Associations between Heart Rate Variability, Emotion Regulation, and Depressive Symptoms among Women: A Replication and Extension

Dissertation

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Abstract

Vagally-mediated heart rate variability (vmHRV) has long been a marker of interest in non-invasively observing the functioning of the heart as well as the efficiency of systems involved in self-regulation. vmHRV during resting conditions has been shown, via positive association, to index individual inhibitory capacity necessary to facilitate top-down attentional and affective processing. Women exhibit higher resting vmHRV on average than men, which suggests that women should exhibit better emotion regulation than men on average. Paradoxically, women endorse more intense and persistent reactions to negative stimuli, more difficulties with emotion regulation (e.g., goal-oriented modulation of affective responses), and greater psychological symptoms (e.g., depressive and anxious) compared to men.

At least two explanations for this paradox are feasible. The first is that higher inhibitory control alone is insufficient to overcome the increased sensitivity and reactivity to negative emotion exhibited among women. The second possibility is that for at least a subset of women, high inhibitory control is utilized to support emotion regulation strategies and coping responses which perpetuate or intensify experience of negative emotions (e.g., sadness and anger). The former hypothesis is supported by sex differences in vmHRV, inhibitory control, emotion regulation, and coping strategies during negative emotion. The latter hypothesis is supported by findings of a curvilinear relationships between vmHRV and depressive symptoms as well as theories of disorders of overcontrol in which the tendency to exert excessive inhibitory control results in a maladaptive response pattern to stress. The current study is a replication and

extension of previous work investigating the associations between vmHRV, emotion regulation, and depressive symptoms in a sample of 227 women. Overall, results replicated the findings of Spangler et al. (2021), supporting a concave curvilinear association between vmHRV and depressive symptoms. Moreover, findings showed a moderating effect of experiential avoidance on the association between vmHRV and depression such that the concave curvilinear association was significant only at high levels of experiential avoidance.

Dedication

This dissertation is dedicated to my mother and father, Drs. Ernesto and Patria Gerardo. I love and thank you both for your guidance, support, and unconditional love.

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Fields of Study

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Chapter 1. Introduction

Vagally-mediated heart rate variability (vmHRV), most commonly measured as high frequency variation in time between inter-beat-intervals (IBIs) of heart beats, has long been a marker of interest in non-invasively observing the functioning of the heart as well as the efficiency of systems involved in self-regulation (Task Force, 1996; Thayer & Lane, 2000; Thayer & Lane, 2009). Importantly, a positive association has been established between vmHRV during resting conditions and measures of inhibitory capacity necessary to facilitate top-down attentional and affective processing (Porges, 1991, 1992). Intriguingly, women exhibit higher resting vmHRV on average than men (Koenig & Thayer, 2016), which suggests that women should exhibit better emotion regulation than men on average. Paradoxically, women endorse more intense and persistent emotional reactions to negative stimuli (Andreano, Dickerson, & Feldman Barrett, 2014), more difficulties with emotion regulation (e.g., goal-oriented modulation of affective responses: Williams et al., 2018), and greater symptoms of emotional disorder (e.g., depressive and anxious symptoms) compared to men (Kessler et al., 2012).

At least two explanations for this paradox are plausible. The first is that higher inhibitory control alone is insufficient to overcome women's higher sensitivity and reactivity to negative emotion. The second possibility is that for at least a subset of women, high inhibitory control is utilized to support emotion regulation strategies and coping responses which are ineffective or actually serve to perpetuate or intensify their experience of negative emotions (e.g., sadness and anxiety). The former hypothesis is supported by findings of sex differences in vmHRV, inhibitory control, emotion regulation, and coping strategies during negative emotion (Aldao & Mennin, 2012; Williams et al., 2018; Zimmermann & Iwanski, 2014). The latter hypothesis is supported by findings of a curvilinear relationship (discussed below) between vmHRV and depressive symptoms (Spangler et al., 2021) as well as theories of disorders of overcontrol in which the tendency to exert excessive inhibitory control results in a maladaptive response pattern to stress (Lynch, 2018). The following discussion highlights these relevant findings and proposes a replication and extension of previous work investigating the associations between these constructs (Spangler et al., 2021; Williams et al. 2018).

Heart Rate Variability

HRV, fluctuations in inter-beat-intervals (IBIs) of the heart, is an established indicator of heart function and individual inhibitory capacity (Task Force, 1996; Thayer & Lane, 2000; Thayer & Lane, 2009). During resting conditions, vmHRV is an index of parasympathetic nervous system function and is inversely correlated with a wide range of risk factors for poor health outcomes (e.g. poor physiological, emotional, cognitive, and behavioral regulation) as well as self-rated health (Alvares, et al., 2013; Beauchaine & Thayer, 2015; Jarczok et al., 2015; Thayer, Ahs, Fredrickson, Sollers, & Wager, 2012; Thayer, Hansen, Saus-Rose, & Johnsen, 2009; Thayer & Lane, 2000; Thayer & Lane, 2009). For example, lower resting vmHRV is associated with poor functioning of the anti-inflammatory reflex (Pavlov & Tracey, 2012), suggesting that lower resting vmHRV may increase overall risk for physical illness (Thayer, Yamamoto, & Brosschot, 2010; see Kemp & Quintana, 2013 for review). Likewise, lower resting vmHRV is considered to be a transdiagnostic, psychophysiological marker of general psychopathology (Beauchaine & Thayer, 2015; Caspi et al., 2014).

Furthermore, higher resting vmHRV predicts emotion regulation (ER; ability to adapt affective reactions in a goal-oriented manner) in daily life (Koval et al., 2013) as well as control of attention during perception of emotional stimuli (Park & Thayer, 2014; Park, Van Bavel, Vasey, & Thayer, 2013). Activity of the vagus nerve is associated with that of executive brain regions, and therefore may indicate an individual's capacity or readiness to regulate emotions and engage in other self-regulatory processes. For example, resting vmHRV is predictive of self-reported ER (Williams, Cash, Rankin, Bernardi, Koenig, & Thayer, 2015) and cognitive control (Anderson et al., 2004; Williams, Thayer & Koenig, 2016) including control of memory retrieval (Gillie, Vasey, & Thayer, 2014) and suppression of intrusive thoughts (Gillie, Vasey, & Thayer, 2015).

