this paper, we reviewed the empirical studies from the 2010-2020 decade that examined the error-related negativity (ERN) changes associated with those states affect's manipulations instead of a trait measurement. We present a qualitative review of the experimental designs and investigate whether studies' results support the hypothesis that the ERN is sensitive to state affect manipulations.

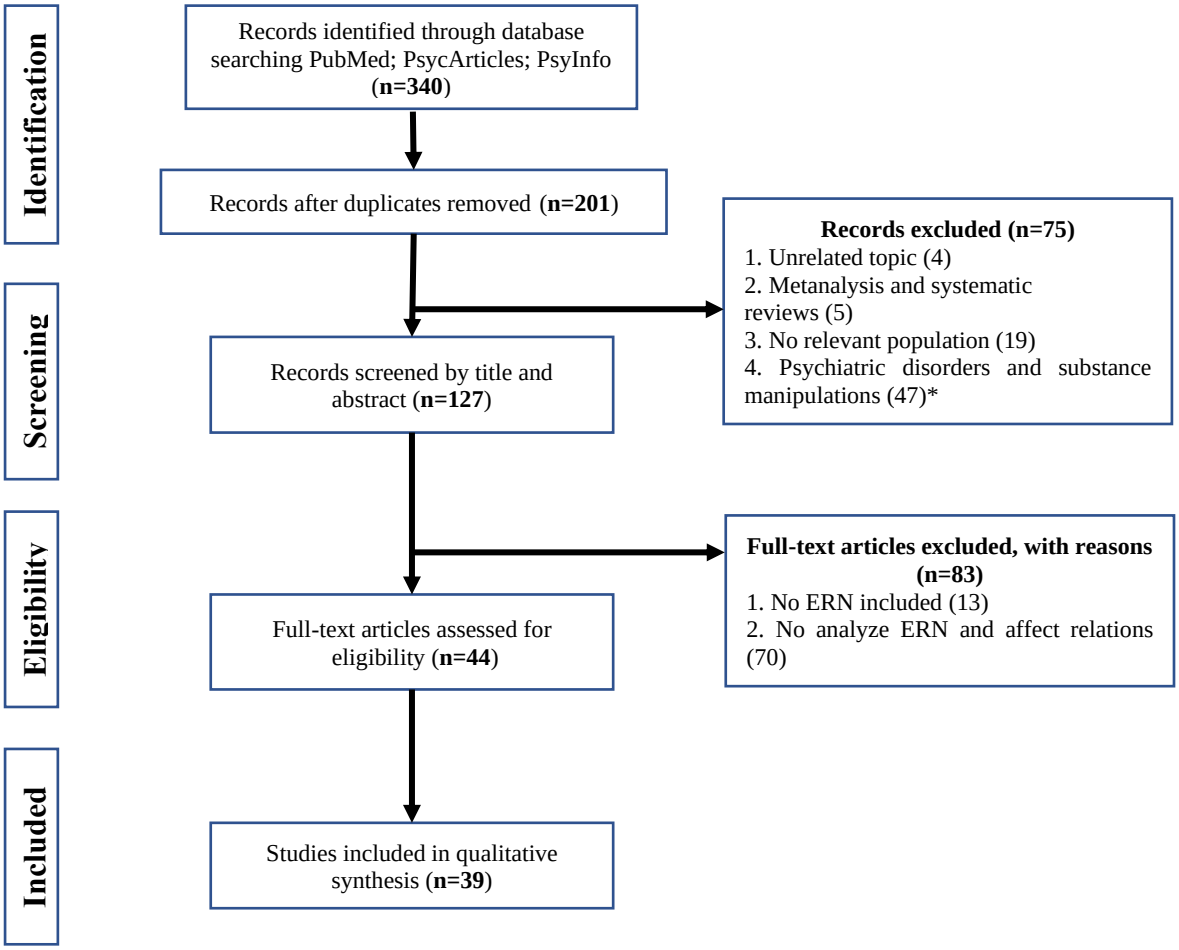
Method

This systematic review was done following the *Prisma guidelines* (Page et al., 2021). We conducted an automated search of papers published from January 2010 to November 2020, using PubMed, PsycINFO, and PsyArticles databases. The search string "ERN" OR "Error related negativity" AND "aversiveness" OR "negative affect" was entered in the standard search field in all the databases. Also, for these searches of electronic databases, manual searches were performed using the reference sections of published texts to find eligible articles. Only papers written in the English language were analyzed. After removing duplicates, exclusion criteria were applied

through seeking titles and abstracts. Figure 5 describes the four phases of this review (*identifying*, *screening*, *eligibility*, and *inclusion*).

Figure 5.

Flowchart depicting article selection. Some articles met more than one exclusion criteria



Note. * 2 articles with alcohol manipulations were included due to relevant interactions with ERN and negative affect.

The following exclusion criteria were adopted: (a) theoretical and review papers, (b) studies with clinical population and substance manipulations, (c) studies with children and adolescents, and (d) studies without EEG techniques. Articles were initially selected according to their abstracts to identify the studies that virtually met the aims. Two independent judges performed the search, selection of papers, and application of the exclusion criteria. The two judges discussed again when discordances were observed until all three agreed. In case of discordances, a third judge was

consulted. An analysis table was constructed, with categories created a priori for the organization of the results. The two judges filled out the table. After removing studies that met exclusion criteria, the remaining papers were fully read to identify the studies' tasks and the results. The experimental tasks were analyzed according to the subjects and type of task.

Results

After performing searches of the databases and removing duplicates, 201 articles were obtained. Figure 5 shows the electronic search steps that led to 39 articles being included in the systematic review. The exclusions based on the title and abstract (n=127) were usually studies with the clinical population; articles that did not use ERN; studies with fMRI; studies that did not analyze ERN and negative affect, and theoretical articles or systematic reviews. The main results are presented below, according to the sample's characteristics, paradigms and designs, behavioral effects, variables, and EEG effects. A description of tasks employed in the selected studies can be found in Table 2. A summary of the key findings is displayed in Table 3.

Table 2.

Description of paradigms and designs in studies included for review

Paradigm	n	Description	Design			Feedback	
			# of studies Within Subjects	# of studies Between Subjects	# of studies Within & Between	Yes	No
Flanker	12	Participants must discern a target stimulus aspect (e.g., form, direction) from within an array of congruent or incongruent “flanker” stimuli.	4	5	3	4	8
Go/No Go	10	Participants must respond or withhold the response, depending on whether respectively a “go” stimulus or a “no-go” stimulus is presented.	2	5	3	3	7

Stroop	4	Participants must discern the color of each stimulus, which might be congruent or incongruent with its linguistic content.	1	2	1	1	3
Probabilistic Learning Task	2	Participants learn to select between abstract stimuli associated with different probabilities of receiving a reward (80/20, 70/30, and 60/40), to prefer the one with the higher probability outcome.		1	1	2	
Simon Task	3	Participants must respond to visual stimuli by making a rightward response to one stimulus and a leftward response to another. Stimuli presentation alternates between laterally congruent and incongruent.	2	1		3	
Weapons Identification Task	2	Participants must indicate having seen a target, backward masked stimulus, as either a gun or a tool, after those stimuli having been primed by either black or white faces.		1	1	1	1
Two-choice Speeded Task	1	A modification of the go/no-go task requiring responses to a low-probability stimulus.	1			1	
Emotional Stop Signal Task	1	Modification of the Stop Signal Task with affective loaded and/or neutral stimuli.	1				1
Punished Inhibitory Control Task	1	A two-alternative forced-choice task with frequent and infrequent stimuli; errors are punished with an aversive stimulus.		1		1	
MSIT (multi-source interference task)	1	Interference task combining Stroop, Flanker, and Simon paradigms. Participants respond by identifying the position of a number (target) that is different from the other two in an array of three numbers of which two are identical.		1			1
Combination of flanker and Simon task	1	A Flanker (letter) task with neutral and angry faces presented after trial responses.		1		1	
AX-CPT task	1	Participants must respond to the letter X only when it is preceded by the letter A. The target´s probability is manipulated.		1			1

Note. n=number of studies employing the task.

Table 3.

Summary of studies included in the systematic review sorted by affect state manipulation

Author	Sample characteristics	Major behavioral effects/outcomes	ERN peak/mean amplitude (location and time window)	ERN major findings
		MOOD		
(Bakic et al., 2014)	*n*=32 (25 F), *M*=22.3, *S.D.*=2.4 years. Positive mood *n*=16 Neutral mood *n*=16	»RTs for deterministic and probabilistic condition. Higher Learning rate for positive feedback. Overall higher learning rates for positive mood.	Mean amplitude (FCz; 0-150 ms post-response).	↑ERN in positive mood for deterministic condition.
(Larson et al., 2013)	*n*=121 Anxious *n*=29 (16 F), *M*=20.0, *S.D.*=1.9. Calm *n*=35 (19 F) *M*=19.8, *S.D.*=1.7. Happy *n*=29 (13 F), *M*=20.3, *S.D.*=2.4. Sad *n*=28 (17 F), *M*=21.3, *S.D.*=5.9.	Congruency effect. PES.	Mean amplitude (6[FCz], 7, 106, and Ref [Cz]; 0-100 ms post-response).	No significant effects on ERN by mood induction. ERN not affected as function of arousal or valence.
(Nigbur & Ullsperger, 2020)	*n*=40 (26 F), *M*=23.2, *S.D.*=3.6, range=18 -33.	Congruency effect and PES.	Mean amplitude (FCz: 0-100 ms post-response).	↑ERN after positive mood induction.
(Olvet & Hajcak, 2012)	*n*=45 (20 F). Neutral *n*=22 (11 F), *M*=18.4, *S.D.*=1.0. Sad *n*=23 (9 F), *M*=18.7, *S.D.*=1.3.	»RTs on error trials.	Mean amplitude (FCz; 0-100 ms post-response).	No significant correlation ERN and mood inductions. MMR: high neuroticism scores, increase sadness and ↑Δ ERN.
(Paul et al., 2017)	*n*=50 Happy *n*=25 (14 F, 8M), *M*=21.8, *S.D.*=2.5. Neutral *n*=25 (15 F, 7 M), *M*=22.4, *S.D.*=2.3.	PES observed (not influenced by mood)	Mean amplitude (FCz; 10-60 ms post-response)	No significant effects of mood on ERN or interaction.

Author	Sample characteristics	Major behavioral effects/outcomes	ERN peak/mean amplitude (location and time window)	ERN major findings
		EMOTION REGULATION STRATEGIES		
(Cano Rodilla et al., 2016)	*n*=99 (50 M), *M*=25.1, *S.D.*=3.9, range 18–35 years. Misattribution *n*=48. Control *n*=51.	More commission errors. Faster No-go reactions.	Peak amplitude (Fz, FCz: 50 ms pre-response-150 ms post- response)	No significant Group main effect for the ERN.
(Elkins-Brown et al., 2018)	*n*=79 for multilevel models *n*=77 for all univariate models. (Misattribution and group control; State Anxiety Induction)	More commission than omission errors.	Mean amplitude (FCz; 15-115 ms post response)	No significant main effect of group for ERN and ΔERN, nor of condition.
(Good et al., 2015)	*n*=108 God's punishment *n*=34 (24 F), *M*=19.4, *S.D.*=1.6. Love/forgiveness *n*=40 (23 F), *M*=20.5, *S.D.*=2.2 Peace from worry *n*=34 (20 F), *M*=19.7, *S.D.*=1.8.	Less Acc in God's punishment group.	Mean amplitude (FCz; 0-100 ms post-response)	↓ERN for Loving God condition than in punishment.
(Hobson et al., 2014)	*n*=41 (29 F, 12 M), *M*=19, *S.D.*=1.64.	»RTs on error trials. Higher Acc for go trials. More commission than omission errors.	Mean amplitude (FCz; 0-100 ms post-response)	↓ERN in down-regulation reappraisal condition.
(Inzlicht & Al-Khindi, 2012b)	*n*=40 (22 F, 18 M), *M*=19.4, *S.D.*=5.2.	»RTs on error trials. More commission than omission errors.	Mean amplitude (FCz; 50ms preresponse-150ms post response)	↓ERN for Misattribution condition.
(Levsen & Bartholow, 2018)	Experiment 1 *n*=47 (20 F) *M*=19.	Black-prime trials: less Acc at identifying tools, more Acc at guns. Acc during Attend greater than during Reappraisal	Mean amplitude (F3, Fz, F4, FC3, FCz, FC4, C3, Cz, and C4; 30-110 ms post-response).	Emotion regulation strategy associated with ↑ERN and increased for response bias.

Author	Sample characteristics	Major behavioral effects/outcomes	ERN peak/mean amplitude (location and time window)	ERN major findings
		(both greater than during Suppression)		
	Experiment 2 *n*=64 (29 F), *M*=18.6.	Black-prime trials: less Acc at identifying tools, more Acc at guns.	Mean amplitude (F3, Fz, F4, FC3, FCz, FC4, C3, Cz, and C4; 30-110 ms post-response).	Emotion regulation strategies associated with ↑ERN for response bias.
(Saunders et al., 2016b)	*n*=41 (24M, 17 F), *M*=18.9, *S.D.*=2.84. Emotion-focused *n*=19, *M*=18.5, *S.D.*=1.1. Thought-focused *n*=22, *M*=19.3, *S.D.*=3.7.	»RTs on error trials. Less Acc on a no-go trial at postinduction. «RTs for emotion focused group. Thought-focused group less cautious (» and less Acc) after induction.	Mean amplitude (FCz; 0-120 ms post-response)	↑ΔERN for emotion-focused group.
(Teper & Inzlicht, 2013)	*n*=38 Meditators *n*=20 (11 F), *M*=33.0, *S.D.*=11.5 Non-meditators *n*=18 (16 F), *M*=37.4, *S.D.*=14.5	Meditators made fewer Stroop errors than controls, although trend was not robust.	Mean amplitude (FCz; 50 before response-150 ms post-response).	↑ERN on meditators and higher emotional acceptance.
(Wang et al., 2014)	*n*=47 Control *n*=15 (8 F), *M*=23.0. Suppression *n*=16 (8 F), *M*=22.5. Reappraisal *n*=16 (7 F), *M*=21.2.	Higher Acc and »responses on congruent trials. Suppression group more errors on incongruent trials.	Mean amplitude (FCz; 20 ms before response-500 ms post-response).	↓ERN and ↓Δ ERN for emotion suppression.
EMOTIONAL PROPERTIES OF STIMULI (VALENCE, AROUSAL, PRIMING)				
(Aarts et al., 2013b)	*n*=18 (16 F), *M*=21.4, *SEM*=0.4.	« RTs for FAs than RTs fast hits. »RTs for negative words following FAs. Less Acc to categorize words as positive following FAs.	Mean amplitude (FCz; 0-60 ms post response)	Significant correlation between Priming effect and Δ ERN. Significant correlation between ERN and the RT difference between negative and positive words (valence).

Author	Sample characteristics	Major behavioral effects/outcomes	ERN peak/mean amplitude (location and time window)	ERN major findings
		Higher Acc following fast hits.		
(Boksem et al., 2011)	*n*=54 (22 M), *M*=20.1, *S.D.*=1.5, range 18-23 years. Happy faces *n*=18 Disgusted faces *n*=17 Sad faces *n*=19	«RTs and larger number of errors on incongruent trials. PES.	Mean amplitude (FCz; 20 before the peak-20 ms after the peak).	↓ERN for disgusted faces group.
(Clayson & Larson, 2019)	*n*=66 Overlaid flanker *n*=32 (16 F, 16 M), *M*=21, *S.D.*=3, range 17-31 years. Interspersed flanker *n*=34 (21 F, 13 M), *M*=21, *S.D.*=6, range 17- 49 years.	Congruency effect. »RTs for interspersed task. «RTs for high arousing images on overlaid task.	Mean amplitude (6 [FCz], 129 [Cz], 7, 106; 0-100 ms post-response).	Overlaid: No significant effect for arousal; ↑ERN for valence. Interspersed: ↑ERN for arousal. No significant effect for valence.
(Leue et al., 2017)	*n*=54 (26 F), *M*=24.3, *S.D.*=2.9, range 19-31 years.	Less Acc in aversive feedback condition.	Mean amplitude (FCz; negative segment average of 50 ms within time window of -50 ms before stimulus onset - 150 ms after stimulus onset).	No main effect of worry inducing faces on ERN. ↑ERN for aversive feedback condition.
(Senderecka, 2018)	*n*=32 (25 F, 7 M).	Higher Stop performance in emotional trials. Better inhibition responses with emotional stop signals.	Mean amplitude (F3, F4, Fz, FC1, FC2, C3, C4, and Cz; 0-80 ms post-response).	No significant effect of neutral and negative arousal on the ERN.
(Sueyoshi et al., 2014)	*n*=20 (15 females), *M*=20.1, *S.D.*=2.1, range 18 - 28 years.	PES. »RTs for objects (Object condition easier than face conditions).	Mean amplitude (FCz; 0-200 ms post-response).	No main effect of condition on ERN, but ERN positively related to interoceptive sensitivity on disgusted face condition.

