Fall 12-2021

The Influence of Emotion Regulation and Neural Cognitive Control on Distress Tolerance

Alicia L. Milam
Old Dominion University, akruz001@odu.edu

THE INFLUENCE OF EMOTION REGULATION AND NEURAL COGNITIVE CONTROL ON DISTRESS TOLERANCE

by

Alicia L. Milam
B.A., B.S. December 2015, University of Texas at San Antonio

A Thesis Submitted to the Faculty of
Old Dominion University in Partial Fulfillment of the
Requirements for the Degree of

MASTER OF SCIENCE

PSYCHOLOGY

OLD DOMINION UNIVERSITY
December 2021

Approved by:

Michelle L. Kelley (Director)

Matt R. Judah (Member)

Konstantin Cigularov (Member)

ABSTRACT

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Alicia L. Milam
Old Dominion University, 2021
Director: Dr. Michelle Kelley

Tolerance of negative emotions has been associated with transdiagnostic negative mental health outcomes. Theory and research implicate emotion regulation and cognitive control as factors in tolerance of negative emotions. But their unique contributions to tolerance of negative emotions and interdependency have been unclear due to methodological limitations. This study aimed to explicate cognitive and emotional factors affecting distress tolerance in a non-clinical sample of emerging adults. Undergraduate psychology students completed self-report measures of emotion regulation ability and tolerance of negative emotions. The N2 ERP component elicited by a Go-NoGo task was also used as a neurophysiological marker of cognitive control with larger mean difference amplitudes indicating greater cognitive control. Age correlated significantly with tolerance of negative emotions and cognitive control and was included as a covariate. Individuals with high emotion regulation ability were found to have greater tolerance of negative emotions. Larger mean N2 difference amplitudes predicted greater tolerance of negative emotions before age was added to the model, but was no longer significant when age was included as a covariate. No significant interactive effects were found between emotion regulatory ability and cognitive control predicting tolerance of negative emotions. These findings suggest that emotion regulation training may be the most appropriate target to increase tolerance

of negative emotions. Future studies should increase power and assess emotional salience and temporal dynamics of self-regulation to further clarify the mechanism of these relationships.

This thesis is dedicated to my husband, my adventure buddy.
Per aspera ad astra.

ACKNOWLEDGEMENTS

I want to thank everyone that has assisted with the completion of this project in the face of unprecedented obstacles during the pandemic. I would like to thank Dr. Matt Judah and Dr. Michelle Kelley for their mentorship during this process and Dr. Konstantin Cigularov for his comments and support. Additionally, I am grateful to the undergraduate research assistants that made data collection possible as well as the collaboration between Old Dominion University and University of Arkansas students.

I am thankful for my cohort, family, and friends who have been instrumental in ensuring appropriate self-care and have acted as a sounding board for my ideas. And to my husband most of all, who found creative ways to support me and provide boundless encouragement, both from afar and here with me, I want to express my appreciation and affection. In times such as these, I am so thankful for your love and revel in the knowledge that the arduous nature of graduate school has only brought us closer. Lastly, I would like to thank the Virginia Space Grant Consortium for their financial support with the Graduate Research STEM Fellowship and for welcoming me into their scientific community.

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CHAPTER I

INTRODUCTION

Low distress tolerance, especially low tolerance of negative emotions, has been identified as a core feature in a wide range of psychological disorders (Zvolensky et al., 2010). Distress tolerance is a relatively stable trait-like construct (Cummings et al. 2013), but its malleability has been suggested by the effectiveness of targeted interventions (Hayes, 2004; Linehan, 1987; Segal et al., 2002). These treatments may benefit from better understanding factors that predict distress tolerance. Distress tolerance is conceptualized as a form of goal-directed self-regulation (Leyro et al., 2010). Goal-oriented models of self-regulation have found that cognitive control and emotion regulation are principal components of self-regulation (Koole & Aldao, 2016; Wagner & Heatherton, 2016), thus they may play a role in distress tolerance.

Limited research supports this (Arici-Ozcan et al., 2019; Bardeen et al., 2015; Benfer et al., 2017; Macatee, Albanese, Clancy, et al., 2018), but little research has examined cognitive control and emotion regulation together in order to understand their unique and interactive associations with distress tolerance. Gaining a better understanding of the effects of emotion regulation and cognitive control on distress tolerance may be crucial to interrupting cycles of maladaptive coping by advancing treatments using self-regulation as a mechanism of change. The proposed study endeavors to examine whether emotion regulation and cognitive control will act as unique predictors of tolerance of negative emotions. Given their theorized relationship, this design will allow each variable to control for the other. This study will also aim to close a gap in the literature concerning specific mechanisms of cognitive-affective self-regulation by evaluating the moderating role of cognitive control in the relationship between emotional regulation ability and tolerance of negative emotions.

Distress Tolerance

Distress occurs when an individual experiences a response to a specific stimuli that creates an internal conflict, negative feelings, discomfort, or pain (Ridner, 2004). An evolutionary perspective of distress would suggest that these unpleasant feelings operate to motivate an individual to respond to a situation or stimulus that has the potential to threaten survival (Bracha, 2004; Carretié et al., 2009; Tracy, 2014). For example, seeing a snake may cause a distressing fear response to act as a cue to avoid the threat. Distress cues can be unreliable due to the complexity of selecting the most adaptive responses for the context. Distress cues may become problematic when they activate too forcefully for the situation, respond to non-threatening stimuli, or drive maladaptive coping strategies (Ghaemi Kerahrodi & Michal, 2020; Swerdlow et al., 2020). Having an appropriate level of tolerance for distress can allow an individual to regulate their behavior in a more adaptive manner (Ke & Barlas, 2020; Myruski et al., 2017). For instance, the ability to endure an unpleasant interaction with a boss or colleague may permit an appropriate interpretation and response that will allow the individual to keep their job.

Distress tolerance is the ability to withstand discomfort in the pursuit of a goal (Leyro et al., 2010). Distress tolerance allows an individual to resist emotional impulses that may be detrimental to their goals and relationships, such as yelling at their boss when they want to keep their job to remain financially stable. According to the hierarchical model of distress tolerance, distress tolerance is comprised of five subdomains: tolerance of uncertainty, tolerance of ambiguity, tolerance of frustration, tolerance of negative emotions, and tolerance of physical discomfort (Bardeen et al., 2013; Zvolensky et al., 2010). Previous literature has found that low distress tolerance, particularly low tolerance of negative emotions, is a transdiagnostic risk factor across a range of psychopathology. Tolerance of negative emotions refers to a secondary reaction to emotional distress distinct from related emotion constructs such as state and trait negative affectivity (Cougle et al., 2011; Keough et al., 2010). Kremyar et al. (2019) evaluated this distinction using factor analysis and found that tolerance of negative emotions loaded onto a factor separate from negative emotionality and demoralization.

Distress tolerance, and its subdomain, tolerance of negative emotions, are important in emerging models of psychopathology, such as the hierarchical taxonomy of psychopathology (HiTOP; Kotov et al., 2017). HiTOP utilizes factor analysis and comorbidity meta-data to create a dimensional classification system for psychopathological symptoms. Within the HiTOP framework, tolerance of negative emotions has been primarily associated with internalizing distress disorders including generalized anxiety disorder (Keough et al., 2010), depression (Benfer et al., 2017; Williams et al., 2013), and posttraumatic stress disorder (PTSD; Erwin et al., 2018; Vujanovic et al., 2011), eating pathology (Anestis et al., 2012; Kelly et al., 2014; Yiu et al., 2018), and fear dimensions (Bernstein et al., 2011) such as obsessive-compulsive disorder (Laposa et al., 2015; Robinson & Freeston, 2014), specific phobias (Michel et al., 2016), and panic disorder (Kutz et al., 2010). Disinhibited externalizing behaviors such as substance abuse (Allan et al., 2015; Zvolensky et al., 2009), suicidality (Anestis, Knorr, et al., 2013; Anestis, Pennings, et al., 2013; Franklin et al., 2011), and self-harm (Peterson et al., 2014; Slabbert et al., 2018), as well as nonpathological disinhibited behaviors (Anestis et al., 2012) including risky sexual behaviors (Tull & Gratz, 2013) and dangerous driving habits (Beck et al., 2013), have also been associated with low tolerance of negative emotions. Evidence suggests that these disinhibited externalized behaviors constitute a maladaptive means of coping with internal distress (Macatee et al., 2016; Anestis et al., 2013; Magidson et al., 2013; Özdel & Ekinci, 2014) demonstrating the pervasive impact tolerance of negative emotions can have on overall functionality and quality of life.

In addition to acting as a risk factor for the development and maintenance of symptoms, tolerance of negative emotions is implicated as a factor in suboptimal treatment outcomes (Cummings et al., 2013; Reese et al., 2019). Low tolerance of negative emotions contributes to interference with treatment engagement (Bornovalova et al., 2012), high treatment dropout rates (Daughters et al., 2005), and decreased symptom reduction following treatment (Banducci et al., 2017). Low tolerance of negative emotions may interfere with behavioral interventions that require the individual to endure distress in pursuit of long-term treatment goals. For example, exposure therapy requires patients to approach and remain in the presence of stimuli or situations that evoke negative emotion (Clark, 2013). Substance use treatments involve tolerance of negative emotions resulting from withdrawal, so it is not surprising that low distress tolerance predicts readiness for change (Ali et al., 2017; Basharpoor et al., 2020) and relapse (Shorey et al., 2017). Cognitive therapies may also be impacted by low tolerance of negative emotions, which has been associated with rigid cognitive schemas and interpretation bias (Kertz et al., 2015; Oglesby et al., 2018), as well as a reluctance to experience the cognitive dissonance involved in therapy to elicit treatment effects (Basharpoor et al., 2021; McHugh et al., 2014). Tolerance of negative emotions also plays a role in the treatment outcomes of acceptance and skill-based therapies, such as Dialectical Behavior Therapy (DBT; Linehan, 1987). Research suggests that patients who complete treatments without addressing distress tolerance are more likely to relapse (Hsu et al., 2013), highlighting the importance of distress tolerance as an important resilience factor (Arici-Ozcan et al., 2019; Hosseinian & Nooripour, 2019). Overall, there is evidence demonstrating the important role of tolerance of negative emotions in mental health treatment outcomes. Thus, a better understanding of tolerance of negative emotions may be important in improving treatment outcomes (Macatee et al., 2015).