Voluminous research has linked greater resting vmHRV to the ability to engage in adaptive ER strategies (Aldao & Mennin, 2012) and suggests that this association is stronger among women compared to men (Thayer et al., 1998; Williams et al., 2015). For example, Williams et al. (2018) found a negative association between vmHRV and self- reported difficulties in ER using the 36-item Difficulties in Emotion Regulation Scale (DERS; Gratz & Roemer, 2004). Specifically, in their sample of young adults, sex moderated the correlation between vmHRV and difficulties in ER such that the association was significantly stronger among women compared to men. These findings are consistent with the hypothesis that women's higher average vmHRV is insufficient to overcome their higher average sensitivity and reactivity to negative emotion.

Despite the large body of research indicating that relatively high resting vmHRV is adaptive, this is not always the case. Recently, Spangler et al. (2021) found a curvilinear pattern of association between vmHRV and symptoms of depression among women that suggests high vmHRV can be associated with *high* depressive symptoms. Whereas women with resting vmHRV below the median showed the typical negative correlation between vmHRV and depressive symptoms, women with vmHRV above the median showed a *positive* correlation between vmHRV and depressive symptoms. The opposite pattern appeared for positive affect such that women with vmHRV below the median showed a positive correlation between vmHRV and positive affect whereas this correlation reversed among women with vmHRV above the median. This finding stands in stark contrast to the finding of Williams and colleagues because depressive symptoms are strongly positively correlated with DERS scores (Weinberg & Klonsky, 2009; Ritschel, Tone, Schoemann, & Lim, 2015; Bjureberg, et al., 2016; Hallion, Steinman, Tolin, & Diefenbach, 2018). Thus, this pattern is incompatible with the idea that women experience higher emotional problems because their higher average vmHRV is inadequate to overcome greater emotional vulnerability exhibited among women. Instead, it implies a path by which women with relatively high resting vmHRV may use their greater regulatory capacity in ways that maintain or worsen ER problems and depressive symptoms.

Throughout the literature, there is evidence of both such patterns: one in which individuals high in ER problems/depressive symptoms are characterized by low resting vmHRV (hereinafter labeled the typical pattern) and one in which they are characterized by high resting vmHRV (hereinafter labeled the atypical pattern). The typical pattern is demonstrated by multiple studies showing that individuals with major depression have lower resting vmHRV than controls (see Kemp et al., 2010 and Koch, Wilhelm, Salzmann, Rief, & Euteneuer, 2019 for review and meta-analytic results). However, it should be noted that most of these studies did not test for the possibility of a curvilinear relationship. The atypical pattern is illustrated by findings by Rottenberg and colleagues (Bylsma, Morris, & Rottenberg, 2008; Rottenberg, 2007; Yarolslavsky, Rottenberg, & Kovacs, 2014). Whereas Rottenberg's group has found the typical pattern, in which depression is linked to low resting vmHRV coupled with further vagal withdrawal in response to negative emotional challenge, they have also found that depression is sometimes linked to high resting vmHRV with an intensification response to negative emotional challenge. Importantly, phasic increases in vmHRV during emotion regulation are associated with effort to self-regulate (Butler, Wilhelm, & Gross, 2006). Thus, this second pattern suggests a path by which women's average higher vmHRV may actually foster depression despite engagement of self-regulatory effort. That is, they may habitually exert their self-regulatory capacity in service of maladaptive ER responses.

The recent investigations (Spangler et al., 2021; Williams et al., 2018) into sex differences in vmHRV and emotion regulation warrant replication as well as further examination of both patterns: low resting vmHRV associated with greater ER problems and depressive symptoms (typical) as well as high resting vmHRV associated with greater ER problems and depressive symptoms (atypical). Further examining the associations between vmHRV, ER, and depressive symptoms among women is needed to reconcile these discordant findings. Importantly, given the potentially limited representation of individuals with both high depression and high vmHRV in both previous studies, it is crucial to perform this replication in a sample designed to over-represent such participants.

Emotion Regulation

Since its inception, the concept of emotion regulation (ER) has evolved into an integral feature in the understanding of psychological disorders and their treatment (Aldao, 2013; Thompson, 1994). There have been multiple varied definitions of ER in the literature. Overall, the construct is described as involving multiple processes, both internal and external, to adapt affective reactions to suit the situation and achieve favorable outcomes (Aldao, 2013; Gross, 1998; Koole, 2009; Thompson, 1994). Among these processes are apparent regulatory strategies used to modulate emotional experiences and expressions. Six strategies in particular have been emphasized throughout the ER literature: acceptance, avoidance, problem-solving, reappraisal, suppression, and perseverative cognition including both worry and rumination (Aldao, Nolen-Hoeksema, & Schweizer, 2010).

Problem solving, reappraisal, and acceptance generally have been conceptualized as adaptive ER strategies and linked to reductions in symptoms of depression (Billings & Moos, 1981; Segal et al., 2002). Problem solving includes attempts to mitigate or resolve a stressor, typically via some action. Ineffective problem solving is theorized as one pathway to development of depression (Nezu, Nezu, Saraydarian, Kalmar, & Ronan, 1986; Nezu & Ronan 1988). Reappraisal involves altering one's perspective and/or interpretation of an event to be less negatively biased (Gross, 1998). Because automatic maladaptive evaluations are proposed as a core feature of depression (Beck, Steer, & Brown, 1996), reappraisal is purported to improve affective and physical responses to emotional stimuli (Gross, 1998). Finally, acceptance, defined as a non-judgmental attitude toward thoughts, sensations, and emotions, is a core tenet of mindfulness-based therapies (present-moment awareness used to reduce distress; Kabat-Zinn, 1990) as well as Acceptance and Commitment Therapy (ACT; Hayes, Strosahl, & Wilson, 1999) which have had success in treating a variety of disorders including depression (Segal et al., 2002). Such interventions suggest that allowing rather than avoiding experience of unwanted emotions leads to reductions in subjective experiences of distress.