Author	Sample characteristics	Major behavioral effects/outcomes	ERN peak/mean amplitude (location and time window)	ERN major findings
(Suzuki et al., 2020)	*n*=97 (55 F) *M*=19.2.	»RTs on error trials in all tasks. «RTs on incongruent trials. Overall effect of PES. Higher Acc on congruent trials for Arrow and Social.	Mean amplitude (Fz, Cz; 10-100 ms post response)	↑ ΔERN in Unpleasant and Pleasant tasks. Arrow=Social < Pleasant=Unpleasant).
(Valt et al., 2017)	*n*=30 (20 F), *M*=25, range: 19–32 years.	No significant behavioral effects.	Mean amplitude (FCz, Fz, FC3, FC4; 0-100 ms post-response).	↓ERN on external signals (relationship between performance and face stimulus)
(van Wouwe et al., 2011b)	*n*=25 (12 F), *M*=24.8 years.	« RTs and less Acc on AY trials.	Mean amplitude (FCz, Fz, FC3, FC4; 0-100 ms post-response).	↓ERN for positive affect condition.
		PUNISHMENT AND REWARD		
(Clayson et al., 2012b)	*n*=69 (41 F, 28 M), *M*=20.9, *S.D.*=3.6, range 18-43 years.	Congruency effect.	Mean amplitude (6). (FCz), 7, 106 and Ref (Cz); 0-100 ms post-response).	No significant correlations Δ ERN and changes in negative affect by feedback.
(Elkins-Brown et al., 2016)	*n*=67 (45 F), *M*=19.1, *S.D.*=1.6.	«RTs and less Acc on high conflict trials.	Mean amplitude (FCz; 0-100 ms post-response).	No significant effect of punishment on the ERN, nor associations with cEMG.
(Maruo et al., 2016)	*n*=24 F, *M*=20.4, *SEM*=0.3.	Congruency effect. PES more pronounced in reward condition.	Mean amplitude (FCz; time window from EMG onset and 200ms following response onset.)	↑ERNs in reward and punishment conditions.
(Potts, 2011)	*n*=64 (47 F), *M*=20.3, *S.D.*=2.3, range 18–27 years.	«RTs to incongruent trials but only in correct responses. « on punishment motivated trials.	Not explicit. ERN extracted from 0–100 ms post-response at FCz.	↑ERN under punishment feedback. ERN differ between punishment and reward.

Author	Sample characteristics	Major behavioral effects/outcomes	ERN peak/mean amplitude (location and time window)	ERN major findings
(Saunders et al., 2015)	*n*=42 (33F), *M*=18.7, *S.D.*=1.2.	Less Acc and «RTs on high-conflict trials. Error rates decreased in punished condition. Frustration predicted careless actions (» and less Acc); anxiety predicted cautious (« and more Acc) responses.	Peak to peak amplitude (FCz: amplitude distance between the maximum negative peak following (0 to 120 ms) and the positive peak preceding (−80 to −20 ms).	↑ERN for punishment.
(Stürmer et al., 2011)	Experiment 2 *n*=22 (12 F), *M* = 24.6.	«RTs in post-error trials. PES larger in reward block.	Peak amplitude (FCz; 0-100 ms post-response).	↑ERN for the reward block.
(Unger, Kray, et al., 2012)	*Experiment 1* (*n*=35) Failure feedback *n*=17 (12 F), *M*=22.6. No-failure-feedback *n*=18 (13 F), *M*=21.7. *Experiment 2* (*n*=33) Failure feedback *n*=16 (11 F), *M*=21.0. No-failure-feedback *n*=17 (12 F), *M*=22.4.	«RTs from pre- to posttest. » erroneous responses in deterministic learning condition. » in post-error Acc from pre- to posttest in failure feedback group.	Mean amplitude (FCz; 0-150 ms post-response).	↑ERN of failure induction on the ERN for deterministic and probabilistic condition at posttest.
ALCOHOL INTAKE AND RESPIRATORY CONTROL				
(Bartholow et al., 2012)	*n*=34 women. *M*=25.6, range 21-35 years.	No different RT by beverage group. Alcohol group less Acc. Black prime trials: More Acc for guns and less for tools. Alcohol group more Acc for guns than tools.	Mean amplitude (FCz; 0-150 ms post-response).	↓ERN for alcohol group.

Author	Sample characteristics	Major behavioral effects/outcomes	ERN peak/mean amplitude (location and time window)	ERN major findings
(Cofresí & Bartholow, 2020)	*n*=74 (38 F) Non-alcohol *n*=21, *M*=23.5, *S.D.*=2.5. Placebo Alcohol *n*=25, *M*=22.2, *S.D.*=5.2. Alcohol *n*=28, *M*=23.08, *S.D.*=2.03.	Post Error Reduction. Interference in Acc, but not in RT, and did not differ by beverage group.	Mean amplitude (Fz, F3, F4, FCz, FC3, FC4, Cz, C3, C4; 25–75-ms post-response)	↓ERN for alcohol group. ERN and EMG correlated in control group.
(Jelinčić et al., 2020)	*n*=41 (32 F), *M*=21.4, *S.D.* (40)=4.50. Range for age unavailable.	No report.	Mean amplitude (FCz; 0-100 ms post-response)	Significant positive correlations between ERN and Respiratory-related Evoked Potentials (RREP), and Somatosensory Evoked Potentials (SEP).
(Tan et al., 2019)	*n*=40 (28 F, 12M), *M*=22.7, *S.D.*=5.2, range 18- 47 years.	«RT and less Acc in Occlusion task.	Mean amplitude (FCz Geodesic net electrodes 5,6,12; 0-100 ms post-response)	Higher levels of anxiety sensitivity correlated with significantly ↑intERN.
OTHER MANIPULATIONS (Stress, anxiety-like state, unpredictable and random contexts)				
(Jackson et al., 2015b)	*n*=23 (11 females), *M*=18.8, *S.D.*=1.3.	Fewer errors during unpredictable condition.	Mean amplitude (FCz; 0-100 ms post-response).	↑ERN during unpredictable tone.
(Masaki et al., 2017)	*n*=28 Group 1 *n*=14 higher sports anxious (7 F), *M*=20.5, *S.D.*=1.3) Group 2 *n*=14 lower sports anxious (8 F), *M*=21.4, *S.D.*=2.3.	Congruency effect.	Mean amplitude (FCz; 20-100 ms post-response).	↑ERN on evaluation condition for higher sport anxious group.
(Pfabigan et al., 2013)	*n*=37 (20 females), *M*=25.3, *S.D.*=3.9, range 19-34 years.	Congruency effect, »RTs on error trials and PES.	Peak amplitude (Fz, Cz: 10-120 ms post-response).	Feelings of helplessness score correlated significantly with ↑Δ ERN.
(Rodeback et al., 2020)	*n*=71 (34 F), *M*=20.7, *S.D.*=2.3.	PES. Higher Acc for go trials.	Mean amplitude (6 (FCz), 7, 106 and	No significant interaction of group and trial on the ERN.

Author	Sample characteristics	Major behavioral effects/outcomes	ERN peak/mean amplitude (location and time window)	ERN major findings
	TSST *n*=36 (18F), *M*=21.2, *S.D.*=2.5. Control *n*=35 (16), *M*=20.1, *S.D.*=2.0		129 (Cz); 0-100 ms post-response).	
(Tullett et al., 2015)	Study 2 *n*=56 Comprehensible order *n*=20 Incomprehensible order *n*=18 Randomness *n*=18	No significant behavioral effects.	Peak amplitude (FCz; 50 ms before-150 ms post-response).	↑ERN for randomness.

Note. Major findings relate to behavioral and EEG effects by paradigms. Information about the final samples used in the studies are reported. N: number; (M): Mean age; (S.D.): standard deviation; (SEM): standard error of the mean of age, reported to one decimal place. Mean, standard deviation, and range of ages only presented if available. M: male; F: Female; RT: Reaction Times; PES: Post-error slowing; ERN: error-related negativity. ↑: increased or larger amplitudes; ↓: reduced or smaller amplitudes. »: faster; «: slower; Acc: accuracy.

Study and sample characteristics

The thirty-nine investigations contained 41 experimental studies, and they employed 2055 subjects, resulting in an average sample size of 50.1 participants. Sample sizes varied widely, from 18 to 121 participants. Twenty-five studies (61%) had a sample with less than 50 subjects; fourteen (34.1%) had a sample size between 50 and 100 participants, and only two (4.9%) employed more than 100 participants. Thirty-three studies (80.5%) had their samples composed of undergraduate students, of which 10 (24.4% of the total) were explicitly performed with undergraduate students of Psychology courses. The other eight studies (19.5%) were conducted with a non-academic population or did not specify the participants' nature.

Concerning sample *age*, one study did not report the mean age in the final sample. Among the 40 studies reported (n=1993), the participants' age ranged from 17 to 49 years, resulting in an average of 22.31 years.

Regarding other characteristics such as gender and racial group, one study did not report the proportion between men and women in its final sample. Among the 40 studies that reported (n=1993), 58.8% (1171) of the participants were female, and 41.2% (n=822) were male. One study had a final sample composed of 100% women, and only a few studies included ethnicity data.

Paradigms and Designs

We observed more than eight paradigms used in the Thirty-nine papers. Moreover, the paradigms are widely used in the study of ERN and cognitive control. The distribution of the number of papers by paradigms used was as follows:

Flanker task (12): Letter version, arrow version, social version, and modified version; Go/No go Task (10), Stroop Task (4): six choices, spatial; Simon task (3); Probabilistic learning Task (2), Weapons Identification Task (2), A combination of flanker and Simon task (1), and

studies used other inhibitory control tasks (5): MSIT (multi-source interference task), Two-choice Speeded Task, Punished Inhibitory Control Task, Emotional Stop signal Task, and AX-CPT task. Nineteen papers used between-subjects designs, eleven used within-subjects, and nine were between and within-subjects analyses. We found seventeen experiments that used feedback to encourage better Reaction Times and were contingent on trials or performance. Twenty-two of the studies did not use feedback in their paradigms. The main description of the paradigms, designs, and use of feedback can be found in Table 2.

On the other hand, we pooled publications according to the used affect manipulations to compare methodologies and results' studies. A summary of extracted data is displayed in Table 3. The following sections will review the results of the included studies.

Variables compared

The compared variables were categorized into two groups: on the first group, the variables related to the experimental elicitation of affective states; on the second, variables were used to assess the participant's affect.

Regarding the elicitation group, the most common variables were related to the type of feedback presented after the task trials (emotional faces, encouraging or derogatory phrases, feedback of money gain/loss), used in 10 studies. Seven studies presented variables related to mood induction procedures (achieved using music, movies, guided imagery, or text passages). In another seven studies, sensory stimuli (tones/noises, respiratory occlusion, electrocutaneous stimulation) were applied to elicit affective states. Six studies presented compared variables related to parts of the task stimuli (objects, faces, words – not shown as feedback). Six more studies used an emotional regulation strategy (emotional attendance, suppression, or reappraisal) towards the experimental manipulation. Five studies involved administering beverage/supplement (e.g., alcohol). Some

others reported unsolvable math tasks, being or not being evaluated during the task, the Trier Social Stress Test (TSST), and the Paced Auditory Serial Addition Task (PASAT); all of them appear only once.

The most frequent measures used to assess the participant's affect were the Behavioral Inhibition System/Behavioral Approach System (BIS/BAS) scale (5 studies) and physiological measures (as HR, HRV, blood pressure, salivary cortisol, Electromyograms (EMGs), and corrugator supercilii (Corr) activation) (5studies). The following questionaries also were widely used across the studies: The State-Trait Anxiety Inventory (STAI) (4 studies); self-reported mood state (4 studies); the Positive and Negative Affect Schedule (PANAS) (3 studies); personality traits (neuroticism trait, NEO-Five-Factor-Inventory, and The Big-Five Inventory) (3 studies); self-reported emotional involvement (3 studies). All the following measures were reported by only one study: Profile of Mood State Scale (POMS); Religious Zeal Scale; Situational Motivational Scale (SIMS); Sport Anxiety Scale (SAS-2); Anxiety Sensitivity Index (ASI); Intrinsic Motivation Inventory (IMI); Helplessness questionnaire; Self-reported wakefulness state.

Behavioral effects

RTs and accuracy by trial type

Fourteen studies observed a congruency effect with slower RTs and less accuracy on incongruent or high conflict trials (Clayson et al., 2012; Clayson & Larson, 2019; Larson et al., 2013; Nigbur & Ullsperger, 2020; Maruo et al., 2016; Masaki et al., 2017; Boksem et al., 2011; Elkins-Brown et al., 2016; Pfabigan et al., 2013; Potts, 2011; Saunders et al., 2015; Suzuki et al., 2020; Tan et al., 2019; van Wouwe et al., 2011). However, Suzuki et al. (2020) reported a significantly higher accuracy on congruent trials for arrow and social flanker tasks but not for unpleasant and pleasant flanker tasks. On the other hand, six studies reported faster RTs on error

trials (Olvet & Hajcak, 2012; Pfabigan et al., 2013; Suzuki et al., 2020; Saunders et al., 2016; Hobson et al., 2014; Inzlicht & Al-Khindi, 2012), and four studies in the Go/No go paradigm reported more commission than omission errors (Cano Rodilla et al., 2016; Elkins-Brown et al., 2018; Hobson et al., 2014; Inzlicht & Al-Khindi, 2012).

RTs and accuracy by conditions

Studies with groups and conditions differ along with findings by manipulations. Slower RTs and less accuracy were observed in 5 studies with punishment and aversive feedback conditions (Aarts et al., 2013; Good et al., 2015; Leue et al., 2017; Potts, 2011; Saunders et al., 2016). Nevertheless, two other studies found a decrease in error rates in the aversive conditions (Jackson et al., 2015; Saunders et al., 2015), and one of them observed that *frustration* predicted more careless actions (faster and less accurate), while *anxiety* predicted slower and more accurate responses (Saunders et al., 2015) increasingly. Tan et al. (2019) pointed out that the RTs in the occlusion task were significantly slower than in the Flanker task. Bakic et al. (2014) reported faster RTs for the deterministic and probabilistic condition and higher learning rates for positive than negative feedback with overall higher learning rates in the positive mood group than in the neutral one. In Unger et al.'s (2012) experiments, erroneous responses were faster in the deterministic than in the probabilistic learning condition with a significant main effect of learning condition: participants in the failure feedback group were more likely to correct their errors on the next repetition of a given stimulus.

Other interesting findings revealed a higher performance in emotional stop tasks and better inhibition with emotional stop signals (Senderecka, 2018), faster RTs for objects instead of emotional faces (Sueyoshi et al., 2014), and a tendency of higher accuracy on meditators (Teper & Inzlicht, 2013). One study reported higher accuracy at identifying guns and less accuracy at

identifying tools on black-prime trials, with the main effect for block instructions in experiment 1 and the main effect for race prime in experiment 2 (Levsen & Bartholow 2018). Lastly, Bartholow et al., 2012 observed less accuracy in the alcohol manipulation group, although RTs overall did not differ from the beverage group's function.