Tolerance of negative emotions has been measured primarily by self-report. Self-report measures of tolerance of negative emotions include the Distress Tolerance Scale (DTS; Simons & Gaher, 2005) and Distress Intolerance Scale (DIS; McHugh & Otto, 2012). The DTI incorporates anxiety sensitivity, tolerance of frustration, and tolerance of emotions; thus, research with the DTI may focus on anxiety and related psychological disorders while the DTS has more broad application and associations with a wider range of psychological disorders connected to tolerance of negative emotions (Bebane et al., 2015; Cougle et al., 2013; Mitchell et al., 2013). In addition to self-reports, only one behavioral measure has been designed to assess tolerance of negative emotions. The Emotional Image Tolerance (EIT) task measures the latency of persistence in viewing unpleasant images after negative emotional distress has been established (Veilleux et al., 2019). However, relationships between the EIT and psychopathology are limited to modest correlations; thus, as a self-reported measure of tolerance of negative emotions, the DTS is likely to have greater clinical utility (Glassman et al., 2016). Tolerance of negative emotions has also been found to be highly correlated with perceived stress, state and trait negative affect, and impulsivity while behavioral distress tolerance is a performance measure more closely related to achievement and not significantly correlated with psychopathology or self-reported distress tolerance (Kiselica et al., 2015). The EIT may be a better representation than the DTS of behavioral persistence through negative affect, but the DTS likely better represents *willingness* to persist through negative affect (Veilleux et al., 2019) or broader beliefs about one’s ability to persist. As reviewed above, such beliefs have been linked to important outcomes by considerable research using the DTS. Given that individuals with low tolerance of negative emotions believe that they are unable to persist through experiencing negative affect, they may seek more immediate relief by engaging in detrimental avoidance or maladaptive coping behaviors (Anestis et al., 2012; Huang et al., 2009; Lass et al., 2020). Other forms of self-regulation, such as emotion regulation, may play a key role in determining the level of confidence an individual has in their ability to tolerate negative emotion.

Emotion Regulation

Emotion regulation refers to any strategy used to alter or control an individual's emotional experience including behavioral, physiological, and subjective aspects of emotional responses (Campos et al., 1989; Gross & Muñoz, 1995). This may be done consciously or unconsciously (Gyurak et al., 2011; Koole et al., 2015; Koole & Rothermund, 2011) and may be either adaptive or maladaptive depending on the strategy chosen in a particular context and the goals of the individual (Aldao & Nolen-Hoeksema, 2012; English et al., 2017; Tamir, 2016; Tamir & Gutentag, 2017). Emotion regulation has emerged as an underlying transdiagnostic mechanism implicated in the development and maintenance of a broad range of psychopathology related to affect (Aldao et al., 2010; Beauchaine & Zisner, 2017; Bradley, 1990) and has been recognized as a feature of psychopathology in every major category of psychiatric disorder in the DSM-5 (American Psychiatric Association, 2013).

The process model of emotion regulation (Gross, 1998, 2001) has been instrumental in creating unifying terminology and defining the time course of regulatory strategies. Gross presents an exhaustive outline of the course of emotional reactivity and regulation using a cognitive-behavioral framework. According to the process model, an emotional response occurs in a given situation in which an emotion-eliciting stimulus is present. The individual attends to the stimulus or a particular aspect of the stimulus, appraises or interprets the stimulus, which then leads to a particular response. Gross (2015) postulates that regulation of an emotional reaction can happen at any point in this process with differential properties at each point (Gross, 2015).

The point at which an emotional reaction is regulated is used to characterize each emotion regulation strategy. Prior to the situation occurring, an individual can engage in situational selection by determining what stimuli to expose themselves to through approach or avoidant behaviors. Situational modification occurs during the presentation of a stimulus and involves a change in the situation itself such as an individual distancing themselves from a stimulus. An individual may also choose to distance themselves mentally from a stimulus using attentional deployment strategies such as distraction. If an individual does not choose to disengage from the stimulus, they may decide instead to reframe their interpretation of a particular stimulus through cognitive change strategies such as cognitive reappraisal. An individual may also attempt to regulate through response modulation which may be viewed as a coping strategy such as expressive suppression or self-harm during or after the occurrence of an emotional reaction (Barrett et al., 2001; Gross, 2014, 2015).

The utilization of a particular regulation strategy will influence the way an individual interacts with the emotional stimulus in the future (Farmer & Kashdan, 2014; Gross, 2002; Williams et al., 2018). Much research has focused on the consequences of using different adaptive or maladaptive regulation strategies in clinical and healthy populations (Aldao et al., 2014; Birk & Bonanno, 2016; Thompson et al., 2010; Vanderhasselt et al., 2014). While a given strategy may be more commonly associated with positive or negative outcomes, it is important to note that regulation strategies are highly context-dependent, and their adaptiveness should be determined by the outcome rather than the chosen process (Birk & Bonanno, 2016; Haines et al., 2016; Koole & Veenstra, 2015).

The ability to deliberately choose and apply a regulatory strategy depends first on the ability to recognize and understand different emotional states, particularly negative emotional states (Kashdan et al., 2015). Kalokerinos et al. (2019) found that low negative emotional differentiation affects the appropriate and effective use of emotion regulation for down-regulating negative emotion, but not adaptive strategy selection. It has also been shown that intrapersonal emotional differentiation is related to interpersonal emotion differentiation which likely impacts the ability to set appropriate affective goals and subsequently use flexible regulation required in social settings (Israelashvili et al., 2019). Regulatory flexibility is the ability to assess internal and external states and choose the regulatory strategy most appropriate to achieve adaptive goals in context as well as shift strategies fluidly. Past findings suggest that this flexibility is a key skill for adaptive emotional regulation and broader reactive resilience (Aldao et al., 2015; Bonanno & Burton, 2013; Haines et al., 2016; Kobylińska & Kusev, 2019; Waugh et al., 2011).

Belief in the controllability of emotions is related to more successful use of regulation (Ford & Gross, 2019; Gutentag et al., 2017) and increased emotion regulation flexibility (Bonanno & Burton, 2013; Kobylińska & Kusev, 2019). The belief that emotions are uncontrollable also leads to higher levels of distress and decreased successful use of adaptive strategies regardless of strategy selection (Kneeland et al., 2016). A possible explanation for this relationship could be that diminished overall self-efficacy for emotion regulation leads to a decrease in regulatory success and an increase in negative affect, as observed with reappraisal specific processes (De Castella et al., 2018; Lee & Hayes-Skelton, 2018; Zlomuzica et al., 2015).

Self-report measures of emotion regulation use three main approaches to assess individual differences: evaluating the frequency of specific strategy usage, stress coping strategy usage, and regulatory competency (Gross, 2014, p. 331). Measures that assess stress coping do not focus on a specific emotion or immediate stimuli; rather, they tend to assess general coping mechanisms for nonspecific stressors without regard for the efficacy, duration, or target of regulation. This approach may be more akin to exploring behavioral patterns impacting mood over time than the other two approaches, which focus on specific emotional responses to immediate stimuli. Although the assessment of specific strategy use is aligned with the process model, research paradigms using this approach must account for the context and goals of the regulatory strategy use. Without the measurement of regulatory flexibility and outcomes following strategy use, conclusions that can be drawn from the assessment of strategy use alone are limited. By asking an individual how effectively they are able to regulate their emotions, the use of measures assessing regulatory competency account for self-efficacy, outcomes following regulation, and are not limited by the context of the regulation (Gross, 2014, p. 333).

Emotion regulation and tolerance of negative emotions are both forms of self-regulation used to cope with negative affect, thus prompting questions about the directionality of their relationship (Van Eck et al., 2017). Belief in a weakened ability to withstand negative affect leads to a sense that the emotional state must be changed, motivating an individual to attempt to regulate their emotions. The degree of effectiveness will then likely be diminished due to the impulsive nature of the regulation attempt with the goal of short-term relief from affect, and subsequent poor strategy selection (McMahon & Naragon-Gainey, 2018; Naragon-Gainey et al., 2017). In a study examining the effective use of emotion regulation strategies in individuals with low and high distress tolerance, Jeffries et al. (2016) found that individuals with low tolerance of negative emotions engaged in more maladaptive and ineffective emotion regulation strategy use such as avoidance, suppression, and distraction rather than more adaptive strategies such as reappraisal and acceptance.

Similarly, emotion regulation predicts an individual's ability to tolerate negative emotion (Arici-Ozcan et al., 2019; Bardeen et al., 2015; Macatee, Albanese, Clancy, et al., 2018), as ineffective emotion regulation is likely to increase distress levels or make it difficult for downregulation of negative affect to occur. This *pattern* may signal to an individual that they are unable to cope with distress (Dryman & Heimberg, 2018), decreasing tolerance of negative emotions. Damaged coping self-efficacy would then be reinforced by future experiences in a cyclical manner such that deficits in both emotion regulation and tolerance of negative emotions may impact psychological well-being and emotional functionality (Ford et al., 2017; Ford & Gross, 2018). Van Eck and colleagues (2017) used factor analyses and latent profile analyses to determine the impact of emotion regulation and tolerance of negative emotions on various negative mental health outcomes finding both unique and interdependent relationships between emotion regulation and tolerance of negative emotions.

Because tolerance of negative emotion determines how overwhelming negative affect is, it is possible for two individuals to report identical subjective distress levels while the individual with higher tolerance of negative emotions is functionally less affected. Those with low tolerance of negative emotions are more likely to devote a greater amount of cognitive resources to attending to negative affect, impairing their ability to make goal-oriented decisions including how to best regulate emotions (Preston et al., 2020). Attentional deployment could also be used to divert attention away from distress or to a given goal, thereby increasing tolerance levels. For instance, Benfer et al. (2017) found that attention to negative emotions moderated the relationship between low negative emotional distress tolerance and internalizing symptoms in individuals that attended to negative emotions without direction but not in those expressly directed to attend to negative emotions. This suggests that emotion regulation ability may relate to tolerance of negative emotions differently based on whether conscious effort is being employed toward thought control in tolerance of negative emotions (Braunstein et al., 2017; Mauss et al., 2007). Thus, cognitive control may also be an important factor in tolerance of negative emotions. The present study hypothesizes that fewer emotion regulation difficulties will predict higher levels of reported tolerance of negative emotion when controlling for cognitive control (Hypothesis 1).

Cognitive Control

Cognitive control, or executive function, involves monitoring and controlling thought processes that influence goals and behaviors, broadly encompassing the cognitive processes of shifting, updating, and inhibition (Friedman & Miyake, 2017). Shifting, or task-switching, refers to moving between mental sets. Goals must be understood and often prioritized to optimally shift focus from one goal to another, implicating shifting in cognitive and psychological flexibility (Herd et al., 2014). Updating is the ability to sustain and amend information while minimizing the influence of distractions and is commonly associated with working memory (Coifman et al., 2019). Inhibition is often referred to as the ability to halt an automatic response, usually due to a conflict in goals (Friedman & Miyake, 2004). The ability to identify a goal, monitor potential conflicts, identify a response as inconsistent with a goal, and halt an automatic, or prepotent, response have all been previously associated with inhibitory control (Miyake & Friedman, 2012; Xie et al., 2017).

Recent literature has found that inhibitory control is the core domain of cognitive control. Utilizing latent variable modeling, Friedman & Miyake (2017) found that their initial three-factor solution describing inhibition, shifting, and updating as the fundamental processes of cognitive control was better characterized as a bifactor model due to a tendency for all behavioral measures of cognitive control to load onto the inhibition factor. Thus, inhibition is now considered the core domain of cognitive control, enabling maintenance of goal focus by preventing distraction.

Attention and conflict monitoring are essential components of inhibitory control. Conflict monitoring theory proposes that increased attentional control is engaged to detect competition between conflicting potential responses or goals (Botvinick et al., 2001, 2004). When the response required by a stimulus differs from the anticipated or prepotent response, inhibitory control is recruited to resolve the conflict. Inhibitory control then utilizes both conflict monitoring and attentional control to prevent an unwanted response that does not align with a particular goal. For example, in the Go-NoGo task, participants must respond to more frequent "Go" stimuli and inhibit responses from "NoGo" stimuli. Conflict between the prepotent tendency to respond to "Go" stimuli and the goal of not responding to "NoGo" stimuli is resolved by the detection of this conflict, triggering recruitment of cognitive control to resolve it through inhibition (Kropotov et al., 2011; Randall & Smith, 2011). The inhibition process may be influenced by salient distractors such as distressing emotions which can make it more difficult to maintain a goal-oriented approach or make the desired goal less clear (Leshem & Yefet, 2019).