On the other hand, avoidance, suppression, and perseverative negative cognition (e.g., brooding rumination) are typically thought of as maladaptive ER strategies and linked to greater symptoms of depression (Rueda & Valls, 2016; Van der Does, 2005; Ottaviani et al., 2015). Here avoidance refers to actions (both external and internal) meant to permit evasion of negative experiences and emotions. In particular, experiential avoidance—maneuvers to escape negative internal experiences such as thoughts, memories, and emotions—is proposed to worsen mood problems (Hayes, Strosahl, & Wilson, 1999). Meanwhile, suppression refers to attempts to refrain from negative emotional expression and thoughts. Suppression of unwanted thoughts has been shown to increase the frequency and intensity of such thoughts (Wang, Hagger, & Chatzisarantis, 2020) and suppression of emotional expression has been shown to be ineffective in reducing the experience of emotion and physiological arousal in the long term. Both avoidance and suppression are risk factors for development of depression and may foster sensitivity to depressive thoughts (Rueda & Valls, 2016; Van der Does, 2005).

Negative perseverative cognition is the chronic repetitive activation of thoughts related to stressful events. The perseverative cognition hypothesis highlights two main types of perseverative cognition: worry and rumination. Worry is persistent recurrent thinking that is typically future oriented and characteristic of anxiety. Rumination is characteristic of depression and conceptualized as persistent recurrent thinking that is typically focused on past events, self-referential, and negatively-valenced (Watkins & Roberts, 2020). Though both worry and rumination are often described as involuntary and uncontrollable processes, individuals in some studies endorse intentional implementation of worry and rumination as well as positive beliefs about these processes as potential ER strategies (Fishback, Chriki, Thayer & Vasey, 2020; Papageorgiou & Wells, 2001; Watkins & Moulds, 2005).

A large body of research on ER continues to grow due to the hypothesized role of ER in the development and maintenance of many forms of psychopathology (Aldao, Gee, De Los Reyes, & Seager, 2016; Kring & Sloan, 2010; Sheppes, Suri, & Gross, 2015). In their review of ER in depression, Joormann and Stanton (2016) specified that cognitive biases and difficulties in inhibitory control are involved in the emotion dysregulation that characterizes mood disorders, thereby building upon the supposition that depressive and many other disorders are products of poor ER (Campbell-Sills & Barlow, 2007; Kashdan & Breen, 2008; Mennin, Holoway, Fresco, Moor, & Heimberg, 2007; Rottenberg, Gross, & Totlib, 2005).

Several therapeutic interventions highlight ER as an important target for treatment (Aldao, Nolen-Hoeksema, Schweizer, 2010). For example, modulation of emotions and reduction of emotional reactivity are secondary behavioral targets of treatment in Linehan's (1993) Cognitive-Behavioral Treatment of Borderline Personality Disorder. Also, awareness of emotions is a critical part of skills training in ACT for anxiety (Hayes, Strosahl, & Wilson, 1999) as well as Mindfulness-Based Cognitive Therapy for depression (Segal, Williams, & Teasdale, 2002). In general, it is suggested that psychotherapy may be employed to enhance use of adaptive ER strategies (e.g., reappraisal) and reduce reliance on maladaptive ER strategies (e.g., rumination). It is worth noting that this dichotomy is a simplified view of ER and that at least one study has shown that both conventionally adaptive (e.g., reappraisal) and maladaptive (e.g., suppression) ER strategies are linked to a phasic vmHRV augmentation response to negative stimuli (Butler, Wilhelm, & Gross, 2006). Similar to the aforementioned atypical pattern of vmHRV found by Rottenberg and colleagues (Bylsma, Morris, & Rottenberg, 2008; Rottenberg, 2007; Yaroslavsky, Rottenberg, & Kovacs, 2014), this finding supports the idea that greater inhibitory control indexed by vmHRV may be utilized to engage in maladaptive coping strategies. As such, there are ongoing efforts to better clarify the conceptualization, measurement, and understanding of ER as a multifaceted, transdiagnostic factor (Gross, 2013; Fernandez, Jazaieri, & Gross, 2016).

Past research suggesting that women report greater attention to emotions than men (Thayer, Rossy, Ruiz-Padial, & Johnsen, 2003) seems to support the idea that women on average exhibit greater vulnerability to negative emotion which is not resolved through high resting vmHRV. Meanwhile evidence that women endorse greater overall use of ER strategies (both adaptive and maladaptive) compared to men bolsters the idea that some women may be utilizing greater inhibitory capacity to engage in ER strategies which worsen depression.