A considerable number of studies (11) did not distinguish between manipulation and control groups for RTs and overall performance. Olvet & Hajcak (2012) reported no difference between neutral and sad mood groups. Likewise, Elkins-Brown et al. (2018), Paul et al. (2017), Rodeback et al. (2020), Tullett et al. (2015), and Valt et al. (2017) found no significant behavioral effects per condition. In the study conducted by Elkins-Brown et al., 2016 the punishment manipulation did not influence mean RTs or the error rates. Stürmer et al. (2011) found no significant difference for mean error rates in the punishment and reward block. In Sueyoshi et al. (2014), RTs for faces did not differ depending on the emotional expression, and Boksem et al. (2011) observed no main effect of social context on RTs nor error rates.

Post Error Slowing (PES)

Eleven studies reported the presence of post-error slowing effect (Boksem et al., 2011, Larson et al., 2013; Nigbur & Ullsperger, 2020; Olvet & Hajcak, 2012; Paul et al., 2017; Pfabigan et al., 2013; Rodeback et al., 2020; Sueyoshi et al., 2014; Stürmer et al., 2011; Suzuki et al., 2020). Maruo et al. (2016) reported that this effect was more pronounced in the reward condition than in the control and punishment conditions. Cofresí & Bartholow (2020) indicated a Post Error Reduction Interference in Accuracy, but not in RT, and did not differ by beverage group.

EEG Acquisition and ERPs Reduction

Methods and technologies to record EEG and calculate ERPs were diverse. Electrode numbers fluctuated between 6 to 129, with 128, 64, and 32 channel systems being the most frequent (24 studies), distributed according to the 10-20 system. Most studies chose Biosemi Active Two system (Biosemi Inc.) and Electrical Geodesics System, including high-density arrays, to get ERPs components. For ocular movement artifacts correction, most of the studies (18) used the procedure described by Gratton, Coles, and Donchin (1983) and remotion with the independent component analysis (ICA) algorithm (14 studies). Components were quantified employing two measures: Thirty-three investigations selected mean amplitude (the most used brain activity measure); five used peak amplitude and latency, and one study did not report explicitly the type of measure employed (Potts, 2011). Several authors across the studies cited the work of Luck (2005) and Clayson (2013) as their primary criterion of choice for mean amplitude, as they identify this measure as a more reliable ERP measure than the peak amplitude. ERN amplitudes were mostly averaged across frontocentral electrode sites FCz, Fz, and Cz. Criteria to select EEG sites for analysis, electrodes, and latency ranges were due to the topographic properties of the dataset, previous works, and visual inspection of the grand-average waveform post response. A summary of the locations and time windows used in the reviewed studies is displayed in Table 3.

EGG effects

Overall, the thirty-nine studies reviewed, twenty-eight reported significant effects of the affect inductions on the ERN amplitudes, and eleven studies could not find significant differences or associations. The following sections will review the results of the included studies, organized by experimental manipulation. A summary of the extracted data is presented in Table 3.

Mood (6 studies)

Out of the three studies that manipulated positive mood, two studies reported significantly enhanced ERN (Bakic et al., 2014; Nigbur & Ullsperger, 2020), but one study did not obtain significant main effects nor interactions (Paul et al., 2017). The other two studies that included negative mood reported no significant associations between the ERN and mood inductions (Larson et al., 2013; Olvet & Hajcak, 2012). However, Olvet and Hajack (2012) also explored if neuroticism as an affective trait could moderate the relationship between the ERN and changes in mood and reported larger ERN among participants with higher neuroticism.

Emotion regulation strategies (9 studies)

Seven studies reported significant effects of the negative affect manipulation on the ERN (Good et al., 2015; Hobson et al., 2014; Inzlicht et al., 2015; Levsen & Bartholow, 2018; Saunders et al., 2016a; Teper & Inzlicht, 2013; Wang et al., 2014). These studies used a down-regulation reappraisal condition (Hobson et al., 2014), suppression and reappraisal (Wang et al., 2014), manipulated religious beliefs about God and compared punishment and love/forgiveness views (Good et al., 2015), mindfulness and meditation techniques (Saunders et al., 2016a; Teper & Inzlicht, 2013) and misattribution of the arousal paradigm (Inzlicht & Al-Khindi, 2012). Three studies identified an enhanced or more prominent ERN (Levsen & Bartholow, 2018; Saunders et al., 2015; Teper & Inzlicht, 2013). Interestingly, the study of Levsen and Bartholow (2018) manipulated reappraisal and suppression in two experiments with the WIT paradigm. In experiment one, they larger ERNs on Black-relative trials, indicating a reduced error processing and increased response bias. In experiment two, significant effects for prime and strategy interactions confirm that suppression and reappraisal increase ERN following black face primes. Finally, out of the seven studies with significant effects, four studies found decrease ERN amplitudes after

experimental inductions (Good et al., 2015; Hobson et al., 2014; Inzlicht & Al-Khindi, 2012a; Wang et al., 2014).

Two studies found no significant effects on the ERN (Cano Rodilla et al., 2016; Elkins-Brown et al., 2018). These specific studies were replications of the misattribution approach by Inzlicht & Al-Khindi (2012), and both failed to replicate the reduced amplitude of the ERN due to misattribution of arousal procedure, pointing out the original study as a possible false positive (Cano Rodilla et al., 2016; Elkins-Brown et al., 2018).

Emotional properties of stimuli (valence, arousal, priming) (9 studies)

Three studies identified enhanced ERN amplitudes using negative and positive words (Aarts et al., 2013a), unpleasant and pleasant tasks (Suzuki et al., 2020), and two different Flanker tasks to evaluate the effect of arousal and valence on the ERN in a concurrent affective manipulation (Clayson & Larson, 2019). This last study found for the Interspeed task a significant effect of arousal but no effect of valence, and the Overlaid task had no significant effect for arousal but a significant effect for valence (Clayson & Larson, 2019). Three studies reported dampened amplitudes throughout their manipulations. Valt et al. (2017) evoked an aversive state through angry faces, Booksem et al. (2011) used disgusted faces as stimuli in a negative affective context, while van Wouwe et al. (2011) used a positive affective condition resulting in smaller ERN.

Conversely, three studies did not find significant effects or associations between the ERN and negative arousing trials (Senderecka, 2018) and emotional faces: worry faces (Leue et al., 2017) and disgusted faces (Sueyoshi et al., 2014). However, Sueyoshi et al. (2014) reported a positive association of the ERN to interoceptive sensitivity on disgusted face conditions. The study of Leue et al. (2017) found a significant effect of aversive feedback condition with larger ERN, regardless of no worry faces induction effects.

Punishment and reward (7 studies)

Out of the seven studies, five studies found significant effects of condition on the ERN (Maruo et al., 2016; Potts, 2011; Saunders et al., 2015; Stürmer et al., 2011; Unger, Kray, et al., 2012). One study manipulated monetary reward and punishment and reported larger ERN amplitudes in both conditions than in the control condition (Maruo et al., 2016). There was no significant amplitude difference between reward and punishment. Another study used a failure induction in two experiments (Unger, Kray, et al., 2012). The authors investigated the effects of failure feedback in deterministic and probabilistic conditions, finding an enhancement of the ERN amplitudes resulting from the failure manipulation in the two learning conditions. Relative to significant effects, Stürmer et al. (2011) found enhanced ERN amplitudes for reward blocks, while Saunders et al. (2015) and Potts (2011) reported larger ERN for punishment feedback.

In contrast, two studies reported no significant effect of the punishment and aversive feedback on the ERN or ΔERN amplitudes (Clayson et al., 2012b; Elkins-Brown et al., 2016). The study conducted by Clayson et al. (2012) intended to replicate a previous study (Wiswede et al., 2009b) that reported an association between increases in negative affect and increases in the ERN amplitude but had a small sample composed only of twelve females. As already mentioned, Clayson et al., 2012 failed to replicate those findings.

Alcohol induction and respiratory control (4 studies)

Two studies tested the hypothesis that alcohol intake could reduce negative affect, and both studies found smaller error-related negativity amplitudes for alcohol than in placebo or control conditions (Bartholow et al., 2012; Cofresí & Bartholow, 2020). Nonetheless, Cofresí and Bartholow (2020) identified an association between the ERN and Corrugator supercilii reactivity (EMG) in the control group.

On the other hand, one study manipulated respiratory and somatosensorial evoked potentials (Jelinčić et al., 2020), reporting a correlation with the ERN. Another study explored the ERN related to interoceptive respiratory sensations and reported enhanced interoceptive ERN amplitudes in individuals with high anxiety sensitivity (Tan et al., 2019).

Other manipulations (Stress, anxiety-like state, unpredictable and random contexts) (5 studies)

Four studies reported enhanced ERN and ΔERN amplitudes (Jackson et al., 2015a; Masaki et al., 2017; Pfabigan et al., 2013; Tullett et al., 2015). The studies manipulated affect state through unpredictable tones (Jackson et al., 2015), feelings of helplessness (Pfabigan et al., 2013), evaluation of performance under pressure (Masaki et al., 2017), and random readings (Tullett et al., 2015). Lastly, one study explored inducing stress and found no effect on the ERN (Rodeback et al., 2020).

Conceptual challenges: Definitions of state affect manipulations and measurement

In this review, we identified heterogeneity in conceptual definitions of what is understood by an affective state manipulation. In most cases, the terms *emotion, affect, mood,* and stimuli with *emotional/motivational significance* are treated as synonymous. To illustrate this issue, the following examples were extracted from some of the reviewed articles:

> "Additional negative *emotions* (such as anger or sadness) were not used. Doing so in future studies will allow us to clarify whether the enhanced correlation between behavioral monitoring and cardiac sensitivity was due specifically to the *feeling* of disgust, or whether it can be elicited with any type of *negative affect*." (Sueyoshi et al., 2014, italics added)

> "(…) that examination of isolated *affective events* is not helpful to disentangle the interaction of cognitive control functions and *affects/moods*." (Nigbur & Ullsperger, 2020, italics added)

> "Specifically, we suggest that directing attention to present-moment *feelings* in the mind and body produced a tonic *state of affective* receptivity in *emotion-focused* participants" (Saunders et al., 2016a)

The unprecise and interchangeable terminology affects the subjacent rationale behind selecting specific instruments to measure the constructs we are dealing with in the field (Ekkekakis, 2013). For instance, experimental manipulations that were categorized in this review under the label of "*Mood*" described in their Method section a variety of experimental inductions: the presentation of video clips (Nigbur & Ullsperger, 2020; Olvet & Hajcak, 2012), guided imagery (Bakic et al., 2014; Paul et al., 2017), and music selection for a particular mood (Larson et al., 2013). However, these inductions correspond to a state manipulation and depending on the theoretical framework, the construct of "mood" is different from "affect" and "emotion". Respectively selecting the instruments to measure those mood changes could not correctly address the conceptual rationale of the target construct.

For example, Olvet and Hajack (2012) described their manipulation as follows:

> "The sad and neutral *mood induction* paradigms were based on the guidelines provided by Rottenberg et al. (2007) for using film clips to elicit *discrete emotions.* (…) To assess *current mood* throughout the experiment, the *valence scale* of the Self-Assessment Manikin was used (Lang, 1980). Participants were asked to rate their *current mood* ranging from one (happy) to nine (sad)." (italics added).

In this case, the target manipulated construct was "mood", where a sad induction consisted of a video clip plus a song. However, "mood" seems to be conceptualized without distinction from

"emotion". The changing states were measured with a scale intended to assess valence, arousal, and dominance while processing emotional stimuli (Bradley & Lang, 1994).

Likewise, this problem can be observed in other studies that manipulated other domains under the extensive scope of affect. For instance, the study of Clayson et al. (2012) induced negative affect through derogatory feedback. Yet, in the Method, they stated:

> "In order to assess changes in *affective state*, participants were administered the *Profile of Mood State Scale* (POMS) before and after task completion (McNair et al., 1992). (…) Individuals rate adjectives that describe *moods or feelings* on a scale ranging from 1 (not at all) to 5." (Italics added).

This conceptual ambiguity highlights the possibility of making measurements of a construct (e.g., mood) and drawing conclusions about another (e.g., emotion). In this sense, the question arises: To which specific affective state domain should be attributed the modulation of the ERN?

Discussion

This study intended to systematically review the literature searching for effects of negative affect and aversiveness manipulations on the ERN event-related potential component. A total of 39 studies were identified, with 28 studies reporting significant effects and modulations on the ERN.

Regarding the paradigms, designs and variables compared, we observed heterogeneity across studies. That hinders comparisons between results. Widely different paradigms were used to seek negative affect effects on the ERN as a dependent variable. In fact, it becomes clear that in the literature presently reviewed, negative affect is a broad term that encompasses mood, emotion, the affective properties of the stimuli such as valence and arousal, and even emotion regulation strategies. That variable terminology prevents the specification of whether studies deal with the same aversiveness concept and levels in their experiments. Moreover, negative states (distress,

sadness, or helplessness) and stimuli emotionality (happy, disgusted, sad, angry) do not refer to the same level constructs, nor should they be expected to elicit the same error-related correlates changes. For instance, in a negative evaluation context, disgusted-face stimuli elicited lower amplitudes in one study (Boksem et al., 2011) but enhanced amplitudes in another (Sueyoshi et al., 2014). Moreover, larger ERN amplitudes were associated with affective priming using angry faces (Valt et al., 2017) and valence words (Aarts et al., 2013a). Nevertheless, manipulating worry-face stimuli did not have a main effect on the ERN, but if aversive feedback were given, the amplitudes were increased (Leue et al., 2017).

To overcome the challenge of evaluating aversiveness effects from an inconsistent conceptualization in the literature, we opted to group the retrieved studies in terms of the independent variables they manipulated to assess alterations in the ERN. The categories comprised 1) mood, 2) emotion regulation strategies, 3) emotional properties of stimuli (valence, arousal), 4) punishment and reward, 5) physiology (alcohol intake, respiratory control), and 5) other manipulations (stress, anxiety, unpredictability). In some studies, the ERN was enhanced by the presence of error punishment (Leue et al., 2017; Maruo et al., 2016; Potts, 2011; Saunders et al., 2015); in others, the observed changes depended on the type of task (affective o neutral) (Suzuki et al., 2020). Variability in results from manipulations of emotional regulation strategies was also observed (Hobson et al., 2014; Saunders et al., 2016a; Teper & Inzlicht, 2013; Wang et al., 2014). Conversely, studies with negative mood inductions did not find ERN effects (Larson et al., 2013; Olvet & Hajcak, 2012), but positive mood induction experiments showed mixed results (Bakic et al., 2014; Paul et al., 2017; van Wouwe et al., 2011a).

Of the 11 included studies that did not obtain significant effects, two (Cano Rodilla et al., 2016; Elkins-Brown et al., 2018) were replications of the paradigm of Inzlicht and Al-Khindi (2012), which had actually found a significant effect of misattribution of arousal on the ERN. Two

relevant issues emerge from this set of studies: a) the replication attempts used higher statistical power (more representative samples), with non-replication findings confirmed by Bayesian Statistics; and b) the possibility of a false positive of the original article (Inzlicht & Al-Khindi, 2012). These results represent an opportunity to show the relevance of the high-powered replications of the ERN paradigms, methodologies, and theories.

Caution should be taken regarding significant effects reported in EEG low-powered studies, especially when treated as solid evidence of the nature of psychophysiological phenomena such as the ERN (Button et al., 2013). In our review, 61% of the studies had a sample with less than 50 subjects, and only two studies (Good et al., 2015; Larson et al., 2013) used more than 100 participants. Furthermore, 80.5% of the reviewed studies were conducted with samples composed of undergraduate students and only a few reported ethnicity data. This fact leads us to the WEIRD (Western, educated, industrialized, rich, and democratic) sample problem (Henrich et al., 2016). Although empirical research publications usually report the characteristics of their samples as a limitation, few studies identified their target population adequately, and the risk of sampling bias remains despite the data collection issues (Muthukrishna et al., 2020).