Many researchers view cognitive control as influential to emotion processing, with emotional responses determined, in part, by the ability to inhibit or regulate an automatic emotional response. Inzlicht et al. (2015) further postulate that emotion is the foundation of cognitive control due to the emotion-based input required for recognizing the value of a particular goal. Neuroimaging studies suggest that both emotionally salient and emotionally non-salient aspects of cognitive control may influence regulatory processes related to emotion both uniquely and interactively (Doré et al., 2017; Ochsner et al., 2012). For instance, Brown et al. (2015) found that individuals with high impulsivity had lower levels of activation in areas associated with emotion regulation on both emotional and non-emotional Go-NoGo tasks. They also found that participants exhibiting more impulsive behavior reported higher subjective distress ratings on emotional Go-NoGo tasks which was associated with lower activation of prefrontal regions indicative of regulatory control. Additionally, self-reported cognitive control has been associated with both emotion regulation ability (Gutiérrez-Cobo et al., 2017; Hayes et al., 2010) and tolerance of negative emotions (Arici-Ozcan et al., 2019; Bardeen & Fergus, 2016; Juarascio et al., 2020; Mitchell et al., 2017).

Tolerance of negative emotions requires an individual to do a cost-benefits analysis to determine whether a given goal is valued above the experience of unpleasant affect (Leyro et al., 2010). To increase tolerance of negative emotions, an individual must be able to look beyond current distress and self-preservation to a later desired goal and inhibit the prepotent response of seeking relief through emotion regulation (Macatee, et al., 2015; Marshall et al., 2011). Clear goal-directed behavior in response to emotional stimuli requires the ability to assess a situation, identify and prioritize a goal, then inhibit an automatic response that is not aligned with that goal (Marks et al., 2019; Sommers & Coffen, 2017). Thus, cognitive control employed for tolerance of negative emotions likely engages conflict monitoring and attentional control for inhibitory control and may interact with emotion regulation.

Effective emotion regulation necessitates the acknowledgment of a conflict between the current affect and the goal affect, therefore also using cognitive resources (Schmeichel, 2007). Cognitive resources are limited and must be allocated in a prioritized manner for efficient processing (Ansari & Derakshan, 2011; Gan et al., 2017; Ortner et al., 2016). Self-regulation requires the use of cognitive resources, restricting the regulatory processes that can occur concurrently (Blair, 2016). For instance, it has been noted that the behavioral measurement of distress tolerance is currently restricted due to excessive cognitive task demands (McHugh & Otto, 2011, 2012; Veilleux et al., 2019). Those with increased access to cognitive resources are better able to complete concurrent tasks requiring cognitive control. In a study using self-reported attentional and emotion regulation capabilities, O'Bryan et al. (2017) found that those with greater attentional control had greater emotional clarity and were better able to engage in goal-directed behaviors under distress.

Cognitive demands are also a concern within the measurement of inhibitory control, forcing researchers to consider and control for confounding experimental task demands. Thus, unless the goal of the study is to explore the impact of increased cognitive demands or limited cognitive resources (Leue et al., 2012; MacNamara & Proudfit, 2014; Xing et al., 2016), simple behavioral tasks are often preferred for assessing performance (Gutiérrez-Cobo et al., 2017; Megías et al., 2017). Neurophysiological measures during a simple behavioral task are useful for objectively evaluating cognitive individual differences using the magnitude of electrical neural activation during cognitive control or assessing the time course of a cognitive process (Woodman, 2010). One such neurophysiological measure is the N2, an event-related potential (ERP) component related to inhibitory control through conflict-monitoring and attentional control aspects of cognitive control (Donkers & Van Boxtel, 2004). The proposed study will examine the association of cognitive control, indicated by the N2 difference wave amplitude, with self-reported tolerance of negative emotions. It is anticipated It is hypothesized that cognitive control will predict higher tolerance of negative emotions when controlling for emotion regulation (Hypothesis 2).

The N2 ERP Component

Event-related potentials (ERPs) are used as time-locked neural markers of particular cognitive processes, elicited by an experimental or behavioral stimulus (Luck, 2014a). An ERP component can be either stimulus-locked or response-locked meaning that the neural signal being assessed is either associated with the presentation of a stimulus or with the subsequent response. ERPs are isolated by measuring the electrical activity from the brain at various points on the scalp across repeated instances of a particular stimulus or response (Luck, 2014a, p. 12-15).

Polarity, latency, and scalp distribution are semi-flexible characteristics of ERP components used to identify and describe them (Luck, 2014b, p. 66). Given common variability in these factors between individuals and paradigms, a component is ultimately defined by the functional process it represents and the neural area of generation. Scalp recordings can make it difficult to definitively identify the propagation point where the neural process originates due to the distribution of electrical activity. Thus, ERPs are identified by fluctuations in functional activity during controlled behavioral tasks and can be manipulated experimentally (Luck, 2014b, p. 67).

Classic behavioral tasks such as the Go-NoGo task are used to assess neural indicators of cognitive control such as the N2 by creating a conflict between the stimuli presented and prepotent response which must be attended to in order to inhibit the initial response. The N2 is a stimulus-locked ERP component, evoked approximately 200 ms after stimulus presentation in the fronto-central region of the scalp (Luck, 2014b; Luck & Kappenman, 2012). The Go-NoGo task requires cognitive control to monitor response conflict and inhibit prepotent responses (Botvinick et al., 1999; Donkers & Van Boxtel, 2004). Participants respond to a set of "Go" stimuli and are instructed not to respond to "NoGo" stimuli. As the Go stimuli are more common, the participant's automatic tendency will be to respond. For the NoGo stimulus, the participant must adequately attend to the stimuli presented, recognize that there is a conflict between the expected or prepotent response and the one required by the presented stimulus, then inhibit the prepotent response. Due to the enhancement of these cognitive control requirements during NoGo trials compared to Go trials, a larger amplitude N2 is seen for NoGo than for Go stimuli (Kropotov et al., 2011; Randall & Smith, 2011). Thus, a mean difference wave, in which the N2 wave for NoGo trials are subtracted from the N2 wave for Go trails, can be used to assess the activation of inhibitory control (Luck, 2012).

The N2 is thought to be comprised of three distinct subcomponents, the N2a, N2b, and N2c also called the mismatch negativity, anterior N2, and posterior N2 respectively (Luck, 2012, p. 334). The mismatch negativity is evoked primarily by auditory stimuli when an individual becomes aware of a stimulus incongruent with other stimuli. The anterior N2 represents inhibitory control through conflict monitoring and attentional control. The posterior N2 is lateralized and split into the N2 posterior bilateral (N2pb) component, which varies based on physical features and the probability of the target stimulus being presented, and the N2 posterior contralateral (N2pc) component which is seen during search tasks and is not sensitive to physical features or probability (Luck, 2012, p. 333).

The N2 is said to be part of an N2/P3 complex because the larger P3, evoked by unexpected stimuli and decision-making processes, reliably follows the N2 (Luck, 2014c, p.96). The final component the commonly co-occurs with the N2 is the anterior P2, usually occurring just prior to the anterior N2 in the 150-250 ms range. The P2 responds in a similar manner as the N2pb, leading some to suggest that the N2pb and anterior P2 represent opposing polarities of the same generator (Luck, 2012, p. 333). While the different components have been distinguished from one another with distinct localizations, time frames, and associated cognitive processes, the density of data requires the anterior N2 to be parsed out from the other components before it can be interpreted. Principal component analysis (PCA) is commonly employed to decompose the different components in a given waveform by extracting factors within the N2 time range and separating distinct components from one another (Dien, 2012).

Limited research has examined associations between the anterior N2 and tolerance of negative emotions. Macatee et al. (2018) used a complex Go-NoGo task to detect fluctuations in the anterior N2 in a clinical sample, with larger (i.e. more negative) NoGo N2 amplitudes associated with higher tolerance of negative emotions. In a separate study, Macatee, Albanese, Crane, et al. (2018) found that distress tolerance was related to the N2 in cannabis users during a stress induction task. Further research is needed to determine whether these associations generalize to a non-clinical sample and represent a basic mechanism of tolerance of negative emotions. Additionally, there is a gap in the literature regarding the unique and interactive effects of emotion regulation and cognitive control on tolerance of negative emotions which may be important in understanding the self-regulatory mechanisms involved in the malleability of tolerance of negative emotions. In this study, it is expected that emotional regulatory ability will interact with cognitive control such that greater cognitive control will strengthen the relationship between emotion regulation and tolerance of negative emotions (Hypothesis 3).

The Present Study

The proposed study aims to elucidate the relationship between neural markers of cognitive control, emotional regulation, and tolerance of negative emotions. The Go-NoGo task will be used to elicit the anterior N2 in order to assess cognitive control. Self-report measures of emotional regulation and tolerance of negative emotions will also be used to account for the role of self-efficacy and self-perception of responses to negative affect in mental health outcomes. It is hypothesized that self-reported emotion regulation will predict self-reported tolerance of negative emotions (Hypothesis 1), cognitive control, indicated by the N2 difference wave amplitude, will be associated with self-reported tolerance of negative emotions (Hypothesis 2), and cognitive control will moderate the relationship between self-reported emotional regulation ability and self-reported tolerance of negative emotions (Hypothesis 3).

CHAPTER II

METHOD

Participants

Participants included 71 undergraduate students recruited from the Old Dominion University psychology research pool. All participants received research credit for their participation. Of the 71 participants, nine were excluded due to excessively poor effort, indicated by getting fewer than 50% of measured trials correct. An additional three participants were excluded due to excessive noise in the data following artifact rejection and interpolation procedures (described in ERP Data Processing). Lastly, two participants were excluded due to missing survey data. The final sample of 57 participants (mean age = 20.24, *SD* = 0.49) met the suggested sample size for analyses.

The suggested sample size was determined by a change in R^2 power analyses with .80 power and the alpha level set at .05 using G*Power 3.1 (Erdfelder et al., 2009). Given that the only other study found to test moderation of a model with similar constructs found a small to medium effect size but used different measures (Bardeen et al., 2015), power analyses were run using a Cohen's f^2 of .15. Results yielded a proposed sample size of 55 participants. Participants were primarily White female freshmen with 71.9% (n = 41) of the sample identifying as female, 70.2% (n = 40) of the sample identifying as White, and consisting of 50.9% (n = 29) freshman. Demographics are further described in Table 1.

Table 1

Demographic Characteristics of the Analytic Sample

	Analytic Sample (n = 57)	
	n	%
Gender		
Male	14	24.6%
Female	41	71.9%
Trans	2	3.5%
Class Standing		
Freshman	29	50.9%
Sophomore	14	24.6%
Junior	7	12.3%
Senior	6	10.5%
Post-baccalaureate	1	1.8%
Race/Ethnicity[a]		
White	40	70.2%
Black	14	24.6%
Asian	2	3.5%
Native American or Pacific Islander	3	5.3%
Hispanic	11	19.3%
Multiracial	12	21.1%

Note. [a] = Total percentages may not sum to 100% due to multiple response allowances.