Overcontrol

A possible explanation for the unexpected pattern of association between high resting vmHRV and ER in women lies in the neurobiosocial theory for disorders of overcontrol (Lynch, 2018). In the model, maladaptive overcontrol is characterized by four core features including low openness, inflexible and compulsive need for order, low social connectedness, and importantly, persistent and inappropriate use of top-down cognitive control resources to inhibit emotions (Lynch, 2018). Lynch posits that biological/genetic influences, environmental factors, and the propensity to exert excessive inhibitory control interact to maintain behavioral patterns of maladaptive overcontrol. In the model, the biological, environmental, and behavioral components are referred to as “Nature”, “Nurture”, and “Coping”, respectively. Under the Nature component, the model identifies low reward sensitivity, high threat sensitivity, high attention to detail, and high inhibitory control as biologically/genetically influenced characteristics of the maladaptive overcontrolled individual (a.k.a. overcontroller). This suggests that part of what identifies those susceptible to disorders of overcontrol is a higher-than-average capacity for inhibitory control. Under the Nurture component, the model identifies parental beliefs and messaging such as “mistakes are intolerable”, “winning is essential”, “never reveal weakness”, “always be prepared”, and “self-control is imperative” as environmental influences. This suggests that overcontrollers are likely to value self-control and therefore inhibition of emotions. The Coping component identifies avoidance of unplanned risks, distress overtolerance, masked inner feelings, and compulsive striving as behaviors that reinforce maladaptive overcontrol. In combining these components, Lynch hypothesizes that chronically depressed individuals’ maladaptive overcontrol is intermittently reinforced as they alternate between high sympathetic nervous system defensive arousal and high parasympathetic nervous system-dorsal vagal complex numbing, specifically through processes such as worry and rumination, which characterize disorders of overcontrol. This is supported by previous research which found that women appear significantly more likely than men to engage in rumination and social support seeking (which may result in co-rumination; Zimmermann & Iwanski, 2014). In overcontrollers, the tendency toward emotional suppression and experiential avoidance may drive the puzzling aforementioned atypical positive association between vmHRV and depressive symptoms in women. For example, a recent investigation found that among individuals with elevated depressive symptoms, those with higher resting vmHRV at time 1 reported greater experiential avoidance (as measured by the Acceptance and Action Questionnaire) at time 2 (3.5-week intervals) as well as increased depressive symptoms at time 3 (Brownlow et al., 2020). This provides additional evidence for a pathway by which high resting vmHRV may lead to maladaptive coping and poor outcomes including depression.

Rumination

One of the emotion regulation strategies discussed earlier, rumination, is posited to be a manifestation of experiential avoidance (Cribb, Moulds, & Carter, 2006; Smith & Alloy, 2009; Giorgio et al. 2010) and may be a potential mechanism by which depressive symptoms become exacerbated among individuals with high resting vmHRV. Rumination is most comprehensively defined as “repetitive, prolonged, and recurrent negative thinking about oneself, feelings, personal concerns, and upsetting experiences.” (Watkins & Roberts, 2020).

There are two dominant theories of rumination: Response Styles Theory (Nolen-Hoeksema, 1991) and Control Theory (Marin, & Tesser,1996). Response Styles Theory conceptualizes rumination as a trait-like tendency that is learned during childhood. In particular, Response Styles Theory hypothesizes that sex differences in socialization increase risk for rumination among women and therefore mediate sex differences in depression (Nolen-Hoeksema, 1991). This theory also postulates that rumination begins automatically and unintentionally when triggered by low mood. Expectedly, rumination is positively correlated with experience of negative emotion, deficits in executive functioning, dysregulated behavior, impaired parasympathetic flexibility (Ottaviani et al., 2016), and symptoms of psychopathology (Nolen-Hoeksema, Wisco, Lyubomirsky, 2008). These links between rumination and poor outcomes align with a typical pathway by which individuals with low resting vmHRV are vulnerable to persistent and uncontrollable rumination due to insufficient inhibitory control.

While there is a large body of evidence supporting this widely accepted theory, it does not take into account potential situational (state rather than trait) differences in utilization of rumination. Control Theory hypothesizes that rumination may be initiated intentionally, particularly when thinking about inadequate goal progress is triggered. Control Theory notes that the nature of individuals' goals is an important factor in their utilization of rumination. For example, high trait ruminators may value avoidance of negative emotional experiences as an important goal. These same individuals also tend to have perfectionistic standards which maintain and exacerbate ruminative thoughts (Brown & Kocovski, 2014). These beliefs overlap with those highlighted earlier in the nurture component of the theory of disorders of overcontrol: "mistakes are intolerable", "winning is essential", "never reveal weakness", "always be prepared", and "self-control is imperative". Thus, through the proposed mechanisms in Control Theory, a second, atypical pathway to rumination is possible whereby individuals with high inhibitory control engage in repetitive thought strategically with the intention to reach valued goals (e.g., avoidance of negative experiences).

Recently a new model emphasizing Habit development, EXecutive control, Abstract processing, GOal discrepancies, and Negative bias (abbreviated H-EX-A-GO-N) integrates both Response Styles Theory and Control Theory (Watkins & Roberts, 2020). In this model, there are several pathways to chronic rumination. For example, negative bias and executive control deficits may give way to habit development through repeated iterations of repetitive thinking. The novel component of this model is that processing style is used to differentiate between when rumination may be helpful (concrete processing—e.g. "How are you deciding what to do next?") and unhelpful (abstract processing—e.g. "Why did this problem happen?"). Abstract processing in particular is thought to prolong and intensify state rumination, impair problem-solving, and perpetuate goal-discrepancies—especially when goals are problematic (e.g., goal is to avoid negative emotion/experiences).

This more comprehensive model most closely corresponds to the hypotheses of the current study in that it accounts for two pathways: 1) learned behavior/habit maintain rumination and 2) failed attempts at problem-solving worsen rumination (Watkins & Roberts, 2020). Given its established importance in the development and maintenance of multiple psychological problems, as well as the potential dual pathway to rumination (via either deficits in inhibitory control or maladaptive overcontrol), further investigation into the nature of rumination may be crucial to understanding its role in the associations between vmHRV, ER, and depressive symptoms.

The Current Study

The first aim of the current study was to replicate findings by Williams et al. (2018) and Spangler et al. (2021) by measuring the associations between vmHRV, ER, and depressive symptoms, among women. It was hypothesized that findings would echo those of Spangler et al. (2021), demonstrating a concave curvilinear (i.e., quadratic) association between vmHRV and self-reported ER difficulties (Hypothesis 1) and depressive symptoms (Hypothesis 2) as well as brooding rumination (Hypothesis 3). Specifically, resting vmHRV was predicted to be negatively correlated with difficulties in ER, depressive symptoms, and brooding rumination among women with resting vmHRV in the lower half of the vmHRV distribution and positively associated among women in the upper half of the vmHRV distribution. Furthermore, Spangler et al. (2021) speculated that curvilinear effect of vmHRV on depressive symptoms may be specific to depression because they found no correlation between vmHRV and broader negative affect, coupled with a significant negative correlation with positive affect. Therefore, it was expected (as a facet of the replication in Hypothesis 2) that a measure of general negative emotion would not be correlated with vmHRV and that curvilinear relationship between vmHRV and depressive symptoms would remain significant even when controlling for symptoms of negative affect.