Although comparing several results is a difficult task, one explanation for the mixed findings within these studies could reside in the unique relationships of the ERN with the nature of the specific procedure and affective state manipulation. Finding increased or reduced ERN amplitudes would depend on the interaction of the different nature of the affective state induction, the different nature of the task and its specific effects (Riesel et al., 2013; Suzuki et al., 2020), and the different nature of errors (Senderecka, 2018). Nonetheless, the issue of precise and clear conceptual distinctions is crucial when investigating specific manipulations' effects (Ekkekakis, 2013), particularly when examining potential links with the ERN (Ekkekakis, 2013; Riesel, 2019a). Our review identified conceptual complications and challenges where terms are treated

interchangeably, which could impact the measurement and conclusions about the target constructs and their effects on error monitoring.

Can the modulation of the ERN be attributed to the emotional stimuli per se? Is the emotional context the factor that modulates the neural correlates of performance monitoring? What does the lack of modulation of the ERN in negative mood inductions tell us about error aversiveness? To address these questions and establish the functional significance of an enhanced or dampened ERN amplitude, it is necessary to conceptualize with precision the constructs (*mood, emotion, affect*) and dimensions (*valence, arousal, dominance)* we are dealing with since state manipulations are more complex due to the breadth of definitions (Hajcak et al., 2012).

Despite the conceptual inconsistencies, the reviewed studies suggest that the ERN is reliably sensitive to direct manipulations of affective states. Until now, much is known about the functioning of the error-monitoring system due to the studies with trait variations in negative affect (Riesel, 2019a; Riesel et al., 2017; Weinberg, Riesel, et al., 2012a). There is also strong evidence that errors are experienced as distressing (Hajcak & Foti, 2008; Jackson et al., 2015a; Spunt et al., 2012), especially in people with high sensitivity to aversiveness and negative affect (Olvet & Hajcak, 2008; Shackman et al., 2011b). Similarly, to determine the precise nature of the affective modulations of the ERN, we underlined the importance of further research in affective states in elucidating the interactions of emotion and cognition in the functioning of performance and error monitoring.

Limitations and future directions

While the review findings suggest in general that the ERN is sensitive to state-specific affect manipulations, heterogeneity of the paradigms and variables studied made it difficult to compare such results. Likewise, the conclusions are based on qualitative analysis of the studies. A meta-

analysis of the selected studies was not conducted, and the effect sizes for the ERN amplitudes differences were not examined. Future studies should include similar variables and conduct a meta-analytic review of the affect states' manipulations and their effects on the ERN.

Authors Contributions

All persons who meet authorship criteria are listed as authors. RMMA, GG, and XNE conceived the study and methodological strategy. XNE, LZB conducted the literature searches. XNE and LZ independently conducted the first two screening phrases and checked the methodological quality of the studies. XNE wrote the manuscript, with all authors contributing significantly to manuscript revision. All authors certify that they have participated sufficiently in work to take public responsibility for the content, including participation in the manuscript's concept, design, analysis, writing, or revision. All authors have approved the final article.

Conflict of Interest Statement

The authors declare that the research was conducted without any commercial or financial relationships that could be construed as a potential conflict of interest.

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CHAPTER III: UNCERTAINTY AND PERFORMANCE MONITORING WITH HIGH OCD SYMPTOMATOLOGY: AN EXPLORATORY OF A PILOT EEG STUDY

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Abstract

Background: Performance monitoring has been consistently overactive in obsessive-compulsive disorder (OCD) and obsessive-compulsive (OC) symptomatology. The present exploratory study aimed to examine the incidence of the ERN and ΔERN components of error responses at a gambling-type task. Methods: Ten participants completed the Flanker task, and the Hilo game with varied conditions of uncertainty, while EEG data was recorded. Results: The ERN was elicited in the Flanker as expected, and behavioral effects were observed as well. The HiLo game was not successfully eliciting the ERPs related to error monitoring; however, significant differences were detected between grand averages waveforms in the low-uncertainty condition. Correlations were found between the Flanker-CRN and grand average waveform for wins in the

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no-uncertainty trials. Conclusions: These findings point to necessary experimental and methodological modifications of the levels of uncertainty in the HiLo game to elicit the event-related potentials of interest robustly. Limitations and future directions are discussed.

Keywords: ERN, CRN, Uncertainty, HiLo game, Flanker task, OC symptomatology.

Introduction

Obsessive-Compulsive Disorder (OCD) is a prevalent and disabling psychiatric condition (Goodman et al., 2021; Ting & Feng, 2011) characterized by intrusive ideas (obsessions) and repetitive behaviors (compulsions) that persist despite feedback (Agam et al., 2014). High anxiety levels and difficulty in controlling signs and symptoms usually accompany this condition (Pereira de Souza, 2021). Neuroimaging and electrophysiological studies of OCD patients have exhibited abnormal patterns of activation in the corticostriatal-thalamocortical (CSTC) circuitry (Burguière et al., 2015; Pena-Garijo et al., 2010; Ting & Feng, 2011). This functional overactivity on the CSTC loops, particularly in the anterior midcingulate cortex (aMCC), the orbitofrontal cortex (OFC), and basal ganglia (BG) (Ahmari & Dougherty, 2015; Manning & Ahmari, 2018; Szechtman et al., 2017) is thought to contribute to the OCD pathogenesis and symptoms manifestation (Burguière et al., 2015; Ting & Feng, 2011).

Likewise, ERP studies have shown hyperactivity of the aMCC in OCD patients during tasks involving error monitoring (Endrass & Ullsperger, 2014; Riesel et al., 2014, 2017), supporting the hypothesis of a persistent and enhanced error signal in OCD and Obsessive-Compulsive (OC) symptoms (Pitman, 1987). The electrocortical index of behavioral errors is the error-related negativity (ERN). It is a negative deflection in the EEG signal, mostly at central and frontocentral medial sites, that occurs following an erroneous response to a task, with a minimum at around 100 ms after the error (Gehring et al., 1993; Hajcak, 2012a). This component shows the exact moment

the error committed is detected, allowing the subject to adapt and continue the task (Hajcak et al., 2011; Meyer et al., 2012; Moser et al., 2013; Olvet & Hajcak, 2008).

There is strong evidence for the association between enhanced ERN and OCD (Klawohn et al., 2014; Perera et al., 2019; Riesel et al., 2017), and it has been suggested as an endophenotype for OCD (Riesel, 2019b; Weinberg et al., 2015b). Furthermore, increased ERN amplitudes are also observed in individuals with high anxiety, perfectionism, and high negative affect (Olvet & Hajcak, 2012; Proudfit et al., 2013; Weinberg, Klein, et al., 2012). Thus, people with high sensitivity to threats like OCD patients would experience errors as especially aversive due to their inherent unpredictable features (Jackson et al., 2016; Proudfit et al., 2013). Further evidence shows that the experience of uncertainty as vastly distressing leads to several symptom expressions in clinical and non-clinical samples (Carleton, 2016; Fourtounas & Thomas, 2016; Pinciotti et al., 2021). However, knowing that OCD individuals find unpredictable situations inherently threatening (Holaway et al., 2006; Jackson et al., 2015a; Tolin et al., 2003; Wheaton & Ward, 2020) raises questions on the influence of uncertainty on sensitivity to error commissioning reflected on neural correlates as the ERN.

The present exploratory study aimed to establish the ERN and ΔERN components of error responses at a gambling-type task. The HiLo game (Krain et al., 2007) manipulates the uncertainty for a subject's bet at the value of a card on three levels: high-uncertainty (trials with 2:1 odds), low-uncertainty (trials with 7:1, 6:2, or 5:3 odds), and no-uncertainty (trials in which the outcome is certain, so losses are not due to chance). As a benchmark, the results were compared to those from Eriksen's Flanker task, which has consistently elicited the ERN in the literature (Riesel et al., 2013). We hypothesized that (1) the HiLo game would elicit the ERN at similar latencies and levels as the Flanker task, but (2) only at no-uncertainty trials. A failed response to a no-uncertainty trial is an

inherent error, whereas, in the uncertain trials, an error will only be settled as such once the drawn card is shown.

This study is a step to validate the HiLo game to manipulate uncertainty objectively and assess its effects on error-related ERP components in future studies with clinical and non-clinical populations. The sample for the current study was composed of people with high OC symptomatology, one of the target populations for upcoming studies.

Methods

Participants

The sample for the present study came from a larger online survey study with 491 Brazilian participants on OCD symptomatology. Fifty-six people with an OCI-R score above the cut-off were invited to take part in the present study. Sixteen people refused to participate, and 20 did not respond. The present sample thus included 20 participants (12 female, mean age=28.05, min=21, max=35). All participants were right-handed and had normal or corrected-to-normal vision. The inclusion criteria were a) being at least 18 years old, b) scoring 21 or higher in the OCI-R, or c) having an OCD diagnosis. The Ethics Committee at the UFRGS Institute of Psychology approved the research protocol, and specific informed consent for this study was obtained before participation. Nine participants were excluded from analyses of Flanker task data due to technical malfunction (n=8) and trial artifacts (n=1). For the HiLo game, nine participants were excluded due to technical malfunction (n=6) and trial artifacts (n=3). Complete data was recorded from 11 participants in the Flanker task and 11 participants in the HiLo game. After preprocessing, 2 participants were excluded from analyses due to poor quality EEG data (n=1) or outlier ERP values (n=1), leaving the final samples at 10 participants in the Flanker Task and 10 participants in the HiLo game.

Measures

Socio-demographic questionnaire

Questions about age, sex, ethnicity, occupation, years of study, and others (see Appendix 3).

Yale-Brown Obsessive-Compulsive Scale

The Y-BOCS (Asbahr et al., 1992; Goodman et al., 1989) is an OCD symptom severity scale, where a lower score indicates better health. It comprises ten items that evaluate time, interference, distress, resistance, control, obsessions (items 1–5), and compulsions (items 6–10). Items from the two subscales are rated from 0 (no symptoms) to 4 (severe symptomatology), generating a total score (range=0–40) and subscale scores for obsessions and compulsions (range=0–20 for each) (Abramovitch et al., 2020) (see Appendix 5).

Obsessive-Compulsive Inventory – Revised

The OCI-R (Foa et al., 2002; Souza et al., 2011) evaluates the severity of OCD in six domains: washing, checking, ordering, obsessing, hoarding, and neutralizing. The 18 items measure the extent of the distress caused by a list of OC experiences. Responses range from 0 ("not at all") to 4 ("extremely") scale. The psychometric properties of the OCI-R are well documented for clinical and non-clinical populations (Abramovitch et al., 2020; Belloch et al., 2013; Wootton et al., 2015). The recommended clinically significant cutoff score of 21 (Belloch et al., 2013; Foa et al., 2002) was used to discriminate high symptomatology (>20) (see Appendix 4).

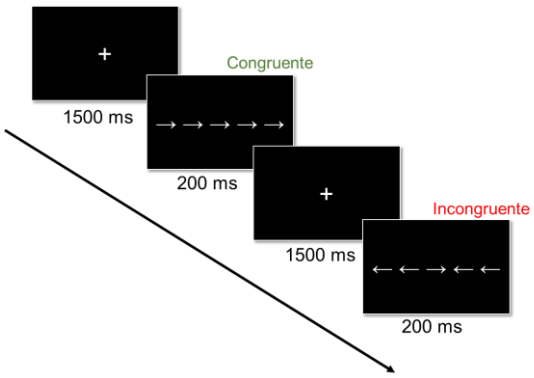
Tasks

Flanker Task

Participants completed an arrow version of the Eriksen Flanker Task, used in numerous studies investigating ERN in OCD (Endrass & Ullsperger, 2014). In this task, participants were asked to determine the direction of a central arrow. Five flanker arrows will appear at the same time and can be either compatible/congruent (← ← ← ← ← and → → → → →) or incompatible/incongruent (e.g., ← ← → ← ← and → → ← → →) (see Figure 6). Instructions were given to respond as quickly and accurately as possible. The task began with a practice block of 32 trials. In each trial, stimuli will remain on screen for 200 ms, followed by an intertrial interval of 1500 ms, during which a standard fixation cross is present. Afterward, they will perform eight blocks of 64 trials each, for a total of 512 trials. Half of the trials were congruent, and half were incongruent. Congruent and incongruent trials were randomized across the experiment. Performance feedback was provided after every block to yield an optimal error rate of nearly 10%. The task was run in Psychopy 2.0 (Peirce, 2009). A graphical representation of the task structure is presented in Fig. 1.

Figure 6.

Trial structure of the flanker task



The HiLo Game

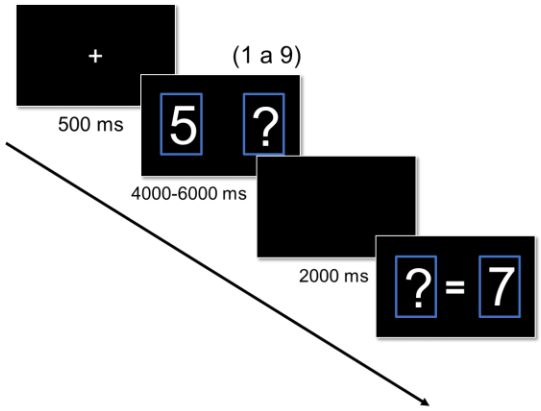
This task was created by Krain et al. (2006) for neuroimaging studies of decision-making versus uncertainty. In our study, participants completed an adapted task consisting of two

randomized blocks of 30 pseudorandomized trials, one of low uncertainty and the other of high uncertainty (see Figure 7). Participants were instructed to watch a computer screen to see a numbered card (1–9) and a mystery card ('?') with an undefined value but never equal to the reference card. They were asked to decide whether the mysterious card was higher or lower than the reference card for each trial. The degree of uncertainty was associated with each card. With cards 1 and 9, subjects could predict with 100% certainty that the mystery card would be higher or lower, respectively. Card 5 had the maximum degree of uncertainty, with a 50% chance that any answers would be correct. The other values reflected intermediate degrees of uncertainty.

At the beginning of each trial, a fixation cross was at the center of the screen. A test block with nine trials (with three different levels of uncertainty) was run to check if participants understood the task and its instructions. The stimulus screen was presented with a jitter, followed by a response prompt from 4 to 6 seconds. Two seconds after a response was made, a screen showed the actual value of the mystery card, and feedback was provided. If the participants answered correctly, they won 100 points and, if they answered wrong, lost 50 points. Afterward, they will have a resting time of 3-5s before the subsequent trial is initiated. The task comprised 12 trials with each card from 1-9, resulting in 108 trials distributed along with three blocks of 36 trials, with 1-minute resting intervals. An example of stimuli and trials is given in Figure 7.

Figure 7.

Trial structure for HiLo game



EEG recording and processing

EEG was recorded continuously throughout the Flanker task using an elastic cap (Electro-cap International Inc., Eaton, OH, USA), with 24 electrode sites placed according to the 10/20 system. All electrodes were sintered Ag/AgCl electrodes, connected to a Mitsar 202 EEG amplifier system (Mitsar LTD, Saint Petersburg, Russia) running EEGSTUDIO 1.14 (Mitsar, Saint Petersburg, Russia), and acquiring EEG data at a 500 Hz sampling rate. Electrode scalp impedances were kept below 5 kΩ, and signals were amplified within a bandwidth of 0.1 to 30 Hz; other frequencies were digitally filtered. Reference electrodes A1 and A2 were linked and attached to subjects' left and right mastoids, respectively.

Acquired data were analyzed through EEGLAB (Delorme & Makeig, 2004) and ERPLAB (Lopez-Calderon & Luck, 2014), two open-source toolboxes for EEG and ERP analysis in MATLAB (MathWorks, Inc, Natick, MA). The EEG signal was band-pass filtered from 0.1 to 30 Hz and corrected for eye movement artifacts (Gratton et al., 1983). Continuous data were separated into epochs ranging from -200 to 1000ms, time-locked to response onset. The 200–0 ms pre-response interval was used as the baseline. Epochs with a voltage greater than 50 µV between sample points or a maximum voltage difference of less than .50 µV within 100 ms intervals were

automatically rejected. Participants with more than 50% of trials with artifacts in their epochs were excluded from analyses.