Procedure

This study was approved by the Old Dominion University Institutional Review Board. Informed consent, including a description of study procedures and goals, was provided to each participant before they began the study. Online questionnaires were completed using Qualtrics on a lab computer in a private room. After the participant completed the questionnaires, an electroencephalography (EEG) cap and electrodes were placed on the participant's head to measure neural activity during behavioral tasks. Electrooculography (EOC) electrodes were also placed lateral to the outer canthus and below the left eye to measure blinks and saccades for correction of eye movement artifacts in the EEG data.

Go-NoGo task instructions were described on the computer screen. Instructions were clarified as necessary by experimenters prior to the completion of ten practice trials. Practice trials were observed by an experimenter, who provided corrective feedback, answered questions, and clarified instructions as needed. In each trial, participants were presented with a Gabor patch oriented in one of four angles (0, 45, 90, and 135 degrees; see Figure 1). Participants were instructed to respond to Gabor patches presented in 3 orientations with a left mouse click (e.g., Go trials) and not to respond to the Gabor patches presented in one orientation (e.g., NoGo trials). The NoGo orientation was presented either vertically or horizontally and counter-balanced across participants. Participants completed approximately 240 trials administered with Presentation (Neurobehavioral Systems, Inc.). Each orientation of Gabor patch was presented for approximately 60 (25%) of the trials, with an approximate collective 180 (75%) Go stimuli and approximately 60 (25%) total NoGo stimuli. Variation in the number of trials due to stimulus randomization was expected. After the Go-NoGo task was completed, the electrodes were removed and the participant was debriefed.

Measures (see Appendix A)

Tolerance of Negative Emotions

The Distress Tolerance Scale (DTS; Simons & Gaher, 2005) is a 15-item self-administered questionnaire that assesses the ability to withstand negative affect and emotional distress. The DTS consists of four subscales evaluating aversiveness (‘I can’t handle feeling distressed or upset’), appraisal (‘I am ashamed of myself when I feel distressed or upset’), attentional absorption (‘When I feel distressed or upset, all I can think about is how bad I feel’), and the desire for immediate regulation of negative emotions (‘When I feel distressed or upset, I must do something about it immediately’). Individuals completing the 15-item questionnaire indicate how true an item is for them when they are upset. Responses are rated using a five-point Likert scale (1 = *strongly agree*, 2 = *mildly agree*, 3 = *agree and disagree equally*, 4 = *mildly disagree*, and 5 = *strongly disagree*). Item six in the Appraisal subscale is reverse-scored. A total DTS score ranges from 15 to 75 with higher scores indicating greater tolerance of distressing negative emotions.

Simons and Gaher (2005) found that the DTS demonstrated good convergent validity, correlating modestly with the frequency of a particular mood (i.e. mood typicality) (r = .17) and positive affectivity (r = .26). Moderate correlations were found with measures of mood acceptance (r = .47), affect lability (r = -.52), negative mood regulation (r = .54), and negative affectivity (r = -.59; ps < .001). The pattern of associations also offers preliminary evidence indicating that the DTS demonstrates good discriminant validity. These findings suggest that tolerance of negative emotions as measured by the DTS is related to but distinct from reactive mood, the tendency to experience negative affect, and negative emotion regulation. Internal consistency was demonstrated in the original university student sample (subscale Cronbach’s α =

.72 - .82). Test-retest reliability over a six-month period (r = .61) suggests that DTS scores are susceptible to change over time and may reflect intraindividual variability. Internal consistency in the current sample was excellent, demonstrating a Cronbach's alpha of .91.

Emotion Regulation Difficulties

The Difficulties in Emotion Regulation Scale-Short Form (DERS-SF; Kaufman et al., 2015) assesses the ability to regulate negative emotional states. Adapted from the original 36-item DERS (Gratz & Roemer, 2004), this 18-item questionnaire asks participants to rate the frequency of orientation and responses to negative emotions on a five-point scale in which 1 = *almost never (0-10%)*, 2 = *sometimes (11-35%),* 3 = *about half of the time (36-65%)*, 4 = *most of the time (66-90%)*, and 5 = *almost always (91-100%)*. The DERS-SF was validated using three samples of adolescents recruited for suicide and self-injury studies as well as two separate samples of undergraduate students. The DERS-SF retained all six subscales from the original DERS with three items per subscale and 81-96% shared variance with the original DERS. The subscales include nonacceptance of emotional responses ('When I'm upset, I feel guilty for feeling that way.'), difficulties engaging in goal-directed behavior ('When I'm upset, I have difficulty getting work done.'), impulse control difficulties ('When I'm upset, I have difficulty controlling my behavior'), emotional awareness ('I pay attention to how I feel.'), lack of access to emotion regulation strategies ('When I'm upset, I believe there is nothing I can do to make myself feel better.'), and lack of emotional clarity ('I have difficulty making sense out of my feelings.').

Kaufman et al. (2015) demonstrated that the DERS-SF had good concurrent validity with measures of depression (*r* = .66), the Revised Symptom Checklist (SCL-90-R; Derogatis & Cleary, 1977) Global Severity Index (*r* = .64), state (*r* = .66) and trait (*r* = .75) anxiety, acceptance of negative emotions (*r* = -.79), and self-concept (*r* = .64; *ps* < .01) comparable in strength and directionality with the original DERS. The three items in the awareness subscale are all reversed scored. Individual item scores are summed to create a total score that ranges from 18 to 90 with higher scores indicating greater difficulty with regulating negative emotions. Excellent internal consistency was also demonstrated in university students in the original validation study (total Cronbach's α = .97; subscale Cronbach's αs ranged from .90 to .96) and in the present sample (Cronbach's α = .92).

N2 ERP Component

The N2 ERP component evoked during the Go-NoGo task was used to assess cognitive control. Specifically, the anterior N2 for the NoGo stimuli is reliably larger (more negative) than the anterior N2 for the Go stimuli, with the magnitude of the difference associated with inhibiting responses on NoGo trials. The difference between these two waves can show elicitation of conflict monitoring and inhibition while partially accounting for individual differences in baseline reactivity to stimuli (Rietdijk et al., 2014). The anterior N2 is also maximal at the fronto-central electrodes (i.e. Fz, FCz, and Cz). Thus, difference waves will be calculated for each participant by subtracting the mean NoGo N2 amplitudes from the mean Go N2 amplitudes at the maximal fronto-central site.

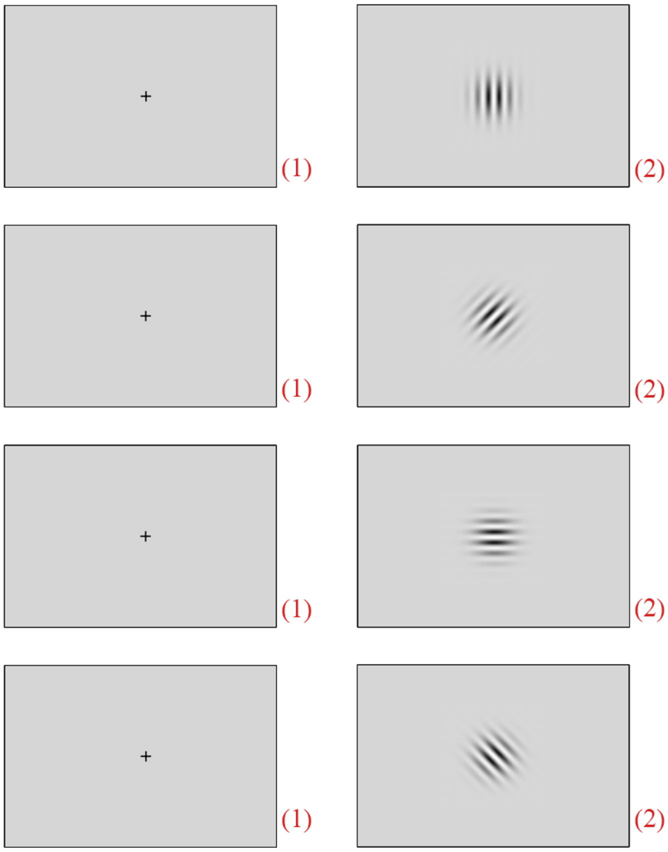
The N2 has demonstrated good convergent validity with performance measures of the Go-NoGo task including response time and NoGo commission error rate (Falkenstein et al., 1999; Jodo & Kayama, 1992; Randall & Smith, 2011). The N2 is evoked by this task at approximately 200 ms following stimulus presentation with a typical window of approximately 175 ms to 350 ms (Luck, 2014c; Rietdijk et al., 2014). Signal-to-noise ratio and internal consistency are excellent (α = .90) for experiments using at least 30 NoGo trials (Leue et al., 2013; Rietdijk et al., 2014). The present study includes approximately 60 (25%) NoGo trials per participant with slight variations in the final number of NoGo trials used for analyses due to stimulus randomization and artifact rejection procedures. Only counter-balanced (vertical or horizontal) Go stimuli were assessed to prevent physical stimulus bias.

Demographics

Information regarding participant age, gender, race, ethnicity, and class standing were gathered to describe the sample and provide information about the generalizability of results. The sample was predominantly white and female (see Table 1 for demographic information). This pattern is typical of undergraduate psychology samples recruited using the Old Dominion University psychology research pool.

Figure 1

Example of Go-NoGo Task Trials



ERP Data Processing

EEG data were collected using a custom 33-channel ActiveTwo BioSemi system sampling at 1024 Hz. One data file was converted from 2048 Hz to 1024 Hz to allow consistent processing and averaging. Initial processing was done in the ERPLAB (Lopez-Calderon & Luck, 2014) in order to parse artifact, or variance in the data that is not due to brain activity, from the relevant data. A high-pass filter (.1 Hz) was applied to separate low-frequency scalp skin conductance from neural activity. An independent component analysis (ICA) was used to identify and correct eye-blink artifacts in the EEG data. ICA solutions were assessed for high amplitude frontal activity in the 20 to 50 microvolt range and smooth activity power spectrums. Components identified as blinks were then rejected and removed from the EEG, with a visual inspection of the pre and post ICA data to ensure that only eye movement was removed.