The second aim of the study was to investigate the role of experiential avoidance in the associations between vmHRV, ER, and depressive symptoms. Specifically, it was hypothesized that (Hypothesis 4) vmHRV would be positively associated with emotion regulation difficulties among individuals who strongly endorsed a goal of experiential avoidance and negatively associated among individuals who endorsed lower levels of experiential avoidance. That is, the expected concave quadratic effect of vmHRV on ER difficulties was predicted to be moderated by (i.e., conditional upon) level of experiential avoidance. Similarly, (Hypothesis 5) vmHRV would be positively associated with depressive symptoms among individuals who strongly endorsed a goal of experiential avoidance and negatively associated among individuals who endorsed lower levels of experiential avoidance. That is, the expected concave quadratic effect of HRV on depressive symptoms was expected to be moderated by level of experiential avoidance. Likewise, (Hypothesis 6) vmHRV would be positively associated with brooding rumination among individuals who strongly endorsed a goal of experiential avoidance and negatively associated among individuals who endorsed lower levels of experiential avoidance. That is, the expected concave quadratic effect of HRV on brooding rumination was expected to be moderated by level of experiential avoidance.

Finally, the third aim of the study was to test the hypothesis (Hypothesis 7) that the association between vmHRV, and brooding rumination would be moderated by the strength of positive beliefs about rumination. That is, individuals with higher levels of vmHRV will be more likely to report brooding rumination if they strongly believe that rumination is beneficial. In contrast, higher vmHRV should predict lower levels of brooding rumination among individuals who do not believe rumination to be beneficial.

Chapter 2. Methods

Participants

The total sample included 227 college students who self-identified as women. Mean age was 18.46 years (SD = 0.743, range = 18 to 22 years). One hundred twenty-seven (55.9%) individuals identified their race as White or European American and sixty-seven (29.5%) individuals identified their ethnicity as not Hispanic or LatinX. Thirty-three (14.5%) individuals did not disclose their race or ethnicity.

Recruitment

Participants were recruited from the Ohio State University (OSU) Research Experience Program (REP), a mechanism whereby undergraduate students may participate in research to earn partial class credit in an introductory psychology course. Because this study was primarily interested in testing the associations between vmHRV, ER, and depression as they have previously been observed among women, only individuals who self-identified as women were invited to participate. Also, individuals who report high worry and sadness were oversampled to examine heterogeneity in the levels of depressive symptoms and ER problems. The question about worry was relevant to a related study. However, worry is strongly associated with depressive symptoms; thus, the two screening questions emphasized identification of individuals with elevated depressive symptoms. Participants completed two items regarding their worry and sadness/depression (Penn State Worry Questionnaire [PSWQ] item 15: “I worry all the time.”;

and Depression Anxiety and Stress Scales [DASS] item 13: "I felt sad and depressed.") during the REP pre-screening phase. Specifically, all individuals in the pre-screened sample were invited to participate if they reported that the statement "I worry all the time" was at least moderately typical of them (i.e., a rating of 3 or higher on the PSWQ's 5-point Likert scale) and/or who reported that during the past week the statement "I felt sad and depressed" applied to them to a considerable degree or more (i.e., a rating of 3 or 4 on the DASS's 4-point Likert scale). This approach was meant to produce a study sample in which women reporting high levels of depression and worry were overrepresented so as to increase statistical power to detect the interaction effects of interest. Additionally, a random subset of women who did not meet these screening criteria were also invited to participate to increase the overall sample size.

Procedure

Participants were instructed to not smoke, engage in vigorous physical activity, or consume caffeine for six hours prior to their laboratory session (Task Force of the European Society of Cardiology and the North American Society of Pacing and Electrophysiology, 1996). They were also required to complete written informed consent upon arrival in the laboratory. Data collection was completed in-person. Participants were briefed of the general protocol of the experiment without suggestion of hypotheses. Next, height, weight, and waist circumference measurements were recorded and an ambulatory device for recording the electrocardiogram (ECG; Firstbeat Bodyguard 2, Firstbeat Technologies Ltd., Jyväskylä, Finland) was applied. Participants were seated in a semi-darkened, sound attenuated experimental room furnished with a camera and microphone. Participants underwent a 10-minute resting baseline period (while breathing spontaneously rather than in a paced fashion). They were instructed to stay awake and sit still with both feet on the floor and their hands on the arms of the chair. Following baseline, the ECG recording device was removed and participants completed a battery of self-report questionnaires in Qualtrics using a provided iPad tablet. In total, the session lasted between 90-120 minutes. The measures used for this study were a subset of a larger battery of questionnaires collected during the experiment session. All questionnaires were administered in random order.

Heart Rate Variability

Cardiac data was recorded during a 10-minute resting baseline period at the outset of the experiment via a 2-lead ECG at a 1000 Hz sampling rate using a Bodyguard 2 portable ECG recorder (Firstbeat Bodyguard 2, Firstbeat Technologies Ltd., Jyväskylä, Finland). Two disposable, pre-gelled, self-adhesive electrodes were attached (1) below the participant's right clavicle and (2) at the bottom of their right rib cage. A time series of the intervals, in milliseconds, between successive R-spikes was extracted and used to calculate vmHRV. Specifically, Kubios vmHRV Analysis Package 3.5 (Tarvainen, Niskanen, Lipponen, Ranta-aho, & Karialainen, 2014) was used to analyze interbeat intervals and calculate measures of vmHRV, including the time domain-measure of vagally mediated vmHRV, root mean square of successive differences (RMSSD). Raw RMSSD values were converted via a natural logarithmic transformation to increase the normality of their distribution (Task Force of the European Society of Cardiology and the North American Society of Pacing and Electrophysiology, 1996). Cases with excessively noisy, unreadable, or missing ECG data were excluded from the study.