Response-locked ERPs were averaged separately for the neural response to correct responses (i.e., the correct response negativity; CRN) and errors (i.e., the ERN). ERPs were quantified as the mean amplitude from 90-190 ms post response, pooled across fronto-central electrode FCz, Cz, where the ERN was maximal. ERPs were calculated through grand averages. Trials with error commission responses were averaged to calculate the ERN, and the Delta ERN was calculated through subtraction of the ERN from the CRN. Comparisons were held within-subjects through t-tests. Alpha levels of .05 were maintained for all tests.

Data analysis

Data from the flanker task were analyzed through a paired-samples t-test with the response (correct vs. error) as the within-subjects factor to examine the difference between the CRN and ERN. Spearman's correlations were conducted to investigate the relationship between behavioral response parameters (i.e., error reaction time, correct reaction time, accuracy) and ERP indices of performance monitoring (ERN, CRN, Δ ERN).

HiLo game data were analyzed through paired-samples t-tests for each of the uncertainty conditions (no-uncertainty, low-uncertainty, and high-uncertainty), with the response (correct vs. error) as the within-subjects factor. Spearman's correlations were conducted to investigate the relationship between behavioral response parameters (i.e., reaction times at win/correct and loss/incorrect trial outcomes). Mean EEG voltages at the 90-190ms time window were calculated across uncertainty conditions and win vs. loss trial outcomes. Uniquely for the no-uncertainty condition, the waveforms were considered ERN and CRN components, respectively, if trials

outcomes were lost or won. Statistical analyses of behavioral and EEG data were conducted using the JASP (Version 1.8; JASP Team, 2021) statistical software.

Results

Flanker task

Behavioral data

Table 4 displays descriptive statistics for the Flanker task behavioral performance. As expected, reaction time for errors and correct responses differed, W=1.00, p=.004, r_{rb}=-0.964, indicating that participants responded significantly faster on error relative to correct trials. The same effect was found for congruent and incongruent trials, indicating that RTs were slower for correct trials. Accuracy between congruent and incongruent trials was also examined. The Wilcoxon tests yielded a main effect of trial type (W=55.00, p=0.006, r_{rb}=1.000), indicating that accuracy was higher for congruent trials than incongruent trials.

Table 4.

Descriptive statistics of behavioral data for Flanker task

	Mean	SD	Wilcoxon W	r_{rb}	Student's t	d
RT correct congruent trial (ms)	429	44.0	35.00**	0.944	4.954	1.567
RT error congruent trial (ms)	275	91.4				
RT correct Incongruent trial (ms)	483	48.0	54.00**	0.964	4.533	1.603
RT error incongruent trial (ms)	386	69.9				
Congruent trial Acc (%)	0.97	0.019	55.00**	1.000	4.757	1.504
Incongruent trial Acc (%)	0.89	0.066				
RT error	390	69.8	1.00***	-0.964	-5.132	-1.623
RT correct	486	49.6				
Overall Acc rate	0.93	0.039				

Note. *N=10.* Notes. SD=Standard deviation; Min=Minimum value; Max=Maximum value; ms=milliseconds. RT- reaction time, Acc- accuracy. **p<.05 *** p<.001*.

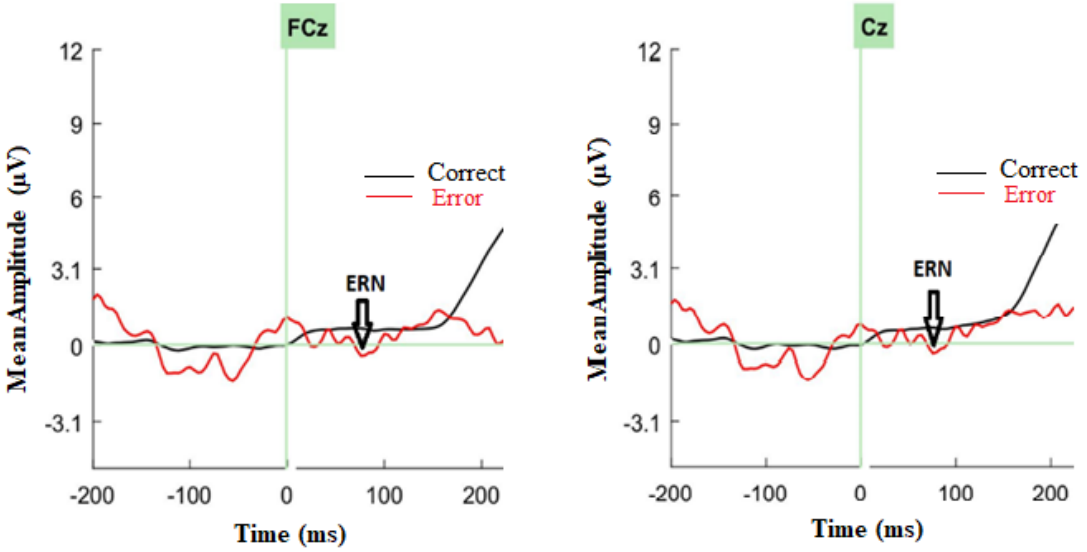
ERP Data

Figure 8 depicts a visual inspection of the pattern of grand average waveforms for both conditions (error-correct) at the electrodes FCz and Cz. The descriptive statistics and correlations

of the ERPs using the timeline window of (0-100ms) are presented in Table 5. ERPs between error and correct trials were examined. As expected, the Wilcoxon test for ERPs between correct and error trials yielded a main effect of outcome (W=2.00, p = .0006, r_{rb}=–.927), indicating that ERN amplitude was more negative on error trials versus correct trials overall. The ERN was more negative than the CRN.

Figure 8.

Flanker task grand averages waveforms for ERN and CRN over frontocentral recording electrodes (FCz, Cz)



Note. ERN was scored between 0 and 100 ms post response.

Table 5.

Descriptive statistics of ERN, CRN, and ΔERN data grand averages

	Mean	SD	Min.	Max.	Wilcoxon W	Effect Size
ERN	-2.69	5.17	-9.81	4.41	2.00*	-0.927
CRN	2.75	6.01	-8.20	11.7		
ΔERN	5.63	3.60	0.04	11.9		

Note. SD=Standard deviation; Min=Minimum value; Max=Maximum value; ERN=Error-related negativity; CRN=Correct-response negativity; ΔERN=ERN minus CRN. ***p*<.*01*.

ERPs and behavioral data

Table 6 displays Spearman correlations between the ERPs (ERN, CRN, ΔERN) and behavioral data. The results indicated a significant negative correlation between the CRN and RTs error for congruent trials (ρ=-0.794, $p < .01$) and a positive correlation between ERN and CRN (ρ=0.790, $p < .01$). No other significant correlations were found between the variables examined.

Table 6.

ERPs and behavioral data correlations

	ERN		CRN		ΔERN	
	ρ	p-value	ρ	p-value	ρ	p-value
Incongruent trial Acc (%)	0.358	0.313	0.406	0.247	0.224	0.537
Congruent trial Acc (%)	0.402	0.249	0.311	0.382	0.104	0.776
Overall Acc rate	0.333	0.349	0.442	0.204	0.297	0.407
RT correct Incongruent trial (ms)	0.006	0.987	0.261	0.466	0.280	0.434
RT error incongruent trial (ms)	0.055	0.892	0.127	0.733	0.018	0.973
RT correct congruent trial (ms)	-0.018	0.973	0.103	0.785	0.188	0.608
RT error congruent trial (ms)	-0.214	0.619	-0.810*	0.020	-0.667*	0.083
RT error	-0.021	0.948	-0.042	0.897	-0.207	0.519
RT correct	-0.105	0.749	0.091	0.783	0.259	0.417
ERN	—	—	0.733**	0.021	-0.030	0.946
CRN			—	—	0.576	0.088
ΔERN					—	—

Note. ERN=Error-related negativity; CRN=Correct-response negativity; ΔERN=ERN minus CRN; RT=reaction time; ms=milliseconds; Acc- accuracy. *$p<.05$, ** $p < .01$.

HiLo game

Behavioral descriptives

The descriptive statistics for Reaction Times (RTs) are presented in Table 7. Additionally, we conducted a Chi-square test (χ^2) for RTs in the three conditions (High Uncertainty, Low Uncertainty, and No Uncertainty). However, the Chi-square yielded an interaction effect (χ^2=14.600, df=2, p=<.001), indicating significant differences in RTs between conditions. Post hoc comparisons, after Bonferroni correction, revealed significant differences in RTs between High and No-Uncertainty conditions (T=3.801, df=18, p=0.004). No other significant differences were found.

Table 7.

Descriptive statistics of Reaction Times for High Uncertainty, Low Uncertainty, and No Uncertainty conditions

	Mean	SD	Min.	Max.	Shapiro-Wilk W	Shapiro-Wilk p
RT High Uncertainty (ms)	0.886	0.297	0.593	1.467	0.812*	0.020
RT Low Uncertainty (ms)	0.763	0.211	0.550	1.206	0.839*	0.043
RT No Uncertainty (ms)	0.633	0.120	0.457	0.795	0.933	0.476

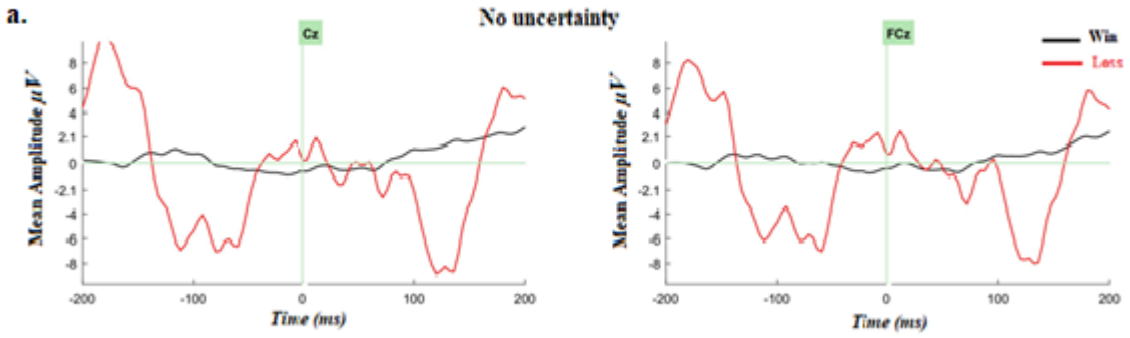
Note. RT- reaction time; ms=milliseconds. *$p<.05$

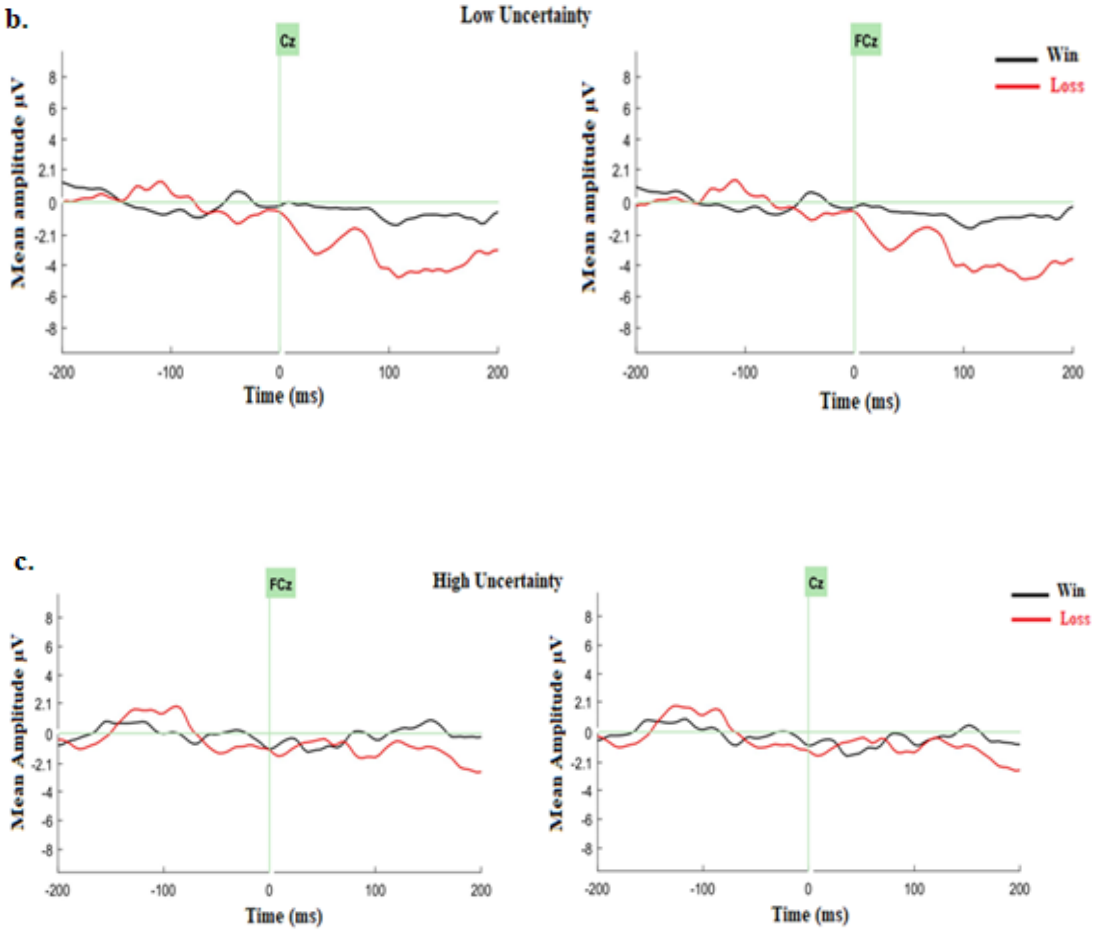
ERPs data

Figure 9 depicts a visual inspection of the HiLo Game Grand Averages waveforms for Wins and Losses over frontocentral recording electrodes (FCz, Cz) in three conditions: (a) No uncertainty, (b) Low uncertainty, (c) High uncertainty. Table 8 displays descriptive statistics for Grand Averages (GA) for the three uncertainty conditions at electrode sites FCz and Cz (90-190ms). The grand average of loss trials in the No-uncertainty condition was not considered since the committed errors were scarce and their variance cannot be analyzed. Furthermore, we conducted a Chi-square test (χ^2) for GA in the three conditions (High Uncertainty, Low Uncertainty, and No Uncertainty wins). The Chi-square yielded no interaction effect (χ^2=1.400, df=2, p=0.497), indicating no significant differences between the waveforms.

Figure 9.

HiLo Game Grand Averages waveforms for wins and losses at electrodes FCz and Cz





Note. a. NO uncertainty; b. Low uncertainty; c. High uncertainty.

Table 8.