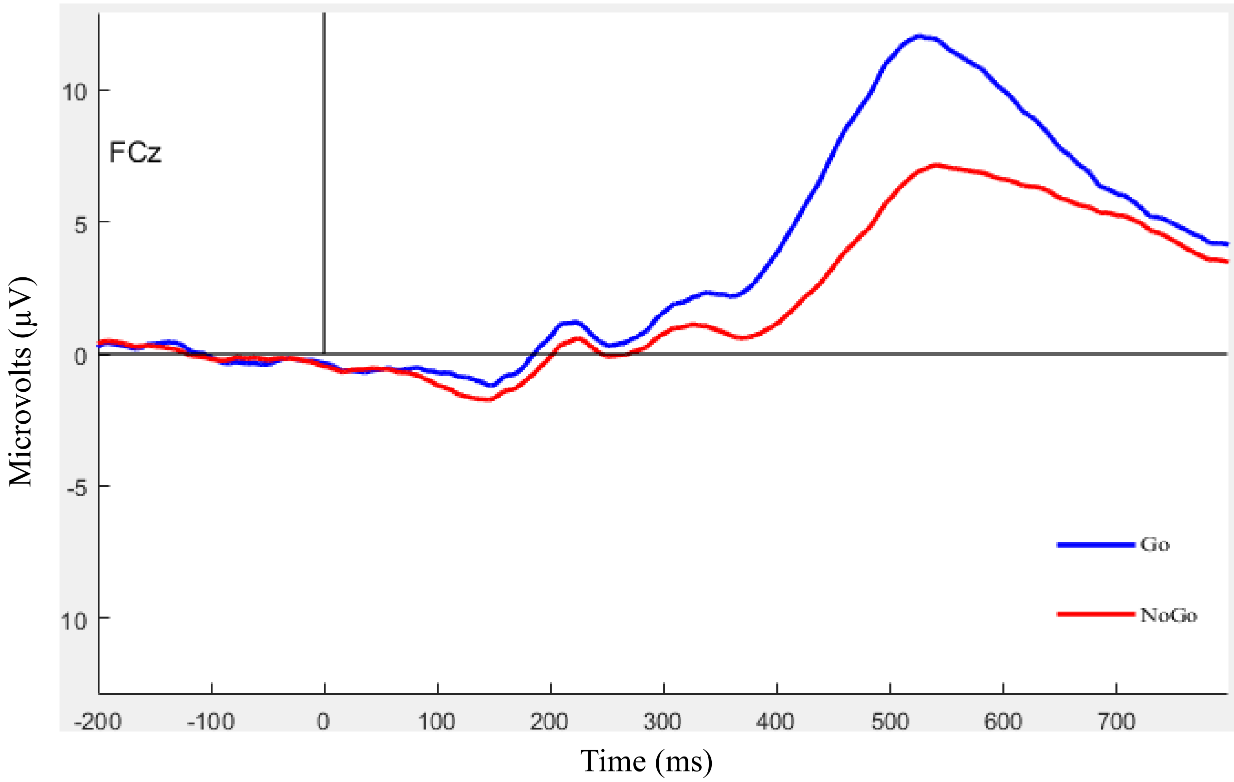
Bins were defined by assigning the appropriate trial type based on the order of events represented by trigger codes in the EEG data. The bins of interest included the counter-balanced Go correct (i.e. counter-balanced Go stimulus followed by a button press) and NoGo correct (i.e. NoGo stimulus followed by no response) bins. Data were then separated into epochs of -200 ms to 800 ms with the presentation of the stimulus at zero.

Artifact rejection was used to determine which trials could be used for analyses and which would be rejected due to noise. Trials with eye-blinks within 200 ms of stimulus presentation were removed as the stimulus presentation time would be inaccurate if the participant’s eyes were closed. Trials were also rejected due to high amplitude noise caused by excessive tension, movement, or disconnected electrodes. Interpolation was reviewed on a case-by-case basis as an option for those with artifact rejection due to poor electrode connection at noncritical measurement sites. Data for participants with fewer than 30 accepted Go or NoGo trials following interpolation were excluded due to excessive noise in the trials (Leue et al., 2013; Rietdijk et al., 2014). Participants with fewer than 30 accepted trials included the nine participants excluded for poor effort.

A 30 Hz low-pass filter was applied in preparation for the PCA to limit the isolation of noise or artifact related factors and to assist with visualization of waveforms. Anterior N2 components were averaged across NoGo trials and Go trials for each participant. The grand average waveform (see Figure 2.) was then computed by averaging the waveforms across the participants. Evidence of overlapping or high-density ERP components common in the N2/P3 complex were found, demonstrating that a principal component analysis (PCA) would be necessary to isolate and accurately assess the amplitude of an anterior N2 component. N2 mean difference amplitudes were derived from the difference between NoGo and Go trial waveforms. Mean amplitudes were used rather than peak amplitudes to prevent high-frequency signals from biasing amplitude measurements (Luck, 2014).

Figure 2

Grand Average ERP Waveform at FCz by Stimulus Type



Principal Component Analysis

Due to the presence of multiple ERP components during the anterior N2's time window beginning approximately 175 ms and ending approximately 350 ms after stimulus presentation. (Luck, 2014c; Rietdijk et al., 2014), a two-step principal component analysis (PCA) using ERP PCA Toolkit (Dien, 2010) was used to separate anterior N2 candidates from other ERP components. Temporal PCA with Promax rotation was first used to reduce dimensionality and identify factors uniquely contributing to the variance in the data. Horn's parallel analysis was used to determine how many components to extract. The resulting scree plot (see Figure 3.) indicated 17 factors for extraction, accounting for 98.3% of the variance in the data. A spatial PCA on each of the 17 temporal factors was then conducted using Infomax rotation to extract components by measurement location. Horn's parallel analysis was used to determine the number of factors to retain. The resulting scree plot (see Figure 4.) indicated the retention of three factors per temporal factor, accounting for 87.9% of the variance in the data.

All factor scores and factor loadings were rescaled to microvolts for visualization and comparison purposes (Dien, 2012). Out of the 51 total components identified by the temporospatial PCA (see Figure 5.), four potential anterior N2 candidates were chosen for further evaluation based on maximal location, peak latency, and modulation by the Go-NoGo task. Component TF07SF1 had a peak latency of 170.90 ms and a maximal negative peak at channel FCz. Component TF10SF1 had a peak latency of 123.05 ms and an overall negative maximal peak at PO3. Component TF08SF2 had a peak latency of 319.34 ms maximal at Fz. Lastly, component TF04SF2 had a peak latency of 270.51 ms and a negative maximal peak at Fz.

Each of these candidates was then assessed visually for modulation by the Go-NoGo task and the polarity of maximal frontocentral peaks. Following visualization of the data, TF10SF1 was found to be slightly more maximal at occipital sites and was earlier than an expected anterior N2, indicating that it may represent a separate N2 component. Despite clear modulation, appropriate latency, and a negative peak maximal at Fz, the overall maximal peak for TF08SF2 was positive and occipital (O1). TF04SF2 did not demonstrate modulation with the Go-NoGo task and was found to be negative at focal sites, but was overall positively and occipitally maximal (O2) upon visual inspection. Strong modulation by the Go-NoGo task, clear peak negativity at a maximal frontocentral site (FCz), and a peak latency near the expected time window made TF07SF1 the only candidate consistent with the anterior N2 literature. Mean amplitude measurements were then taken from factor TF07SF1 (see Figure 6.) from 160 ms to 180 ms, centered around the factor peak. The Go mean amplitudes were then subtracted from the NoGo mean amplitudes to create a NoGo minus Go difference mean amplitude to be used for analyses.