Self-Report Measures

Difficulties in Emotion Regulation Scale

Difficulties in ER were assessed using the aforementioned Difficulties in Emotion Regulation Scale (DERS; Gratz & Roemer, 2004), which shows excellent internal consistency ($\alpha = .880$). Participants are asked to indicate on a scale from 1 (almost never) to 5 (almost always) how often a series of statements regarding their experience of and reaction to feelings, especially when upset, apply to them. Subscales include (a) nonacceptance of emotional responses (nonaccept; example item: “When I’m upset, I feel ashamed with myself for feeling that way.”); (b) difficulties engaging in goal-oriented behavior when experience negative emotions (goals; example item: “When I’m upset, I have difficulty getting work done.”); (c) difficulties in controlling impulsive behavior when experiencing negative emotions (impulse; example item: “When I’m upset, I lose control over my behaviors.”); (d) lack of emotional awareness (awareness; example item: When I’m upset, I take time to figure out what I’m really feeling.” reverse scored); (e) lack of strategies to regulate emotions (strategies; example item: “When I’m upset, I believe there is nothing I can do to make myself feel better.”); and (f) lack of emotional clarity (clarity; example item: “I am confused about how I feel.”). This measure exhibited high internal consistency in the current sample, as demonstrated by a Cronbach’s alpha coefficient of 0.94.

Depression Anxiety and Stress Scales

The Depression Anxiety and Stress Scale (DASS) is a 42-item instrument designed to assess symptoms/experiences related to depression, anxiety, and stress. Participants are asked to read each statement and indicate how much it applied to them over the past week on a scale from

0 (did not apply to me at all) to 3 (applied to me very much, or most of the time). Subscale scores are each comprised of 14 items and include depression (DASS-D; example item: "I couldn't seem to experience any positive feeling at all."), anxiety (DASS-A; example item: "I was worried about a situation in which I might panic and make a fool of myself."), and stress (DASS-S; example item: "I found myself getting upset by quite trivial things."). Items within the depression subscale measure symptoms of depression, particularly anhedonia and dysphoria. The anxiety subscale items describe symptoms of acute anxiety, such as acute physiological hyperarousal. The stress subscale represents more generalized symptoms of distress/negative affect, such as feeling tense, getting upset easily, irritability, and nervousness. Subscale scores are calculated by summing the items associated with each of the three constructs. This measure has been shown to possess satisfactory psychometric properties (Lovibond, & Lovibond, 1995). The DASS-D and DASS-S exhibited high internal consistency in the current sample, as demonstrated by Cronbach's alpha coefficients of 0.94 and .89 respectively.

Acceptance and Action Questionnaire

The Revised Acceptance and Action Questionnaire (AAQ-II) is a one-factor measure with higher scores indicating greater psychological inflexibility and experiential avoidance. Participants are instructed to rate how true each statement is for them on a scale from (1) never true to (7) always true (example item: "My painful experiences and memories make it difficult for me to live a life that I would value."). The revised measure has been shown across multiple samples to have satisfactory structure, reliability, and validity ($\alpha = .84$; Bond et al., 2011). This measure exhibited acceptable internal consistency in the current sample, as demonstrated by a Cronbach's alpha coefficient of 0.86.

The Ruminative Responses - Brooding Scale

The Ruminative Responses Scale (RSS) is a 22-item measure used to assess the frequency with which people respond to sad mood with rumination. Participants are instructed to indicate whether they *generally* (1) almost never, (2) sometimes, (3) often, or (4) almost always think or do each item when they feel down, sad, or depressed. Subscales include three types of rumination: depressive (example item: “think about how sad you feel”), brooding (example item: “think about a recent situation, wishing it had gone better”), and reflection (example item: “go away by yourself and think about why you feel this way”). The RRS has previously demonstrated good internal consistency and validity (Nolen-Hoeksema & Morrow, 1991). The RRS Brooding scale exhibited good internal consistency in the current sample, as demonstrated by a Cronbach’s alpha coefficient of 0.80.

Adapted Positive Beliefs about Rumination Scale

The Adapted Positive Beliefs about Rumination Scale (PBRS-A) is a 9-item measure assessing the extent to which participants believe that recurrent thinking would be helpful. Participants are instructed to indicate how much they *generally* agree with each item on a scale from (1) do not agree to (4) agree very much (example item: “I need to think about things that have happened in the past to make sense of them.”). The iteration used in the current study was adapted to reduce references to negative mood or events, especially the words “rumination” and “depression”. The original measure has been shown to have high consistency and good test-retest reliability (Papageorgiou & Wells, 2001; Watkins & Moulds, 2005). This measure exhibited high internal consistency in the current sample, as demonstrated by a Cronbach's alpha coefficient of 0.85.

Data Analytic Strategy

Where appropriate, the data analytic strategies of Williams et al. (2018) and Spangler et al. (2021) were applied. All statistical tests were conducted using SPSS and the PROCESS macro for SPSS (Hayes, https://www.processmacro.org/index.html). Descriptive statistics were performed in order to compare the sample demographics and data to those of the studies by Williams et al. (2018) and Spangler et al. (2021). Zero-order correlations (Pearson's *r*) were used to assess the associations between all measures. All tests were two-tailed, significance levels were evaluated using an alpha of 0.05.

For all regression models, variables were mean centered via conversion to z-scores for ease of interpretation of the main-effects and effects were reported as unstandardized regression coefficients (B) with standard error coefficients in parentheses (*SE*), semi-partial correlation coefficients (*sr*), and significance (*p)* values were also reported. The quadratic term was created by squaring mean-centered lnRMSSD. It was intended that relevant covariates (e.g., age, race, ethnicity, body mass index [BMI], respiration, and menstruation) be examined where possible, as they have been suggested to significantly impact resting vmHRV (O'Brien, O'Hare, & Corrall, 1986; Brownlow et al., 2020; Soares et al., 2020; Hill and Siebenbrock, 2009; Schmalenberger et al., 2019). However, the sample was quite homogenous in age (range = 18 to 22 years), race (66.1% White or European American) and ethnicity (92.7% not Hispanic or Latinx). Also, many participants did not provide data for race (13.2%), ethnicity (13.2%), or menstruation (23% missing or not menstruating due to contraceptive devices). After conducting analyses both with and without BMI and respiration, results were unchanged. Both models are reported for each set of analyses, but these two covariates were excluded from the final results which were interpreted to maximize degrees of freedom.