Descriptive statistics of Grand Averages at FCz and Cz in three conditions: Low Uncertainty, Low Uncertainty, and No Uncertainty (ERPs)

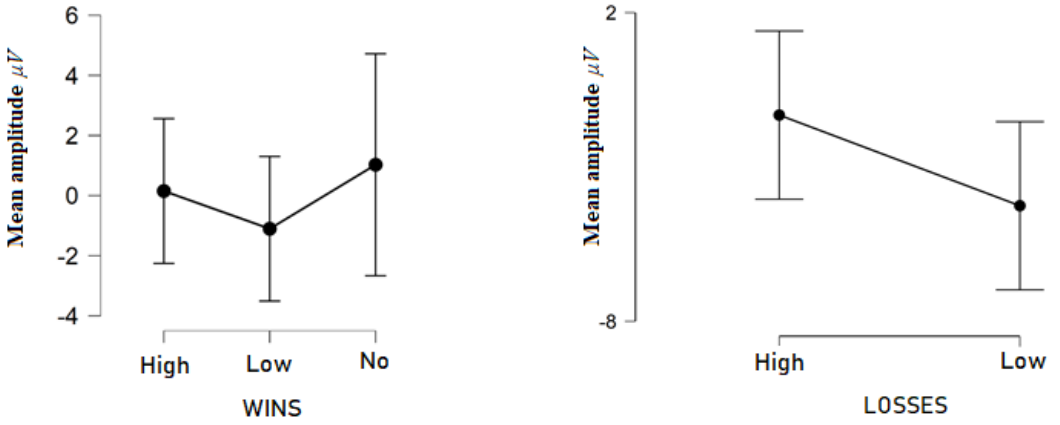
	Mean	SD	Min.	Max.	Shapiro-Wilk W	Shapiro-Wilk p
GA High U Cz	-0.793	2.74	-4.18	4.96	0.915	0.314
GA Low U Cz	-2.574	3.03	-8.70	0.61	0.871	0.104
GA No U win Cz	1.615	4.63	-4.14	11.02	0.934	0.488
GA High U FCz	-0.584	2.79	-3.76	5.32	0.896	0.199
GA Low U FCz	-2.679	3.07	-8.17	1.37	0.932	0.464
GA No U win FCz	-1.027	5.14	-6.54	10.67	0.970	0.890

Note. GA=Grand Averaged; U=Uncertainty. *$p<.05$.

Visual inspection of the grand averages suggests that processing of error (loss) and correct (win) responses are processed similarly in the context of high uncertainty. That is confirmed by the Wilcoxon test (W=33.0, p=0.625, r_{rb}=.200), indicating no significant amplitude differences between the grand averages for wins and losses in the high uncertainty condition descriptive statistics presented in appendix 8). The subjects would have difficulty identifying errors from correct responses (wins from losses), resulting in comparable negativity and waveforms. These results are consistent with previous evidence that suggests this pattern is present when subjects are more uncertain of the accuracy and outcome of their responses (Pailing & Segalowitz, 2004). In addition, in visual inspection, grand average waveforms of Wins in Low and High uncertainty conditions seem to occur more prominent than the No uncertainty condition, with more negative values under the curve. However, no significant differences emerged when comparing grand averages from the win responses to the different uncertainty conditions (χ^2=2.400, df=2, p=0.301) (descriptive statistics presented in appendix 9). Likewise, visual inspection of the Losses for Low and High uncertainty conditions seemed to have a different pattern, although no significant differences were found (W=42.000, df=9, p=0.160, r_{rb}=.527), nevertheless with a moderate effect size. One possible explanation of this lack of significance is the confidence interval size due to the relatively small sample size. Figure 10 plotted the Means and standard deviations for wins and losses gran averages at the FCz electrode when the tendency previously mentioned can be observed.

Figure 10.

Descriptives plot of the grand averaged for wins and losses at the FCz electrode in the three uncertainty conditions of the HiLo game



Another interesting result in the low uncertainty condition was observed. Visual inspection of the waveforms suggests a difference in processing wins and losses. This response effect (win x loss) (W = 48.00, p= 0.037, r_{rb}= .745) was yielded with a strong size effect (descriptive statistics presented in appendix 10). These analyses suggest that differences in the waveform patterns (total and per response) are related to changes in the degree of uncertainty.

Grand Averaged waveforms and behavioral data

Table 9 displays Spearman correlations between the Grand Averages (High Uncertainty, Low Uncertainty, and No-Uncertainty) at electrodes FCz and Cz (90-190ms) and behavioral data. The results indicated a significant positive correlation between the RT in High Uncertainty and RT in Low Uncertainty (ρ=0.685, p=0.035). Furthermore, RT in Low Uncertainty yielded a significant correlation with RT in No-Uncertainty (ρ=0.855, p < .001). RT in No Uncertainty correlated with RT in High Uncertainty (ρ=0.926, p=.004). No other significant correlations were found between the variables examined.

Table 9.

Grand Averaged waveforms and behavioral data correlations

		1	2	3	4	5	6
1. GA_HighU	ρ		0.370	-0.406	-0.091	-0.176	-0.503

	p-value		0.296	0.247	0.811	0.632	0.143
2. GA_ LowU	ρ	-0.006		-0.418	-0.176	-0.370	-0.442
	p-value	1.000		0.232	0.632	0.296	0.204
3. GA_NoU_WinCRN	ρ	-0.285	-0.285		0.139	-0.236	0.042
	p-value	0.427	0.427		0.707	0.514	0.919
4. RT HighU	ρ	0.055	-0.188	0.115			
	p-value	0.892	0.608	0.759			
5. RT LowU	ρ	0.115	-0.333	-0.139	0.685*		
	p-value	0.759	0.349	0.707	0.035		
6. RT No U	ρ	-0.273	-0.321	0.042	0.624	0.855**	
	p-value	0.448	0.368	0.919	0.060	0.004	

Note. GA=Grand Averaged; U=Uncertainty; WinCRN=Wins Correct-related Negativity; RT=Response Time. * p < .05, ** p < .01. Values under the diagonal correspond to the electrode FCz. Values above the diagonal correspond to the electrode Cz.

Flanker task vs. HiLo game

We compared Flanker response-related potentials CRN, ERN, and ERN in the 0-100ms epoch, and HiLo response-locked grand averages in the 90-190ms epochs, by uncertainty condition (no-uncertainty, low-uncertainty, and high-uncertainty). Spearman correlations are shown in Table 10. Results showed significant correlations between the Flanker CRN and No-uncertainty win GA at the electrode Cz in the HiLo game (ρ=0.691, p=0.023), and a significant correlation between Flanker CRN and ERN (ρ=0.764, p=0.009).

Table 10.

Spearman correlations between Flanker response-related potentials CRN, ERN and ΔERN in the 0-100ms epoch, and HiLo response-locked grand averages in 90-190ms epochs at electrodes FCz and Cz, by uncertainty condition (no-uncertainty, low-uncertainty, and high-uncertainty)

		Flanker_CRN		Flanker_ERN	Flanker_deltaERN
Flanker_CRN	ρ	—			
	p-value	—			
Flanker_ERN	ρ	0.764	**	—	
	p-value	0.009		—	
Flanker_deltaERN	ρ	0.591		0.018	—
	p-value	0.061		0.968	—
90_190ms_Cz_noU	ρ	0.709	*	0.406	0.536

		Flanker_CRN	Flanker_ERN	Flanker_deltaERN
	p-value	0.028	0.247	0.094
90_190ms_Cz_lowU	ρ	-0.527	-0.515	-0.364
	p-value	0.127	0.133	0.273
90_190ms_Cz_highU	ρ	-0.264	-0.209	-0.091
	p-value	0.313	0.560	0.797
90_190ms_FCz_noU	ρ	0.509	0.264	0.482
	p-value	0.114	0.435	0.137
90_190ms_FCz_lowU	ρ	-0.467	-0.564	-0.318
	p-value	0.178	0.096	0.341
90_190ms_FCz_highU	ρ	-0.091	0.042	-0.027
	p-value	0.811	0.919	0.946

Note. U=Uncertainty; ms=milliseconds; ERN=Error-related negativity; CRN=Correct-response negativity; ΔERN=ERN minus CRN. * $p < .05$, ** $p < .0,1$.

Discussion

The ERN was measured in the present exploratory study while participants completed the Flanker Task and the HiLo Game. As expected, the ERN was elicited in the Flanker task (i.e., larger negative deflection on error trials than on correct trials), suggesting the automatic error monitoring in the task. In contrast, contrary to hypothesized, the HiLo game at the no-uncertainty trials was not successfully eliciting the ERN. Most probably, the design of the HiLo game in the deterministic-like condition (no-uncertainty trials) is too easy to elicit enough errors in participant's responses and subsequently is not likely to elicit behavioral and neural error-detection differences; a limitation also addressed by Krain et al. (2006) when implementing this task with fMRI acquisition.

Regarding the Flanker task, expected accuracy differences across trial types (congruent and incongruent) were found. Further correlational analyses indicated a significant negative correlation between the CRN and RTs error for congruent trials, indicating that the CRN was dampened when

the participants dedicated more time to respond to the easy trials, and the outcome was an error. However, the CRN did not yield a significant correlation with accuracy (incongruent and overall). This lack of significance may be due to the relatively small sample size. Nevertheless, future studies should investigate this component more, considering that recent literature has shown a consistent relationship between enhanced CRN and obsessive-compulsive disorder (Endrass & Ullsperger, 2014; Riesel et al., 2021). Moreover, there is increased concern about the correctness of actions even in the absence of errors in OCD patients (Klawohn et al., 2014).

Concerning the HiLo game, different patterns of win and loss waveforms emerged by uncertainty conditions. When subjects performed high uncertainty trials (card 5), the odds are 2:1, resembling complete randomness; for this condition, our results suggested difficulty differentiating error from correct responses. Previous studies have pointed out similar findings with experimental manipulations of uncertainty, although with deterministic tasks to elicit early error-detection components (Pailing & Segalowitz, 2004). On the other hand, in low uncertainty trials, the opposite pattern was observed. Subjects could differentiate between wins and losses, suggesting a changing signaling pattern related to the degree of uncertainty experienced. In this condition, the ERN could not be elicited probably due to the high variability in the degree of uncertainty (trials with 7:1, 6:2, or 5:3 odds).

This study also observed a strong correlation between the CRN-like component (win waveform) in the no-uncertainty condition and the CRN elicited in the Flanker Task. This result suggests that correct responses (in Flanker) and wins (in HiLo) may be similarly processed when the outcome's uncertainty is null; therefore, the HiLo no-uncertainty trials may be comparable to the Flanker correct trials. To our knowledge, this is the first study to compare performance monitoring between a Flanker task and the Hilo game, and conclusions about the nature of the observed associations are difficult to draw. Several studies of error monitoring with gambling tasks

similar to the HiLo game have successfully elicited the ERN, and the majority have reported larger amplitudes of ERPs following losses (Chandrakumar et al., 2018; Wang et al., 2017). Nonetheless, they have been focused on the valence of feedback and risk-taking, and levels of uncertainty faced by the individuals have not been determined. Another common issue identified in gambling task studies is that clear dissociations between components and their time windows are problematic. That is because they usually are not adequately differentiated (i.e., Error-related negativity from the feedback-related negativity) (Chandrakumar et al., 2018).

As outlined above, the ERN, CRN, and deltaERN were successfully elicited in the Flanker task in the present investigation. Whereas the ERPs were not elicited in HiLo Game, our results provided insight into quantitative and qualitative differences by degrees of uncertainty conditions. The HiLo game is a task used in a few studies. Nevertheless, it offers an experimental manipulation of uncertainty intrinsic to the task and would have the advantage of avoiding psychophysical unknown intrasubject differences that can emerge in studies with subjective uncertainty manipulations (Jackson et al., 2015a; Pailing & Segalowitz, 2004). This task also explores behavioral and neural responses in different conditions (from deterministic-like to randomness). Especially the low uncertainty condition is more realistic-like because there is some level of predictability in the world, and we often are operating and learning in that kind of situation.

Moreover, to ensure a robust and reliable generation of error-related potentials in the HiLo game, the task could decompose the degrees of uncertainty even more. Each trial in the Hilo game has five possible arrangements, and each arrangement has a different probability of success. The high uncertainty condition has a 50% chance of success, while the no-uncertainty has a 100% chance of success. Nevertheless, the low uncertainty condition has three possible arrangements with different probabilities: 62.5% to cards 4 and 6, 75% to cards 3 and 7, and 87.5% to cards 2 and 8 (see appendix 7). The low uncertainty condition embraces a broader range of uncertainty,

whereas the high and no-uncertainty conditions have only one stable probability. Future studies would benefit from the differentiation between those levels of uncertainty and increasing the number of trials in the HiLo game to elicit the error-related potentials of interest.

Limitations and Further Considerations

The present study has several limitations. Most importantly, the analyses are primarily exploratory, and while the results provide some insight into the relationship between performance monitoring and uncertainty, consolidation in future studies is needed. Moreover, our sample was not only small but consisted exclusively of subjects with high OC symptomatology. We recommend that future investigations apply the OCI-R after electrophysiological recording to ensure similar symptoms and valid responses regarding the sample symptomatology. Another limitation is that we did not have any kind of contrast group (control group or groups with different levels of OC symptomatology).

Furthermore, future studies should explore deeply the relationship between error processing alterations and OC symptom severity under objective uncertainty experimental tasks like the one provided by the HiLo game. Further modifications of the HiLo game as an experimental uncertainty model may better understand the maladaptive mechanisms and OCD and the role of uncertainty in error monitoring in other clinical and non-clinical samples. Additional behavioral data such as a post-error slowing (PES) should also be included in forthcoming analyses of the Flanker task and the Hilo game to investigate task-specific variance in behavioral indicators across tasks.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have influenced the work reported in this paper.

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CHAPTER IV: GENERAL DISCUSSION

In this dissertation, we discussed the main theories of error monitoring, reviewed studies investigating aversiveness of errors and negative affect, and conducted one exploratory EEG study on the influence of error-related potentials in a deterministic task (Flanker) and a gambling task with varying uncertainty conditions (HiLo game). This section summarizes the main findings of the dissertation and how they relate to the broader fields of performance monitoring and the study of affect states and traits in a clinical and non-clinical population.

Study 1. Aversiveness of errors and negative affect in error monitoring

Study 1 reviewed experiments on affective states, aversiveness, and the error-related negativity (ERN) to summarize the conclusions in the field. We concluded that there is considerable evidence that the ERN is sensitive to affective states manipulations. However, comparison between results was difficult due to the heterogeneity of paradigms, designs and variables compared. This review also highlighted difficulties with assessing negative affect in error monitoring. In the literature reviewed, negative affect is a broad term that comprises affect, mood, and emotion. Hence the problem. The theoretical conceptualization on the matter is confusing, and the terms are often treated as interchangeable. That could impact the amassment of empirical findings and hider conclusions about the target constructs and their effects on error monitoring (Ekkekakis, 2013; Riesel, 2019a). We showed that different criteria lead to different measures of affect across studies. Therefore, choosing how to define affective states is a crucial issue to be considered when designing studies on error monitoring and affect manipulations (Hajcak et al., 2012).

Despite the conceptual inconsistencies, the reviewed studies suggest that the ERN is reliably sensitive to direct manipulations of affective states and that errors are experienced as distressing (Hajcak & Foti, 2008; Jackson et al., 2015a; Spunt et al., 2012). That is especially true for people with high sensitivity to aversiveness and negative affect (Olvet & Hajcak, 2008; Shackman et al., 2011b). Nevertheless, the conclusions of our review are based on a qualitative analysis of the studies. A meta-analysis of the selected studies was not conducted, and the effect sizes for the ERN amplitudes differences were not examined. Conducting a meta-analytic study of the affect states' manipulations and their effects on the ERN would be beneficial because we also identified high-powered replications challenges. Two studies with higher statistical power with non-replication findings (Cano Rodilla et al., 2016; Elkins-Brown et al., 2018) were replications of the paradigm of Inzlicht and Al-Khindi (2012). We highlighted cautiousness regarding significant effects reported in EEG low-powered studies (Button et al., 2013) because 61% of the reviewed studies had a sample with less than 50 subjects.

We conclude that to make meaningful contributions to the field; it is necessary to conceptualize with precision the constructs (*mood, emotion, affect*) and dimensions (*valence, arousal, dominance)* we are dealing with (Hajcak et al., 2012) to determine the precise nature of the affective modulations of the ERN.

Study 2. Performance monitoring under uncertainty

Study 2 was exploratory. In an OC symptomatology sample, we attempted to establish the ERN and ΔERN components of error responses at a gambling-type task (HiLo game). As a benchmark, the results were compared to those from Eriksen's Flanker task, which has consistently elicited the ERN in the literature (Riesel et al., 2013). However, we failed to elicit the error-related potentials of interest at the HiLo game. These results might be due to the simple nature of the

paradigm, especially in the no-uncertainty trials where participants are not prone to err; a limitation also referred by Krain et al. (2006) when implementing this task with fMRI acquisition. The HiLo game is an experimental paradigm with three levels of uncertainty decomposed as follows: high-uncertainty (trials with 2:1 odds), low-uncertainty (trials with 7:1, 6:2, or 5:3 odds), and no-uncertainty (trials in which the outcome is certain, so losses are not due to chance). Although the ERPs were not elicited in this study, our results provided insight into quantitative and qualitative differences by degrees of uncertainty conditions. Interesting findings were obtained by comparing the two tasks as well.