Figure 3

Temporal PCA with Promax Rotation Horn's Parallel Analysis Scree Plot

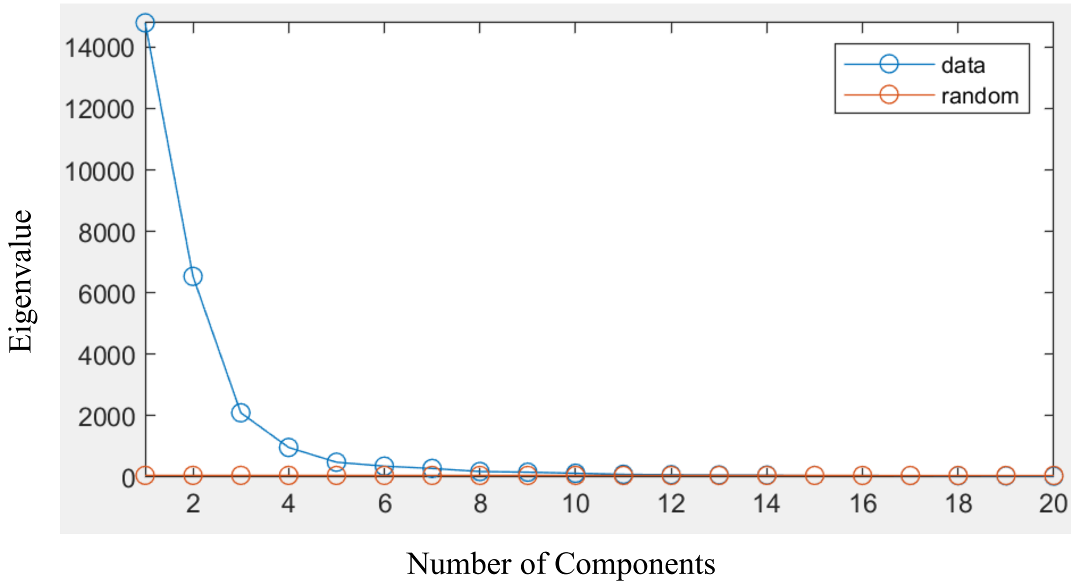


Figure 4

Spatial PCA with Infomax Rotation Horn's Parallel Analysis Scree Plot

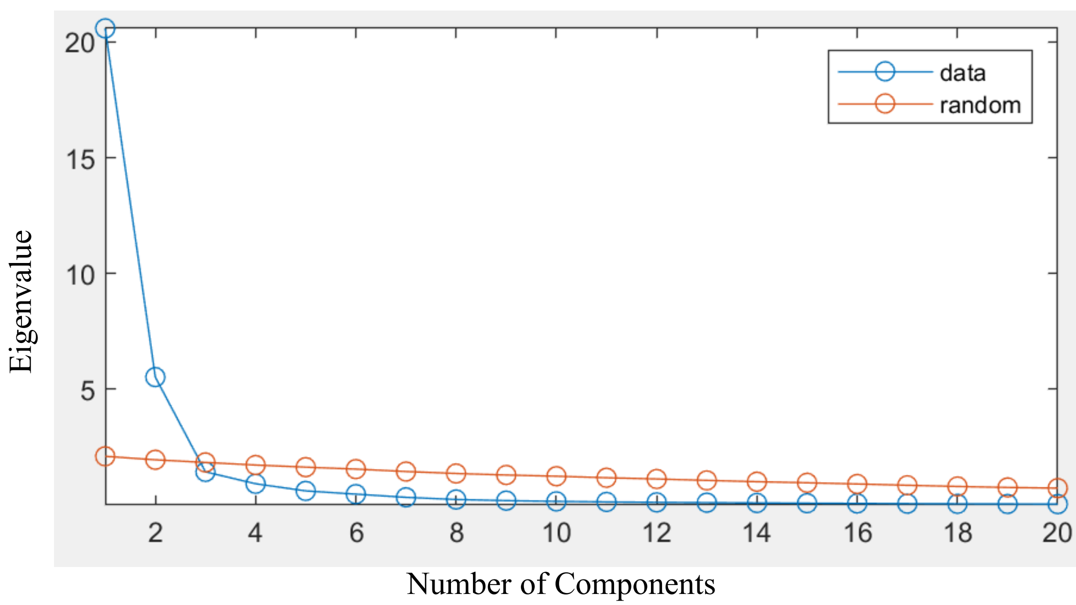


Figure 5

Temporospatial PCA Factor Waveforms by Stimulus Type

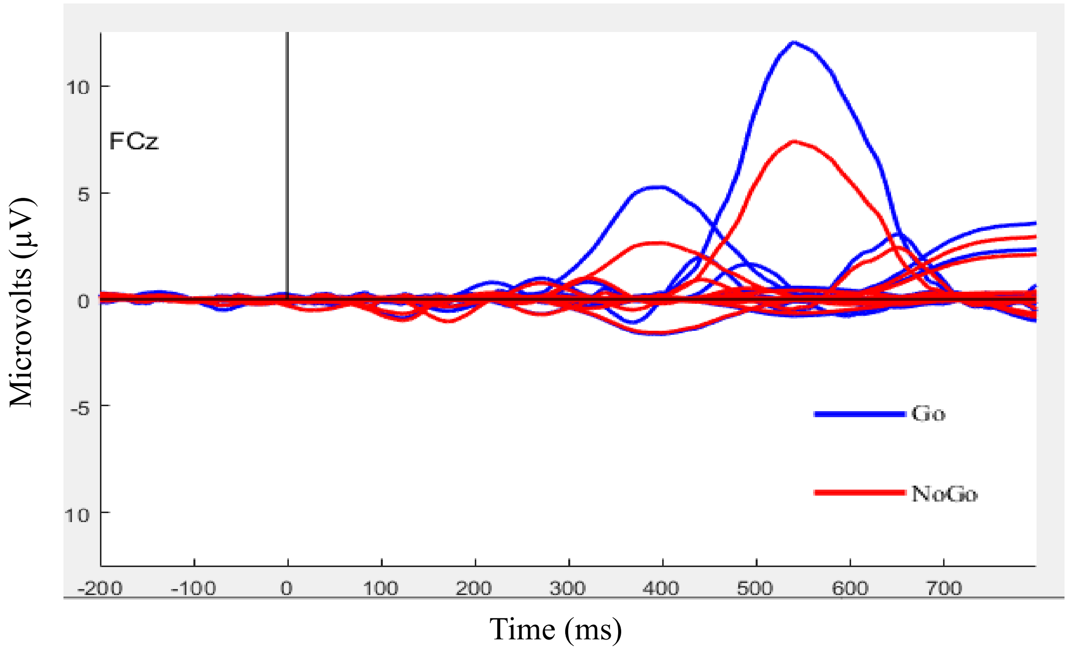
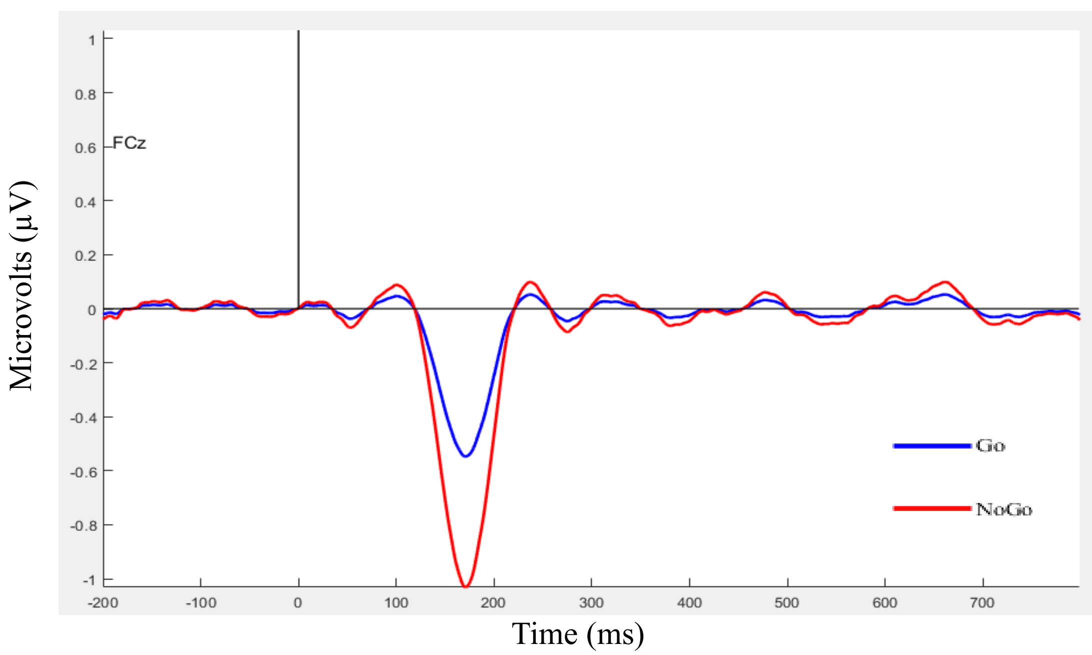


Figure 6

Temporospatial PCA Factor TF07SF1 Anterior N2 Waveform by Stimulus Type



Analysis Plan

Univariate outliers for each variable were checked using boxplots to identify extreme outliers beyond three standard deviations from the median to be assessed individually and Winsorized as necessary. Multivariate outliers were assessed for leverage using Mahalanobis distances, discrepancy using studentized deleted residuals, and influence using Cook's D and DFBETAS. Predictors required acceptable collinearity with a tolerance above 0.2 and variance inflation factor below 10 for inclusion in the model. Linearity was assessed using scatter plots with a LOWESS line for each predictor. Transformation was considered for unmet linearity assumptions. Homoscedasticity of residuals was assessed by predicting the standardized squared studentized deleted residuals from the predictors. A heteroscedastic-consistent estimator of standard error was used to correct for the violated homoscedasticity assumption. A Durbin Watson test between 1.5 and 2.5 was used to determine whether the residual independence assumption was met. Lastly, a Q-Q plot of standardized residuals and each predictor was visually assessed for normal distribution of residuals.

A multiple regression analysis was then run in SPSS v.27 (IBM Corp., 2020) using the PROCESS macro v. 3.5 (Hayes, 2017) to enable bias corrected bootstrapping estimates of confidence intervals around the coefficients when performing a moderation analysis. The analysis aimed to determine whether emotional regulation predicts tolerance of negative emotions (Hypothesis 1), establish the relationship between cognitive control and tolerance of negative emotions (Hypothesis 2), and show whether emotion regulation and cognitive control interact such that at different levels of cognitive control, emotion regulation ability would have a greater or lesser impact on tolerance of negative emotions (Hypothesis 3). Zero-order correlations were included to evaluate the model for suppression effects and potential covariates.

A significant interaction would prompt probing by testing the simple slopes at the mean, one standard deviation above the mean, and one standard deviation below the mean. The Johnson-Neyman Technique would also be implemented to determine the values of cognitive control for which emotion regulation ability is significant.

CHAPTER III

RESULTS

Preliminary Analyses

Assumptions were tested for a multiple regression assessing whether emotion regulation ability (ER), the mean difference anterior N2 amplitude (N2), or their interaction (ER*N2) predicted tolerance of negative emotions. Variable distributions and outliers were visually examined using histograms and boxplots. No extreme univariate outliers were identified. Emotion regulation was slightly positively skewed but was well within the bounds of normal skew and kurtosis (skew = 0.71, kurtosis = 0.14) (Kim, 2013). N2 was mildly leptokurtic (skew = 1.04, kurtosis = 4.12). Both variables were reassessed as normally distributed (ER skew = 0.79, ER kurtosis = 0.15; N2 skew = -0.32, N2 kurtosis = -0.82) following multivariate outlier corrections.

Leverage was assessed using Mahalanobis distances with 3 cases found to exceed the chi-squared critical value of 11.34. No studentized deleted residual cases were found to exceed the t-critical value of 4.04 assessing discrepancy. Influence was evaluated using Cook's D and standardized DFBETAs, with one case exceeding the f-critical value of 0.85 and no cases exceeding the cut-off of +/-1 for small to medium samples respectively. Analyses were run with and without outliers and it was determined that multivariate outliers impacted the interpretation of results. Cases with multivariate outliers were Winsorized to the value at 95% or 5% of the sample distribution for the given variable as necessary (Hayes, 2017).

Linearity was assessed using scatterplots of each predictor with unstandardized residuals and LOWESS lines. Despite a mildly negative quadratic curve in emotion regulation, the

Winsorized predictors were found to be approximately linear. Significant results predicting the standardized squared studentized residuals from the predictors indicated that the residuals did not have constant variance and differed from the mean (p = .035). The HC3 heteroscedastic-consistent estimator of standard error was used to correct for the violated homoscedasticity assumption (Davidson & MacKinnon, 1993). Normality of residuals was met with no excessive deviations from the normal fit line on a visually assessed Q-Q plot of unstandardized residuals and expected normal values. Residual independence (Durbin Watson = 1.98) and acceptable multicollinearity (N2 *VIF* = 1.10; ER *VIF* = 1.11; N2*ER *VIF* = 1.20) were also affirmed.

Age, gender, and ethnicity were evaluated for inclusion in the model as covariates based on correlations with the outcome variable. Point-biserial correlations showed a significant correlation (p = .028) of -.29 for gender and a nonsignificant correlation (p = .737) of -.07 for ethnicity with tolerance of negative emotions. Pearson correlations also found a significant correlation between age (r = .34, p = .009) and tolerance of negative emotions. Based on significant correlations with the outcome variable, the model was run both with and without age and gender to assess the impact on model interpretation. The model interpretation did not change when gender was added to the model but did differ when age was added to the model. Participants ranged from 18 to 28 years old with one extreme outlier at 42 years old. Analyses were conducted with and without age as a covariate for comparison purposes.

Table 2

Pearson Correlations, Means, and Standard Deviations of Study Variables

Variable	1	2	3	4
1. Tolerance of Negative Emotions	--			
2. Emotion Regulation Difficulties	-.64***	--		
3. N2 Difference Amplitude	.27*	-.01	--	
4. Age	.34**	-.23	.31*	--
Mean	50.47	40.08	-0.70	20.46
SD	12.53	13.99	0.31	3.70

Note. *$p < .05$, **$p < .01$, ***$p < .001$. Tolerance of Negative Emotions = Distress Tolerance Scale total score. Emotion Regulation Difficulties = Difficulties with Emotion Regulation Scale total score. N2 Difference Amplitude = The difference between the mean amplitude on NoGo and Go trials.

Primary Analyses

Zero-order bivariate correlations were evaluated for all variables included in the model (see Table 2.). All correlations were in the theorized direction with tolerance of negative emotions correlating negatively with difficulties with emotion regulation (r = -.64, p < .001) and positively with the N2 difference amplitude (r = .27, p = .046), representative of greater cognitive control. Difficulties with emotion regulation were not significantly correlated with the N2 difference amplitude (r = -.01, p = .918) or age (r = -.23, p = .079). Age was correlated positively and significantly with both tolerance of negative emotions (r = .34, p = .009) and the N2 difference amplitude (r = .31, p = .018).

Variables were centered around the mean to reduce multicollinearity and analyses were run both with and without age (M = 20.46, SD = 3.70) as a covariate. The omnibus model consisting of difficulties with emotion regulation (M = 40.08, SD = 13.99), the N2 difference amplitude (M = -0.70, SD = 0.31), and the interaction term significantly predicted tolerance of negative emotions, accounting for 52.4% of the variance in tolerance of negative emotions (M = 50.47, SD = 12.53), $F(3, 53) = 14.70$, p < .001, R^2 = .524. Emotion regulation was uniquely associated with tolerance of negative emotions when controlling for cognitive control, B = -0.63, 95% CI [-0.87, -0.39], p < .001. Cognitive control was also uniquely associated with tolerance of negative emotions, controlling for emotion regulation, B = 0.98, 95% CI [0.03, 1.93], p = .043. The addition of the interaction term to the model accounted for an additional 5.5% of the variance (ΔR^2 = .055) in tolerance of negative emotions $\Delta F(1, 53) = 3.25$, p = .077. Cognitive control was not found to significantly moderate the relationship between emotion regulation and tolerance of negative emotions, B = 0.10, 95% CI [-0.01, 0.21], p = .077.