Hypotheses 1-3 were tested respectively via multiple regression models (Cohen, 2003) to predict difficulties in ER (DERS z-scores), depressive symptoms (DASS-D z-scores), and brooding rumination (RRS-B). Each model included the (1) linear and (2) quadratic terms of lnRMSSD as predictors. For Hypotheses 2, a model with the same predictors was run predicting characteristics of more general negative affect (as indexed by the DASS stress subscale [DASS-S]). Finally, a model was run predicting DASS-D scores with DASS-S included as a covariate. These latter analyses reflect the expectation that vmHRV's association with depressive symptoms primarily involves symptoms specific to depression (e.g., low positive emotion) rather than more general symptoms of negative emotion. In the study by Spangler et al. (2021), resting vmHRV was neither linearly nor nonlinearly correlated with negative affect, as indexed by the Positive and Negative Affect Schedule (PANAS). The authors therefore argued that there is specificity in the emotional outcomes with which resting vmHRV is nonlinearly related. Thus, it was predicted that the HRV quadratic term would not significantly predict DASS-S and that controlling for DASS-S scores would not change results for the model predicting DASS-D scores.

Hypotheses 4-6 were tested via regression models predicting DERS, DASS-D, and RRS-B scores respectively. In addition to the lnRMSSD linear and quadratic terms, these regressions included the AAQ score representing experiential avoidance, and the lnRMSSD-linear x AAQ and lnRMSSD-quadratic x AAQ interaction terms to test the moderating effect of experiential avoidance on the association between vmHRV and the dependent variables. As in the case of

Hypothesis 2, Hypothesis 5 was tested predicting DASS-S scores and DASS-D scores controlling for DASS-S to investigate whether the effect of experiential avoidance on the association between vmHRV and DASS-D was unique to depression, rather than due to broader negative affect.

Hypothesis 7 was tested via a regression model predicting brooding rumination (RRS-B) with lnRMSSD-linear, lnRMSSD-quadratic, positive beliefs about rumination (PBRS-A) and the lnRMSSD-linear x PBRS-A and lnRMSSD-quadratic x PBRS-A interaction terms to test the moderating effect of positive beliefs about rumination on the association between vmHRV and the brooding rumination.

Because power to detect interactions in this study was low, it is important to acknowledge and discuss observed patterns in the data that do not meet statistical significance by the standards of the omnibus test but are still informative for future research. For example, though tests of interactions were the focus of the primary hypotheses, any findings exhibiting a positive association between resting vmHRV and difficulties in ER, depressive symptoms, or brooding rumination provides further evidence of the atypical pattern described previously by Spangler et al. (2021). For this reason, in all interactions examined, simple slopes were probed at all levels of significance using the Johnson-Neyman technique. Where illustration was warranted, these effects were depicted at high (+1 SD) and low (-1 SD) values of the moderator variable.

Chapter 3. Results

Preliminary Analyses

Analyses were completed using the data of 204 participants having complete vmHRV and questionnaire data (89.9% of the original data set). Of the 23 excluded cases, 19 were missing vmHRV data, attributable to experimenter error or equipment malfunctions, two cases were missing DASS data due to participant omission, one case was missing AAQ-II data due to participant omission, and one case was missing PBRS-A data due to participant omission. For four participants, one item, each, of the DERS data was missing completely at random (Little's Missing Completely at Random test $p = 0.244$). Therefore, expectation maximization was used to impute the missing data for these individuals.

Descriptive Statistics

As discussed under the methods section, all participants self-identified as female during the prescreening process. The mean age of the sample was 18.5 years ($SD = 0.76$) and the majority of the participants identified themselves as White or European American (66.1%) and not Hispanic or Latinx (92.7%). Notably 13.2% of participants did not disclose their race or ethnicity. Table 1 shows descriptive statistics.

Correlations

Table 2 shows zero-order (Pearson's) correlations for all variables. Unexpectedly, resting lnRMSSD was not significantly associated with DERS total scores (r = -0.041, p = 0.561). Resting lnRMSSD was significantly negatively associated with DASS-D (r = -0.148, p = 0.035) but not DASS-S (r = -0.024, p = 0.729). Also, resting lnRMSSD was not significantly correlated with AAQ-II total scores (r = -0.114, p = 0.103), RRS-B (r = -0.098, p = 0.165), PBRS-A total scores (r = 0.026, p = 0.716), BMI (r = -0.104, p = 0.139), or respiration (r = 0.057, p = 0.415).

DERS total scores were significantly positively associated with DASS-D (r = 0.615, p < 0.001), DASS-S (r = 0.656, p < 0.001), AAQII total scores (r = 0.766, p < 0.001), and RRS-B (r = 0.620, p < 0.001). DASS-D was also significantly positively associated with DASS-S (r = 0.678, p < 0.001), AAQII total (r = 0.688, p < 0.001), RRS-B (r = 0.617, p < 0.001), and BMI (r = 0.160, p = 0.022). DASS-S was significantly positively associated with AAQII (r = 0.628, p < 0.001), and RRS-B (r = 0.606, p < 0.001). AAQII total was significantly positively associated with RRS-b (r = 0.682, p < 0.001) and PBRS-A total (r = 0.168, p = 0.017). Finally, RRS-B was significantly positively associated with PBRS-A total (r = 0.206, p = 0.003).

Primary Analyses

Hypothesis 1: Concave quadratic association between resting vmHRV and ER difficulties

As shown in Table 3 and depicted in Figure 1, in the model predicting DERS total, neither the lnRMSSD-linear (B(*SE*) = -0.040 (0.069), *sr* = -0.04, p = 0.573, 95% CI [-0.179, 0.099]) nor the lnRMSSD-quadratic (B(*SE*) = 0.016 (0.047), *sr* = 0.02, p = 0.745, 95% CI [-

0.078,0.109]) terms were significant. Inclusion of BMI and Respiration as covariates did not change these results (see Table 3).