First, different patterns of waveforms emerged by uncertainty conditions. In the no-uncertainty condition, loss waveform was not considered due to scarce error commissioning, so the variance could not be analyzed. Results from the high uncertainty conditions indicated no significant differences between wins and losses waveforms, suggesting difficulty differentiating error from correct responses. In the low uncertainty condition, significant differences emerged between waveforms, while the ERPs were not generated. We suggest that the ERN could not be elicited probably due to the high variability in this level of uncertainty (trials with 7:1, 6:2, or 5:3 odds).

Second, the ERPs of interest were elicited in the Flanker task as expected. Interestingly, correlational analyses between behavioral data and ERPs indicated a significant correlation between the CRN and Response times in error congruent trials. We interpreted this in light of recent evidence regarding increased concern about the correctness of actions in OCD patients (Endrass & Ullsperger, 2014; Klawohn et al., 2014; Riesel et al., 2021). Likewise, we found a strong correlation between the CRN-like component (win waveform) in the no-uncertainty condition and the CRN

elicited in the Flanker Task. This result suggests that the HiLo win no-uncertainty trials may be comparable to the Flanker correct trials.

Finally, even if the error-related potentials could not be elicited in this study, that does not mean that the paradigm is not valuable for studying performance monitoring. Previous studies have studied the influence of uncertainty in error monitoring by manipulating subjective uncertainty through the unpredictability of the stimuli (Jackson et al., 2015b), attentional demands (Pailing & Segalowitz, 2004), or by associating the ERN with Intolerance to Uncertainty measure (Jackson et al., 2016). However, we outline the relevance of the HiLo game as an experimental paradigm that manipulates uncertainty objectively in the study of event-related potentials.

We conclude that the differentiation between the levels of uncertainty, focused on the low uncertainty condition, and increasing the number of trials in the HiLo game would elicit the error-related potentials of interest. As our analyses were exploratory, the results must be interpreted with caution. Future studies with larger sample sizes and different populations are needed.

Concluding remarks

Since Falkenstein et al. (1991) and Gehring et al. (1193) observed the error-related negativity (ERN), error monitoring processes have been widely studied in non-clinical and clinical samples (Hajcak, 2012b; Riesel, 2019b; Weinberg & Hajcak, 2011). Several theories of the functional significance of the ERN have been proposed (Alexander & Brown, 2010; Botvinick et al., 2001; Holroyd & Coles, 2002). However, as the ERN is thought to be detected by the midcingulate cortex (MCC), and in this structure, negative affect, pain, and cognitive control have been consistently integrated (Shackman et al., 2011), theories have emerged based on the motivational meaning and aversiveness of errors (Hajcak et al., 2005; Hajcak & Foti, 2008; Weinberg, Klein, et al., 2012).

The relationship between error monitoring and affective processes is complex. One of the biggest challenges in psychological and affective neuroscience is the conceptual consensus of emotion (Ekkekakis, 2013). This lack of theoretical consistency is systematically observed across paradigms, variables, and designs regarding experimental studies of error monitoring and affective states (Núñez-Estupiñan et al., 2021). Despite the conceptual confusion in the literature surrounding the constructs of affect, emotion, and mood, empirically substantial progress has been made in the understanding between error monitoring and the affective phenomena.

There is considerable evidence that the ERN is stable and related to trait vulnerability (Olvet & Hajcak, 2012; Weinberg, Riesel, et al., 2012) and has been proposed as a reliable psychiatric endophenotype (G. A. Miller & Rockstroh, 2013; Weinberg, Riesel, et al., 2012; Weinberg & Hajcak, 2011; de Souza et al., 2018). Nevertheless, there is growing evidence that the affective state inductions can modulate the ERN (Dreisbach & Fischer, 2012; Senderecka, 2018; Núñez-Estupiñan et al., 2021). We believe that implementing paradigms as the HiLo game, with proper modifications, would allow studying the ERN under the same level of emotional construct. The HiLo game could be conceptualized (following the distinctions proposed by Ekkekakis, 2013) as an intrinsic emotional task that manipulates uncertainty, a feature that makes the task promising to unveiled error monitoring-emotion interactions in OC symptomatology, other clinical samples, and non-clinical samples. Further theoretical and empirical investigation is needed if we seek a consensus and to be certain about the common and distinct phenomena regarding the electrophysiological signals to committing errors in deterministic and uncertain situations.

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APPENDICES

Appendix 1. Parecer consubstanciado do CEP

UFRGS - INSTITUTO DE PSICOLOGIA DA UNIVERSIDADE FEDERAL DO

PARECER CONSUBSTANCIADO DO CEP

DADOS DO PROJETO DE PESQUISA

Título da Pesquisa: Intolerância à incerteza e monitoramento de performance no Transtorno Obsessivo-Compulsivo

Pesquisador: Gustavo Gauer

Área Temática:

Versão: 2

CAAE: 94810418.6.0000.5334

Instituição Proponente: Instituto de Psicologia - UFRGS

Patrocinador Principal: MINISTERIO DA CIENCIA, TECNOLOGIA E INOVACAO

DADOS DO PARECER

Número do Parecer: 2.963.027

Apresentação do Projeto:

Na versão 2 deste estudo será investigada a negatividade relacionada ao erro(ERN), um potencial relacionado a evento e evocado por erros em tarefas cognitivas. O ERN(erro) tem sido considerado um endofenótipo potencial do transtorno obsessivo-compulsivo (TOC) podendo auxiliar na compreensão do funcionamento neurológico do transtorno e gerando benefícios para o seu tratamento. Participarão deste estudo 30 pessoas com alto sintomas de TOC e 30 controles com baixo sintomas de TOC. Será utilizada a Tarefa de Flanker, para gerar erros e o Teste Hi-Lo, para induzir intolerância à incerteza. Além do ERN (erro) serão registradas a negatividade relacionada à resposta correta(CRN) e a negatividade relacionada ao feedback (FRN). Será utilizado um design experimental, comparando um grupo clínico com um grupo controle saudável. Uma tarefa comportamental será realizada enquanto dados eletrofisiológicos dos participantes são registrados. Serão utilizados dois questionários e duas tarefas em um computador.

Objetivo da Pesquisa:

Objetivo Primário: O estudo visa elucidar a relação entre sintomas de TOC, monitoramento de performance e intolerância à incerteza. Também busca comparar as amplitudes do ERN e FRN (negatividade relacionada ao feedback) de uma amostra de participantes com alto sintomas de TOC, com uma amostra de baixos sintomas.

Endereço: Rua Ramiro Barcelos, 2600
Bairro: Santa Cecília **CEP:** 90.035-003
UF: RS **Município:** PORTO ALEGRE
Telefone: (51)3308-5698 **Fax:** (51)3308-5698 **E-mail:** cep-psico@ufrgs.br

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Objetivo Secundário: Investigar a influência da intolerância à incerteza no ERN e de uma amostra não clínica.Também gerar dados complementares sobre intolerância à incerteza e tomada de decisão. Um outro objetivo é explorar se a intolerância à incerteza pode ser preditiva sobre amplitude do ERN(erro) em ambos os grupos, gerando dados para futuras pesquisas.

Avaliação dos Riscos e Benefícios:

Riscos: Não há riscos concretos neste estudo. Os possíveis desconfortos decorrentes da participação na pesquisa são a possibilidade de se sentir incomodado em executar as tarefas. Além disso, a colocação da touca para registrar as ondas cerebrais poderá deixar o cabelo com resíduos do gel.

Benefícios: Os possíveis benefícios decorrentes da participação na pesquisa são ajudar, de maneira pessoal, a reconhecer algum problema existente do qual o participante não tinha conhecimento. Poderá também ajudar profissionais da área da saúde a avaliar mais corretamente pacientes com dificuldades psicológicas, o que influencia em um melhor tratamento para estas pessoas.

Comentários e Considerações sobre a Pesquisa:

Nas intervenções de terapia cognitiva-comportamental, a IU (Intolerância a Incerteza) tem sido considerada um dos principais tópicos de tratamento. Contudo, mais estudos empíricos são necessários para determinar se tratar a IU (Intolerância à Incerteza) é suficiente para melhorar significativamente os sintomas de TOC.

Considerações sobre os Termos de apresentação obrigatória:

O Termo de Consentimento Livre e Esclarecido está claro, quando explica que o participante responderá alguns questionários, participará de duas tarefas no computador, e registra que, se houver algum desconforto e necessidade de algum atendimento especializado o participante será encaminhado adequadamente. Registra que os dados coletados serão tratados confidencialmente e que serão guardados por cinco anos no Instituto de Psicologia da UFRGS no 1º andar sala 121 na Rua Ramiro Barcelos,2600.

Recomendações:

Não há recomendações a fazer.

Conclusões ou Pendências e Lista de Inadequações:

O projeto de pesquisa está aprovado por este CEP.

Considerações Finais a critério do CEP:

Endereço: Rua Ramiro Barcelos, 2600
Bairro: Santa Cecília **CEP:** 90.035-003
UF: RS **Município:** PORTO ALEGRE
Telefone: (51)3308-5698 **Fax:** (51)3308-5698 **E-mail:** cep-psico@ufrgs.br

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Este parecer foi elaborado baseado nos documentos abaixo relacionados:

Tipo Documento	Arquivo	Postagem	Autor	Situação
Informações Básicas do Projeto	PB_INFORMAÇÕES_BÁSICAS_DO_PROJETO_1132292.pdf	16/09/2018 19:13:49		Aceito
TCLE / Termos de Assentimento / Justificativa de Ausência	TCLE_Gerson_atualizado.pdf	16/09/2018 19:13:08	Gerson Siegmund	Aceito
Outros	ata_quali_gerson.pdf	02/07/2018 10:02:26	Gerson Siegmund	Aceito
Projeto Detalhado / Brochura Investigador	Projeto_plataforma_Brasil.docx	30/06/2018 18:24:31	Gerson Siegmund	Aceito
Folha de Rosto	flrostogerson050618.pdf	05/06/2018 11:52:13	Gustavo Gauer	Aceito
Outros	YBOCS.pdf	04/06/2018 10:30:38	Gerson Siegmund	Aceito

Situação do Parecer:
Aprovado

Necessita Apreciação da CONEP:
Não

PORTO ALEGRE, 15 de Outubro de 2018

Assinado por:
Milena da Rosa Silva
(Coordenador(a))

Endereço: Rua Ramiro Barcelos, 2600
Bairro: Santa Cecília **CEP:** 90.035-003
UF: RS **Município:** PORTO ALEGRE
Telefone: (51)3308-5698 **Fax:** (51)3308-5698 **E-mail:** cep-psico@ufrgs.br

Appendix 2. Termo de consentimento livre e esclarecido

TERMO DE CONSENTIMENTO LIVRE E ESCLARECIDO

Você está sendo convidado (a) para participar de um estudo que tem como finalidade entender como o nosso cérebro reage a erros e como tomamos decisões frente a situações de incerteza. Esta pesquisa está sendo realizada pelo Instituto de Psicologia da Universidade Federal do Rio Grande do Sul.

Se você aceitar participar da pesquisa, os procedimentos envolvidos em sua participação consistirão em responder alguns questionários, e participar de duas tarefas em um computador. Durante a tarefa no computador, a sua atividade cerebral será registrada por sensores (eletrodos) colocados com uma touca no couro cabeludo, na face (testa) e orelhas. Além disso, é colocado um cinto na altura do peito para manter a touca firme. Nenhum desses instrumentos emite qualquer sensação como choque ou calor. As tarefas terão duração aproximada em torno de 25 minutos cada e a colocação dos eletrodos com a touca em torno de 30 minutos.

Os possíveis desconfortos decorrentes da participação na pesquisa são a possibilidade de você se sentir incomodado em responder as perguntas do questionário, pois algumas perguntas são referentes à sua vida particular. Se você se sentir desconfortável, você poderá solicitar ao pesquisador a interrupção em qualquer momento, e caso necessite de algum atendimento especializado, comunique ao pesquisador que ele realizará o encaminhamento adequado. Ainda, você pode se sentir cansado ao responder as perguntas e executar a tarefa. Caso isto aconteça, você pode comunicar ao pesquisador, que imediatamente lhe atenderá no sentido de contornar a situação. Além disso, a colocação da touca para registrar as ondas cerebrais poderá deixar seu cabelo com resíduos do gel.

Os possíveis benefícios decorrentes da participação na pesquisa são ajudar, de maneira pessoal, a reconhecer algum problema existente do qual você não tinha conhecimento. Ao mesmo tempo que isso é um benefício, pode também ser um risco, pois talvez você perceba algum problema que até então não lhe incomodava. Porém se isso acontecer, e você manifestar interesse, a equipe de pesquisa lhe entregará uma lista de locais que oferecem atendimento psicológico a baixo custo. Sua participação poderá também ajudar profissionais da área da saúde a entender como a intolerância à incerteza e o monitoramento de erro afetam a nossa vida diária, resultando em benefício para as pessoas em geral.

Sua participação na pesquisa é totalmente voluntária, ou seja, não é obrigatória. Caso você decida não participar, ou ainda, desistir de participar e retirar seu consentimento, não haverá nenhum prejuízo ou consequência.

Não está previsto nenhum tipo de pagamento pela sua participação na pesquisa e você não terá nenhum custo com respeito aos procedimentos envolvidos.

Caso ocorra alguma intercorrência ou dano, resultante de sua participação na pesquisa, você receberá todo o atendimento necessário, sem nenhum custo pessoal.

Os dados coletados durante a pesquisa serão sempre tratados confidencialmente. Os resultados serão apresentados de forma conjunta, sem a identificação dos participantes, ou seja, o seu nome não aparecerá na publicação dos resultados. Os dados obtidos serão utilizados apenas para fins de pesquisa e serão mantidos por pelo menos cinco anos no Instituto de Psicologia da Universidade Federal do Rio Grande do Sul, Rua Ramiro Barcelos, 2600, 1º andar, sala 121.

Caso você tenha dúvidas, poderá entrar em contato com o pesquisador responsável, Dr. Gustavo Gauer, pelo telefone (51) 3308 5303, ou com o pesquisador Gerson Siegmund pelo telefone (51) 3029 4439. O respectivo Comitê de Ética em Pesquisa responsável por este projeto situa-se na Rua Ramiro Barcelos, 2600 (telefone: 3308 5698, e-mail: cep-psico@ufrgs.br).

Esse Termo é assinado em duas vias, sendo uma para o participante e outra para os pesquisadores.

_____ _____

Nome do participante da pesquisa Assinatura

_____ _____

Nome do pesquisador que aplicou o Termo Assinatura

Porto Alegre, de de 2018

Appendix 3. Questionário Sociodemográfico

Questionário Sociodemográfico

Nome (Iniciais):

Sexo: M☐ F☐ Outro☐

Data de nascimento: _____/_____/_____

Cor, Raça ou Etnia:

- ☐ Branca
- ☐ Negra
- ☐ Amarela
- ☐ Parda
- ☐ Indígena
- ☐ Outro (espefique)

Estado civil:
☐Solteiro ☐ Casado ☐ Divorciado ☐ União estável ☐Viúvo ☐Outro(qual?)