Age was added to the model as a covariate and the omnibus model again significantly predicted tolerance of negative emotions, accounting for 52.6% of the variance in tolerance of negative emotions, $F(4, 52) = 11.95$, $p < .001$, $R^2 = .546$. Age was not a significant predictor of tolerance of negative emotions when controlling for emotion regulation and cognitive control, B = 0.54, 95% CI [-0.12, 1.21], $p = .104$. Emotion regulation was uniquely associated with tolerance of negative emotions, controlling for cognitive control and age, B = -0.63, 95% CI [-0.36, -0.84], $p < .001$. Cognitive control was no longer uniquely associated with tolerance of negative emotions when controlling for emotion regulation and age, B = 0.69, 95% CI [-0.25, 1.63], $p = .145$. The addition of the interaction term to the model accounted for an additional 6.1% of the variance ($\Delta R^2 = .061$) in tolerance of negative emotions, $\Delta F(1, 52) = 3.77$, $p = .058$. Cognitive control did not significantly moderate the relationship between emotion regulation and tolerance of negative emotions, B = 0.10, 95% CI [-0.00, 0.21], $p = .058$.

A post-hoc power analysis was conducted for each interaction using G*Power 3.1 (Erdfelder et al., 2009) with a sample size of 57, alpha set to .05, and a Cohen's f^2 calculated from the ΔR^2 for each interaction effect. The first model included three predictors and the addition of the interaction term increased R^2 by .055. The small effect size was determined by dividing the increase in R^2 by one minus the increase in R^2 to get a Cohen's f^2 of .058. The power analysis revealed a power of .43 for detecting an effect of this size. This calculation was repeated for the model with age added as a covariate to include four predictors in the model. The addition of the interaction term increased R^2 by .061 with a calculated Cohen's f^2 of .065. A power of .47 was found for detecting an effect of this size.

Table 3

Unstandardized Regression Coefficients Predicting Distress Tolerance without Age

Predictor	*B(SE)*	t
Constant	50.57(1.25)	40.38***
Emotion Regulation Difficulties	-0.63(0.12)	-5.34***
N2 Difference Amplitude	0.98(0.47)	2.08*
Interaction	0.10(0.05)	1.80

* $p < .05$, ** $p < .01$, *** $p < .001$

Table 4

Unstandardized Regression Coefficients Predicting Distress Tolerance with Age

Predictor	*B(SE)*	t
Constant	39.42(7.03)	5.61***
Emotion Regulation Difficulties	-0.60(0.12)	-5.05***
N2 Difference Amplitude	0.69(0.47)	1.48
Interaction	0.10(0.05)	1.94
Age	0.54(0.33)	1.66

* $p < .05$, ** $p < .01$, *** $p < .001$

CHAPTER IV

DISCUSSION

The present study aimed to examine the association between emotion regulation, cognitive control, and tolerance of negative emotions. Emotion regulation (Hypothesis 1) and cognitive control (Hypothesis 2) were expected to uniquely predict tolerance of negative emotions. It was also hypothesized that emotion regulation and cognitive control would have interactive effects when predicting tolerance of negative emotions (Hypothesis 3). Bivariate correlations with tolerance of negative emotions were used to assess potential covariates. Gender was significantly correlated with tolerance of negative emotions such that females were had better tolerance of negative emotions than males. Due to the small number of males (n = 14) in the sample, caution should be taken when generalizing this interpretation. Gender was not included as a covariate because inclusion in the model did not change model interpretation. Age was found to be significantly positively correlated with both tolerance of negative emotions and cognitive control indicating that as age increased, both distress tolerance and cognitive control increased.

Hypothesis 1 was supported, as fewer reported emotion regulation difficulties were found to predict higher tolerance of negative emotions in the sample when controlling for cognitive control. Consistent with Hypothesis 2, higher cognitive control, represented by a larger or more negative N2 difference amplitude, was significantly predictive of higher tolerance of negative emotions scores when controlling for emotion regulation. However, the effect was no longer significant when age was added to the model as a covariate. Though age was not a significant predictor of tolerance of negative emotions, the change in results suggests that age accounted for a portion of the variance previously attributed to cognitive control in predicting tolerance of negative emotions. Hypothesis 3 examined the interactive effects of emotion regulation and cognitive control predicting tolerance of negative emotions. Results did not find evidence that cognitive control moderated the relationship between emotion regulation and tolerance of negative emotions. However, the study may have been underpowered to make conclusive statements about interactive effects.

Implications

The study replicates findings of the strong association between emotion regulation and tolerance of negative emotions (Conway et al., 2021; Jeffries et al., 2016; Van Eck et al., 2017). Given the theorized relationship between emotion regulation and cognitive control (Ochsner & Gross, 2008) including literature suggesting that emotion regulation relies on cognitive control (Inzlicht et al., 2015), previous studies have neglected to control for cognitive control when assessing the relationship between emotion regulation and tolerance of negative emotions. This study was able to determine that emotion regulation and cognitive control account for unique variance in tolerance of negative emotions. Findings suggest that the process by which emotion regulation impacts tolerance of negative emotions is at least partially distinct from the process by which cognitive control impacts tolerance of negative emotions. This implies that emotion regulation requires more than attending to, recognizing conflict in, and inhibiting a given emotional response to influence willingness to tolerate negative emotions.

Though the exact mechanism of the relationship between emotion regulation and tolerance of negative emotions is unknown, decreased frequency of emotion regulation due to lack of regulatory self-efficacy may decrease the threshold for tolerance to distress due to the belief that regulation will be unsuccessful (De Castella et al., 2018; Ford & Gross, 2019). Those with better emotion regulation abilities may also be able to tolerate distress because they engage in multiple emotional regulatory strategies (Ford et al., 2019) and employ both short-term and long-term regulatory goals to control the intensity of their emotional responses (Shafir et al., 2015). This may allow them to cope with negative emotions more efficiently and increase their willingness to experience negative emotions (Millgram et al., 2019). In contrast, when emotion regulation and distress tolerance goals do not match, that may also lead to regulatory strategy use that diminishes tolerance of negative emotions (Sheppes, 2020). For instance, individuals with strong cognitive reappraisal skills are likely able to re-frame the meaning of negative emotions or distress to indicate progress towards a goal, which may increase acceptance (Troy et al., 2018) and motivation and make them more willing to tolerate emotional distress (English et al., 2017). However, when cognitive reappraisal is used to regulate an emotion unrelated to a task-oriented goal, the regulatory goal itself demonstrates a lack of willingness to tolerate negative emotions in pursuit of a goal (Millgram et al., 2015; Tamir et al., 2020; Vishkin et al., 2020). In addition to self-efficacy and matching goals, it is also likely that the cognitive processes used in emotion regulation and the impact of tolerance of negative emotions differs depending on the type of emotion regulation used (Naragon-Gainey et al., 2017).

It has been postulated that inhibition and emotional regulation may rely on similar neural processes with differences in application based on emotional salience (Moodie et al., 2020). For instance, Buodo et al. (2017) found that neural inhibitory control differed based on the emotional salience of the stimuli. Results of the present study finding a unique association between cognitive control and tolerance of negative emotions suggest that attentional control, inhibition, and conflict monitoring play a role in tolerating negative emotion beyond strategic emotional regulatory selection (Bigman et al., 2017). Because tolerance of negative emotions is an inherently emotional process, significant findings using a Go-NoGo task without emotionally salient stimuli imply the use of distinctly cognitive processes in tolerance of negative emotions. Willingness to tolerate negative emotions in pursuit of a goal may then incorporate attentional control as a means of sustaining motivation, conflict monitoring to assess costs and benefits, and inhibitory control to prevent avoidance or a similar short-term relief-seeking behavior from distress (Andrés et al., 2021; Chung et al., 2021; Leyro et al., 2010). It is possible, however, that these cognitive processes in tolerance of negative emotions relate differently to emotionally salient and non-emotionally salient stimuli, thus there may be a need to explore direct comparisons between stimulus types more thoroughly in future studies.

The significance of these results also depended in part on whether age was included as a covariate in the model. Many studies have found that the N2 is impacted by age, but the age range and neural development of the sample also play a role in whether and how age impacts the data. Lamm & Lewis (2010) found that children and adolescents developed more efficient neural processes for emotional regulatory and inhibitory control as they aged. Similarly, Kadosh et al. (2014) used behavioral methods to confirm that attentional control and emotion regulatory ability increased throughout adolescence. On the opposite end of the lifespan, Zhou et al. (2015) found that it was necessary to decrease cognitive task demands in a study assessing the N2 in older adults, with decrease inhibition and a diminished N2 predicting decreased tolerance of negative emotions. While studies using a developmental and lifespan framework have found significant differences in age-related functioning, other studies relating cognitive control to distress tolerance have found mixed results using age as a covariate. Macatee, Albanese, Clancy, et al. (2018) found that age acted as a significant covariate for the P2, but not the N2. Both Bardeen et al. (2015) and Macatee, Albanese, Clancy, et al. (2018) found no significant correlation of age with distress tolerance and no interpretational differences when evaluating age as a covariate.

It is likely that age was a deterministic covariate due to the sample being made up of emerging adults ranging from 18 to 28 years old (with one extreme outlier at 42 years old), creating greater variability in cognitive control and subsequent N2 amplitudes based on the level of neural development. Increased white matter integrity and cortical growth in the dorsolateral prefrontal cortex during emerging adulthood contribute to the development of cognitive control, including planning, delaying gratification, impulse control, and self-monitoring (Henin & Berman, 2016) which are sensitive to environmental changes (Friedman et al., 2016). Emerging adults also learn to regulate their emotions more effectively using environmental feedback, with regulatory strategy use predicted psychosocial functioning (Brewer et al., 2016). While the magnitude of the N2 response may depend in part on the age and neural maturity of the participant, the lack of significance following the addition of age to the model more likely indicates that age acts as a third variable to explain rather than negate the initial significant results.

The lack of significant moderation may be attributed to a number of methodological or theoretical factors. Firstly, the effect sizes found in this study were smaller than anticipated, potentially due to the use of different data collection modalities in analyses. A smaller effect size would require greater power to detect than may have been present in the sample. Given the small effect size and low post-hoc power, it is likely that the study did not have the power to detect interactive effects. Other factors related to how emotion regulation and cognitive control interact such as emotional salience of the stimuli and temporal positioning of cognitive processes in relation to the stimulus may also have influenced results. For instance, Tottenham et al. (2011) found that emotion regulation ability and cognitive control concurrently increased from childhood to adolescence and adolescence to emerging adulthood using an emotional Go-NoGo task.

The potential influence of results by temporal characteristics would be consistent with the dual mechanisms of control framework (Braver, 2012) and process specific timing hypothesis (Sheppes & Gross, 2011). The dual mechanism of control framework states that task-related, trait-related, and neural integrity factors all play a role in the variability of cognitive control and proposes that proactive and reactive inhibitory cognitive control have different mechanisms similar to top-down and bottom-up processing (Einhäuser et al., 2008; Ochsner et al., 2009). The process specific timing hypothesis states that emotion regulation processes differ based on the stage of information processing that they occur in. Antecedent-focused emotion regulation happens early in the information processing, is less likely to be impacted by emotional intensity, and requires less effort, but is usually best suited for short-term goals. Response-focused emotion regulation processes are better suited for long-term goals, but require greater effort and tolerance of initial distress. Taken together, these two frameworks suggest that temporal dynamics may impact the relationship between emotion regulation, cognitive control, and tolerance of negative emotions. It may be beneficial for future studies to assess the differences in interactive effects using early and late processing for group comparisons.