Escolaridade:
☐ Ensino Fundamental Incompleto
☐ Ensino Fundamental Completo
☐ Ensino Médio Incompleto
☐ Ensino Médio Completo
☐ Ensino Superior Incompleto
Curso: _____
☐ Ensino Superior Completo
Curso: _____
☐ Pós-Graduação Incompleta
Área: _____
☐ Pós-Graduação Completa
Área: _____

Nacionalidade: _____

Cidade e Estado onde reside: _____

Profissão: _____

Renda mensal familiar aproximada: R$_____

Filhos: Não tem ☐ 1☐ 2☐ 3☐ 4 ou mais ☐

Saúde
Você toma alguma medicação? Qual(is)?
Você faz algum acompanhamento psicoterapêutico?
Você sofre de algum problema médico?
Alguma fez já foi diagnosticado por algum psiquiatra ou psicólogo? O que, e quando?

Appendix 4. Sociographic Questionnaire

Demographic Questionnaire V1 04/04/2014

Demographic Questionnaire

1) **Sex:** *(please tick one)* Male ☐ Female ☐

2) **Age:** _____ **D.O.B.** _____

3) **Marital Status:** *(please tick one)*

Single ☐ Separated / Divorced ☐

Married or cohabiting ☐ Widowed ☐

4) **If single, separated, divorced or widowed, are you currently in a long term relationship?** *(please tick one)*

Yes ☐ No ☐

5) **Current Employment:** *(please tick one)*

Unemployed ☐ Long-term sick leave ☐

Employed or Self-employed ☐ Retired ☐

Student (Full-time) ☐ Homemaker ☐

6) **Occupation:**
What is your current or last (if not currently working) occupation?

_____

7) **Education:**

What is the highest qualification you have obtained (*please tick one*)?

☐ GCSE, CSE or O level

☐ National Vocational Qualification (NVQ)

☐ A level

☐ Other higher education qualification (e.g. diploma)

☐ University degree

☐ Post graduate qualification (e.g. Masters, PhD)

8) **Ethnic origin:** (*please tick one*)

White	☐	Black or Black British	☐
Mixed	☐	Chinese or Chinese	☐
British	☐	Asian or Asian British	☐

Any other ethnic group
(please specify) _____

9) Please specify below what your first spoken language is :

_____

10) **What is your total household income (per year)?**

_____

Appendix 5. Inventário de obsessões e compulsões - OCI-R

INVENTÁRIO DE OBSESSÕES E COMPULSÕES - OCI-R

As afirmativas a seguir referem-se a experiências que muitas têm em sua vida diária.
Circule o número que melhor descreve **O QUANTO** a experiência mencionada tem lhe causado ansiedade ou incomodado **NESTE ÚLTIMO MÊS.** Os números referem-se às seguintes etiquetas verbais:

0 = Nem um pouco
1 = Um pouco
2 = Moderadamente
3 = Muito
4 = Extremamente

1. Tenho guardado tantas coisas que elas atravancam o caminho.	0	1	2	3	4
2. Verifico coisas mais freqüentemente que o necessário.	0	1	2	3	4
3. Fico perturbado se os objetos não estão arrumados apropriadamente (de maneira adequada).	0	1	2	3	4
4. Sinto-me compelido a (tenho necessidade de) contar enquanto estou fazendo coisas.	0	1	2	3	4
5. Acho difícil (não gosto de) tocar um objeto quando eu sei que ele já foi tocado por estranhos ou certas pessoas.	0	1	2	3	4
6. Acho difícil controlar meus próprios pensamentos.	0	1	2	3	4
7. Coleciono coisas de que não preciso.	0	1	2	3	4
8. Verifico repetidamente portas, janelas gavetas, etc.	0	1	2	3	4
9. Perturbo-me se outras pessoas mudam a forma como arrumei as coisas.	0	1	2	3	4
10. Sinto que tenho que repetir certos números.	0	1	2	3	4
11. Às vezes tenho que me lavar ou me limpar pelo simples fato de me sentir contaminado.	0	1	2	3	4
12. Pensamentos desagradáveis vêm à minha mente contra a minha vontade e não consigo me livrar deles.	0	1	2	3	4
13. Evito jogar coisas fora, pois tenho receio de que. possa precisar delas mais tarde.	0	1	2	3	4
14. Verifico repetidamente o gás, as torneiras e os interruptores de luz após desligá-los.	0	1	2	3	4
15. Necessito que as coisas estejam arrumadas em uma certa ordem.	0	1	2	3	4
16. Sinto que há números bons e maus.	0	1	2	3	4
17. Lavo minhas mãos com maior freqüência e por mais tempo que . o necessário (do que a maioria das outras pessoas).	0	1	2	3	4
18. Freqüentemente tenho pensamentos sórdidos/sujos (maus ou ruins) e tenho dificuldade de me livrar deles.	0	1	2	3	4

TOTAL

Appendix 6. Escala obsessivo-compulsivo de Yale-Brown – Y-BOCS

ESCALA OBSESSIVO-COMPULSIVO DE YALE-BROWN – Y-BOCS

As questões 1 a 5 são sobre **PENSAMENTOS OBSESSIVOS**.

Obsessões são idéias, imagens ou impulsos indesejados que penetram no pensamento contra a vontade ou esforços para resistir a eles. Geralmente envolvem temas relacionados a danos, riscos ou perigos. Algumas obsessões comuns são: medo excessivo de contaminação, dúvidas recorrentes sobre perigo, preocupação extrema com ordem, simetria ou perfeição, medo de perder coisas importantes.
Por favor, responda cada questão assinalando o quadrado respectivo.

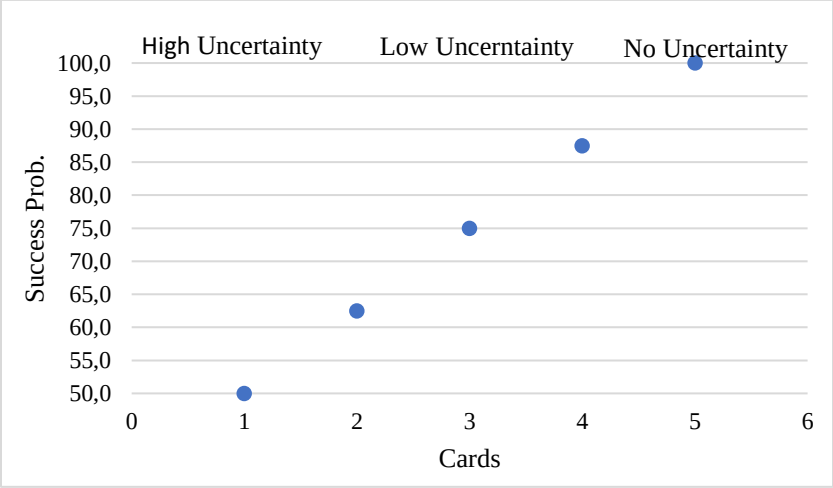
1. **TEMPO OCUPADO** POR PENSAMENTOS OBSESSIVOS P.: *Quanto de seu tempo é ocupado por pensamentos obsessivos?* 0 = Nenhum 1 = Menos de 1 hora/dia ou ocorrência ocasional 2 = 1 a 3 horas/dia ou freqüente 3 = Mais de 3 horas até 8 horas/dia ou ocorrência muito freqüente 4 = Mais de 8 horas/dia ou ocorrência quase constante	4. **RESISTÊNCIA** CONTRA OBSESSÕES P.: Até que ponto você se esforça para resistir aos seus pensamentos obsessivos? *Com que freqüência você tenta não ligar ou distrair a atenção desses pensamentos quando eles entram na sua mente?* 0 = Faz sempre esforço para resistir, ou sintomas mínimos que não necessitam de resistência ativa. 1 = Tenta resistir a maior parte das vezes 2 = Faz algum esforço para resistir 3 = Entrega-se a todas as obsessões sem tentar controlá-las, ainda que faça isso com alguma relutância 4 = Cede completamente a todas as obsessões de modo voluntário
2. **INTERFERÊNCIA** provocada pelos PENSAMENTOS OBSESSIVOS P.: *Até que ponto seus pensamentos obsessivos interferem com seu trabalho, escola, vida social ou outras atividades importantes? Há qualquer coisa que você não faça por causa deles?* 0 = Nenhuma 1 = Alguma: leve interferência com atividades sociais ou ocupacionais, mas o desempenho geral não é prejudicado 2 = Moderada: clara interferência no desempenho social ou ocupacional, mas conseguindo ainda desempenhar 3 = Grave: provoca prejuízo considerável no desempenho social ou ocupacional 4 = Muito grave: incapacitante	5. GRAU DE **CONTROLE** SOBRE OS PENSAMENTOS OBSESSIVOS P.: Até que ponto *você consegue controlar os seus pensamentos obsessivos? É habitualmente bem-sucedido quando tenta afastar a atenção dos pensamentos obsessivos ou interrompê-los? Consegue afastá-los?* 0 = Controle total 1 = Bom controle: geralmente capaz de interromper ou afastar as obsessões com algum esforço e concentração 2 = Controle moderado: algumas vezes capaz de interromper ou afastar as obsessões 3 = Controle leve: raramente bem sucedido quando tenta interromper ou afastar as obsessões, consegue somente desviar a atenção com dificuldade. 4 = Nenhum controle: as obsessões experimentadas como completamente involuntárias, raramente capaz, mesmo que seja momentaneamente, de desviar seus pensamentos obsessivos.
3. **SOFRIMENTO** relacionado aos PENSAMENTOS OBSESSIVOS P.: Até que ponto os seus pensamentos obsessivos o perturbam ou provocam mal-estar em você? (Na maior parte dos casos, a perturbação/mal-estar é equivalente à ansiedade; contudo, alguns pacientes podem descrever as suas obsessões como perturbadoras mas negam sentir ansiedade. (Avalie somente a ansiedade que parece ser desencadeada pelas obsessões, não a ansiedade generalizada ou a ansiedade associada a outras condições). 0 = Nenhuma 1 = Não atrapalha muito 2 = Incomoda, mas ainda é controlável 3 = Muito incômoda 4 = Angústia constante e incapacitante	Uso do entrevistador _____ ESCORE OBSESSÕES (parcial)

As questões seguintes são sobre **COMPORTAMENTOS COMPULSIVOS.**
As **compulsões** são impulsos que as pessoas têm que fazer para diminuir sentimentos de ansiedade ou outro desconforto. Freqüentemente, elas têm comportamentos intencionais repetitivos, propostos, chamados rituais. O comportamento em si pode parecer apropriado, mas se torna um ritual quando feito em excesso. Lavar, conferir, repetir, organizar, acumular coisas e outros comportamentos podem ser rituais. Alguns rituais são mentais. Por exemplo, pensar ou dizer coisas várias vezes em voz baixa.

6. **TEMPO GASTO** COM COMPORTAMENTOS COMPULSIVOS P.: ***Quanto tempo você gasta com comportamentos compulsivos? Quanto tempo você leva a mais do que a maioria das pessoas para realizar atividades rotineiras por causa de seus rituais? Com que freqüência você faz rituais?*** 0 = Nenhum 1 = Leve: menos de 1 hora/dia ou ocorrência ocasional de comportamentos compulsivos 2 = Moderado: passa 1 a 3 horas/dia realizando as compulsões (ou execução freqüente de comportamentos compulsivos) 3 = Grave: mais de 3 horas/dia até 8 horas/dia ou execução muito freqüente de comportamentos compulsivos 4 = Muito grave: passa mais de 8 horas/dia realizando compulsões (ou execução quase constante de comportamentos compulsivos - muito numerosos para contar)	9. **RESISTÊNCIA** às COMPULSÕES P.: ***Até que ponto você se esforça para resistir às suas compulsões?*** 0 = Faz sempre esforço para resistir ou sintomas tão mínimos que não necessitam de resistência ativa 1 = Tenta resistir na maior parte das vezes 2 = Faz algum esforço para resistir 3 = Cede a todas as compulsões sem tentar controlá-las, ainda que faça isso com alguma relutância 4 = Cede completamente a todas as compulsões de modo voluntário
7. **INTERFERÊNCIA** provocada pelos COMPORTAMENTOS COMPULSIVOS Até que ponto suas compulsões **interferem em sua vida social ou profissional? Existe alguma atividade que você deixa de fazer por causa das compulsões? (se atualmente não estiver trabalhando, avalie até que ponto o desempenho seria afetado se o paciente estivesse empregado)** 0 = Nenhuma 1 = Alguma: leve interferência com atividades sociais ou ocupacionais, mas o desempenho global não está deteriorado 2 = Moderada: clara interferência no desempenho social ou ocupacional, mas conseguindo ainda desempenhar 3 = Grave: provoca prejuízo considerável no desempenho social ou ocupacional 4 = Muito grave: incapacitante	10. GRAU DE **CONTROLE** SOBRE O COMPORTAMENTO COMPULSIVO P.: Com que força você se sente obrigado a executar os comportamentos compulsivos? Até que ponto consegue controlar as suas compulsões? 0 = Controle total 1 = Bom controle: sente-se pressionado a realizar as compulsões mas tem algum controle voluntário 2 = Controle moderado: sente-se fortemente pressionado a realizar as compulsões e somente consegue controlá-las com dificuldade 3 = Controle leve: pressão muito forte para executar as compulsões; o comportamento compulsivo tem que ser executado até o fim e somente com dificuldade consegue retardar a execução dessas compulsões 4 = Nenhum controle: a pressão para realizar as compulsões é experimentada como completamente dominadora e involuntária; raramente capaz de, mesmo que seja momentaneamente, de retardar a execução das compulsões
8. **SOFRIMENTO** relacionado aos COMPORTAMENTOS COMPULSIVOS P.: Como você sentiria se fosse impedido de realizar sua(s) compulsão(ões)? Quão ansioso você ficaria? 0 = Nenhum 1 = Leve: ligeiramente ansioso se as compulsões forem interrompidas, ou ligeiramente ansioso durante a sua execução 2 = Moderado: A ansiedade sobe a um nível controlável se as compulsões forem interrompidas, ou a ansiedade sobe a um nível controlável durante a sua execução 3 = Intenso: aumento proeminente e muito perturbador da ansiedade se as compulsões forem interrompidas, ou aumento de ansiedade proeminente e muito perturbador durante sua execução 4 = Muito intenso: ansiedade incapacitante a partir de qualquer intervenção com o objetivo de modificar as compulsões, ou ansiedade incapacitante Durante a execução das compulsões	Uso do entrevistador _____ ESCORE COMPULSÕES

ESCORE TOTAL: _____ (OBSESSÕES +COMPULSÕES

Appendix 7. Probability distribution across uncertainty conditions in the HiLo game.



Appendix 8. Descriptive statistics for wins and losses in High Uncertainty

	LossCz	WinCz	LossFCz	WinFCz
Valid	10	10	10	10
Missing	0	0	0	0
Mean	-1.248	-0.338	-1.320	0.152
Median	-1.780	0.024	-0.665	0.604
Std. Deviation	4.274	2.697	3.968	2.922
Shapiro-Wilk	0.977	0.934	0.946	0.951
P-value of Shapiro-Wilk	0.945	0.488	0.623	0.680
Minimum	-8.262	-5.243	-7.383	-4.928
Maximum	6.825	3.094	6.427	4.219

Appendix 9. Descriptive statistics for grand averages wins in the three uncertainty conditions at electrode FCz and Cz

winsGA	Mean	SD	N
HU_FCz	0.152	2.922	10
LU_FCz	-1.103	2.838	10
NU_FCz	1.027	5.144	10
HU_Cz	-0.338	2.697	10
LU_Cz	-1.010	3.280	10
NU_Cz	1.615	4.638	10

Note. HU= high uncertainty; LU= low uncertainty; NU=no-uncertainty; GA= grand averages.

Appendix 10. Descriptive statistics for wins and losses in Low Uncertainty

	LossCz	WinCz	LossFCz	WinFCz
Valid	10	10	10	10
Missing	0	0	0	0
Mean	-4.139	-1.010	-4.256	-1.103
Median	-3.136	-0.670	-3.826	-0.223
Std. Deviation	4.507	3.280	4.396	2.838
Shapiro-Wilk	0.922	0.960	0.943	0.898
P-value of Shapiro-Wilk	0.371	0.790	0.589	0.208
Minimum	-10.835	-6.571	-10.201	-6.144
Maximum	1.907	3.391	3.220	2.031