Findings suggest that managing cognitive demands may be important to ensure the availability of cognitive resources for tolerance of negative emotions. Thus, an individual wishing to pursue a goal that will require tolerance of negative emotion should attempt to decrease their task demands in areas unrelated to the desired goal. Based on respective effect sizes, emotion regulation training is also likely to incur benefits over cognitive control training for those with difficulties persisting through emotional distress in the service of a goal. Previous interventions such as DBT (Linehan, 1987) have used emotion regulation training and distress tolerance training concurrently, without regard for the order of effects. It may then be helpful to use emotion regulation training to increase regulatory self-efficacy in order to increase the effectiveness of distress tolerance skills training. Emotion Regulation Therapy (Renna et al., 2017) and Affect Regulation Training (Berking & Lukas, 2015; Berking & Whitley, 2014) have focused on emotion regulation ability for the treatment of anxiety and depression, but current findings suggest that these interventions may have broader applications for subclinical populations as well.

Limitations

The results must be considered in light of several limitations to the generalizability of findings. Convenience sampling was utilized in the present study with primarily white, female psychology undergraduate students. Due to the structure of the university research pool, selection bias may have been present for participants willing and able to complete the on-campus study, though no evidence of selection bias was found in the study variables. The cross-sectional nature of the data also limits the interpretability of causality from results. The present study data was collected in conjunction with a larger study, thus the length of the study tasks requiring sustained attention may also have contributed to mental fatigue effects. The sample size may also have limited the analyses and interpretability of results. Though the sample size provided the power required to detect medium effects sizes, power may not have been sufficient to detect the small interactive effects. Lastly, the inclusion of covariates may have been limited by the sample size. Due to low numbers of participants in respective groups, it was difficult to make meaningful evaluations about group differences in gender and ethnicity. Additionally, covariation of affect using the Positive and Negative Affect Schedule (PANAS; Watson et al., 1988) was not possible to include due to missing data. Future studies including larger and more diverse samples may assist with the replications of current findings.

CHAPTER V

CONCLUSION

Self-regulation research has supported a line of literature focusing on goal-oriented regulation mechanisms to gain a better understanding of factors that allow an individual to effectively adapt to a given situation. This study aimed to close a gap in the literature concerning specific mechanisms of cognitive-affective self-regulation by evaluating the relationships between emotion regulation ability, cognitive control, and tolerance of negative emotions. Findings contributed to the body of research by confirming that the effects of emotion regulation on tolerance of negative emotions are partially distinct from cognitive control. It was also determined that it may be beneficial to view the association between cognitive control and tolerance of negative emotions from a developmental lens. Studies incorporating neuroimaging to assess cross-modal processes required for tolerance of negative emotions at different stages of cognitive and emotional development may also be helpful in elucidating cognitive mechanisms involved in the tolerance of negative emotions.

Future studies may wish to assess differences in self-regulatory processes as influenced by emotionally salient and non-emotionally salient stimuli. It may also be beneficial to explore whether effects are dependent on the temporal characteristics of the cognitive and emotional regulatory processes associated with tolerance of negative emotions. Longitudinal comparisons of self-efficacy and behavioral emotion regulation may also assist in gaining a better mechanistic understanding of how emotion regulation impacts tolerance of negative emotions and determine causal effects.

Results strengthen evidence for the use of emotion regulation training to increase tolerance of negative emotions and suggest that interventions using emotion regulation skills are likely to work better for increasing tolerance of negative emotions than interventions focused solely on cognitive training. Findings indicate the importance of regulatory self-efficacy in the pursuit of goals that may require tolerating negative emotions. This research also has implications for future research on the identification of goals as an important aspect of the ability to self-regulate and tolerate distress. Advances in our understanding of self-regulatory processes influencing tolerance of negative emotions can allow more focused treatment of distress tolerance related mental health disorders and can provide training for those at increased risk for mental health disorders.

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APPENDIX A

DEMOGRAPHICS

1. What is your age? ________

2. What is your student status?

( ) Full-time ( ) Part-time

3. What is your class standing?

( ) Freshman

( ) Sophomore

( ) Junior

( ) Senior

( ) Graduate

( ) Other (please specify) _____________

4. Current residence:

( ) On-campus dormitory

( ) On-campus living-learning community

( ) Off-campus house or apartment

( ) Greek-affiliated residence (fraternity/sorority)

( ) With family

( ) Other (please specify) _____________

5. What is your GPA? ____________

6. What is your involvement in social fraternities or sororities?

( ) A current member

( ) Currently pledging

( ) Not a member, but regularly or occasionally attend Greek social events

( ) Not a member, and do not attend Greek events

7. Are you currently employed?

( ) I am not employed

( ) I typically work about 20 hours or less per week

( ) I typically work about 20 to 35 hours per week

( ) I typically work more than 35 hours per week

( ) Other (please specify) _____________

8. What is your gender?

( ) Male ( ) Female ( ) Trans* ( ) Other

9. What is your relationship status?

( ) Single

( ) Married

( ) Divorced / Separated

( ) In a committed relationship

( ) Other (please specify) _________________

10. Are you Hispanic or Latino?

( ) Yes ( ) No

11. My ethnicity is (select all that apply):

( ) Black, African American, Afro-Caribbean, Black African, Other in this category.

( ) White, Caucasian, European American, White European, Other in this category.

( ) East Asian, Asian American, Amerasian, Asian-Caribbean, Other in this category.

( ) Latino/a, Hispanic, Spanish, Latin American, of Spanish speaking-South American/Caribbean heritage, Other in this category.

( ) South Asian, South Asian American, of South Asian heritage, Other in this category.

( ) Middle Eastern, Arab, Non-Black North African, Other in this category.

( ) Native American, American Indian, Alaskan Native, Other in this category.

( ) Pacific Islander, Other in this category.

12. How do you define your sexual identity? Would you say that you are:

( ) Only homosexual

( ) Mostly homosexual

( ) Bisexual

( ) Mostly heterosexual

( ) Only heterosexual

( ) Other (please specify) ________________________.

APPENDIX B

DIFFICULTIES IN EMOTION REGULATION SCALE-SHORT FORM

Please indicate how often the following apply to you:

	Almost never (0-10%)	Sometimes (11-35%)	About Half of the time (36-65%)	Most of the Time (66-90%)	Almost Always (91-100%)
1. I pay attention to how I feel.	1	2	3	4	5
2. I have no idea how I am feeling	1	2	3	4	5
3. I have difficulty making sense out of my feelings.	1	2	3	4	5
4. I care about what I am feeling.	1	2	3	4	5
5. I am confused about how I feel	1	2	3	4	5
6. When I'm upset, I acknowledge my emotions.	1	2	3	4	5
7. When I'm upset, I become embarrassed for feeling that way.	1	2	3	4	5
8. When I'm upset, I have difficulty getting work done.	1	2	3	4	5

9. When I'm upset, I become out of control.	1	2	3	4	5
10. When I'm upset, I believe that I will end up feeling very depressed.	1	2	3	4	5
11. When I'm upset, I have difficulty focusing on other things	1	2	3	4	5
12. When I'm upset, I feel guilty for feeling that way.	1	2	3	4	5
13. When I'm upset, I have difficulty concentrating.	1	2	3	4	5
14. When I'm upset, I have1difficulty controlling my behaviors.	1	2	3	4	5
15. When I'm upset, I believe there is nothing I can do to make myself feel better.	1	2	3	4	5
6. When I'm upset, I become irritated with myself for feeling that way.	1	2	3	4	5
17. When I'm upset, I lose control over my behavior.	1	2	3	4	5
18. When I'm upset, it takes me a long time to feel better.	1	2	3	4	5

APPENDIX C

DISTRESS TOLERANCE SCALE

Directions: Think of times that you feel distressed or upset. Select the item from the menu that best describes your beliefs about feeling distressed or upset

1	2	3	4	5
Strongly agree	Mildly agree	Agree and disagree equally	Mildly disagree	Strongly disagree

1. Feeling distressed or upset is unbearable to me.
2. When I feel distressed or upset, all I can think about is how bad I feel.
3. I can’t handle feeling distressed or upset.
4. My feelings of distress are so intense that they completely take over.
5. There’s nothing worse than feeling distressed or upset.
6. I can tolerate being distressed or upset as well as most people.
7. My feelings of distress or being upset are not acceptable.
8. I’ll do anything to avoid feeling distressed or upset.
9. Other people seem to be able to tolerate feeling distressed or upset better than I can.
10. Being distressed or upset is always a major ordeal for me.
11. I am ashamed of myself when I feel distressed or upset.
12. My feelings of distress or being upset scare me.
13. I’ll do anything to stop feeling distressed or upset.
14. When I feel distressed or upset, I must do something about it immediately.
15. When I feel distressed or upset, I cannot help but concentrate on how bad the distress actually feels.

VITA

Alicia L. Milam

Old Dominion University
Department of Psychology
250 Mills Godwin Life Sciences Building
Norfolk, VA 23529

Education

05/2024 (*expected*)	Virginia Consortium Program in Clinical Psychology Ph.D. Clinical Psychology (APA Accredited) Advisor: Michelle L. Kelley, Ph.D.
12/2021 (*expected*)	Old Dominion University M.S. Psychology Advisor: Michelle L. Kelley, Ph.D.
12/2015	University of Texas at San Antonio B.A. Psychology & B.S. Biology Concentration: Neurobiology

Background

Alicia L. Milam is a third-year student in the Virginia Consortium Program in Clinical Psychology. She works with Dr. Michelle L. Kelley's Laboratory assessing the affective consequences of trauma in military service members. She has also worked with Dr. Matt R. Judah in the Emotion Research and Psychophysiology Laboratory where she uses psychophysiological methods to examine cognitive-affective processing. Her primary research interests include self-regulation with an emphasis on processes such as emotion regulation and cognitive control.

Selected Publications and Presentations

Kelley, M. L., Chae, J. W., Bravo, A. J., **Milam, A. L.,** Agha, E., Gaylord, S. A., Vinci, C., & Currier, J. M. (2021). Own soul's warning: Moral injury, suicidal ideation, and meaning in life. *Psychological Trauma: Theory, Research, Practice, and Policy*. doi: 10.1037/tra0001047

Milam, A. L., Judah, M. R., Hager, N. M. (2021). The influence of negative affect regulation and neurophysiological markers of cognitive control on distress tolerance. Conference paper presented at Virginia Space Grant Consortium virtual student research conference.

Gonzalez, D. A., Soble, J. R., & **Kruzelock, A.** (2018). Plasticidad cognitiva y rehabilitación postquirúrgica [Cognitive plasticity & post-surgical rehabilitation]. In A. A. J. Magaña & J. C. L. Girón (Eds.), Cognicion en neuropsiquiatria: Clínicas de neurociencias III [Cognition in neuropsychiatry: Clinical neuroscience]. ISBN 978-9929-778-18-4