Hypothesis 2: Concave quadratic association between resting vmHRV and depressive symptoms

As shown in Table 3 and depicted in Figure 2, in the model predicting DASS-D, both the lnRMSSD-linear (B (*SE*) = -0.141 (0.070), *sr* = -0.14, *p* = 0.043, 95% CI [-0.277, -0.005]) and lnRMSSD-quadratic (B (*SE*) = 0.102 (0.048), *sr* = 0.15, *p* = 0.030, 95% CI [0.030, 0.194]) terms of vmHRV were significant. In contrast, as shown in Table 4, in the model predicting DASS-S, neither the lnRMSSD-linear (B (*SE*) = -0.021 (0.070), *sr* = -0.02, *p* = 0.762, 95% CI [-0.160, 0.118]), nor lnRMSSD-quadratic (B (*SE*) = 0.42 (0.047), *sr* = 0.06, *p* = 0.381, 95% CI [-0.052, 0.135]) terms of vmHRV were significant. Finally, as expected and as shown in Table 4, in the model predicting DASS-D with DASS-S partialed out, both the lnRMSSD-linear (B (*SE*) = -0.126 (0.051), *sr* = -0.13, *p* = 0.013, 95% CI [-0.226, -0.027]) and lnRMSSD-quadratic (B (*SE*) = 0.074 (0.034), *sr* = 0.11, *p* = 0.030, 95% CI [0.007, 0.141]) terms remained significant. Inclusion of BMI and Respiration as covariates did not change these results (see Table 4).

Hypothesis 3: Concave quadratic association between resting vmHRV and brooding rumination

As shown in Table 5, and depicted in Figure 3, in the model predicting RRb, neither the lnRMSSD-linear (B (*SE*) = -0.095 (0.070), *sr* = -0.095, *p* = 0.177, 95% CI [-0.234, 0.043]) nor the lnRMSSD-quadratic (B (*SE*) = 0.033 (0.047), *sr* = 0.050, *p* = 0.480, 95% CI [-0.060, 0.127]) terms of vmHRV were significant. Inclusion of BMI and Respiration as covariates did not change these results (see Table 5).

Hypothesis 4: Moderating effect of experiential avoidance on the association between resting vmHRV and ER difficulties

Table 6 shows the results of a regression analysis testing the moderating impact of AAQ-II scores on the associations between vmHRV and DERS scores. The overall model was significant ($R^2 = 0.594$, $p < 0.001$). Regarding the main effects, only AAQ-II total significantly predicted DERS total (B (*SE*) = 0.801 (0.056), $sr = 0.651$, $p < 0.001$) at the sample average of HRV. Addition of the interactions between AAQ-II and both the lnRMSSD-linear (B (*SE*) = 0.051 (0.047), $sr = 0.050$, $p = 0.275$, $\Delta R^2 = 0.003$) and lnRMSSD-quadratic (B (*SE*) = -0.030 (0.030), $sr = 0.045$, $p = 0.322$, $\Delta R^2 = 0.002$) terms did not significantly contribute to the model's predictive power. Therefore, the AAQ-II total did not significantly moderate the relationship between vmHRV and DERS total. Probing further, at a low level of AAQ-II (i.e., -1 *SD*), the lnRMSSD-linear effect was not significant (B = -.022 (*SE* = 0.073), $p = .758$). At a high level of AAQ-II (i.e., +1 *SD*), that effect was also not significant (B = .079 (*SE* = 0.060), $p = .187$). At a low level of AAQ-II (i.e., -1 *SD*), the lnRMSSD-quadratic effect was not significant (B = 0.023 (*SE* = 0.051), $p = .655$). At a high level of AAQ-II (i.e., +1 *SD*), that effect was also not significant (B = -0.037 (*SE* = 0.038), $p = .330$). Furthermore, the Johnson-Neyman technique revealed no evidence of any effect of the quadratic term at any level of AAQ-II scores. Inclusion of BMI and Respiration as covariates did not change these results (see Table 6).

Hypothesis 5: Moderating effect of experiential avoidance on the association between resting vmHRV and depressive symptoms

Table 7 shows the results of a regression analysis which tested the moderating impact of AAQ-II scores on the associations between vmHRV and DASS-D scores. The overall model was significant ($R^2 = 0.504$, $p < 0.001$). AAQ-II total scores significantly predicted DASS-D at the sample average level of HRV (B (*SE*) = 0.625 (0.062), *sr* = 0.509, $p < 0.001$). However, neither the lnRMSSD-linear term nor the lnRMSSD-quadratic term was significant at the sample average level of AAQ. Addition of the lnRMSSD-linear x AAQ-II significantly contributed to the predictive power of the model (B (*SE*) = -0.120 (0.051), *sr* = -0.117, $p = 0.021$, $\Delta R^2 = 0.014$). Although the lnRMSSD-quadratic x AAQ-II interaction term did not achieve significance at the $p < .05$ level, it approached significance (B (*SE*) = 0.056 (0.033), *sr* = 0.084, $p = 0.094$, $\Delta R^2 = 0.007$). Both interactions are discussed further below. Inclusion of BMI and Respiration as covariates did not change these results (see Table 7).

PROCESS was used to examine the pattern of the lnRMSSD-linear x AAQ-II interaction. As shown in Figure 4, at a low level of AAQ-II (i.e., -1 *SD*), the lnRMSSD-linear effect was not significant (B = 0.090 (*SE* = 0.081), $p = .268$). In contrast, at a high level of AAQ-II (i.e., +1 *SD*), that effect was significantly negative (B = -0.150 (*SE* = 0.066), $p = .024$). Simple slopes across all observed scores on the AAQ-II were examined using the Johnson-Neyman technique. Results revealed that the lnRMSSD-linear effect was significantly positive for AAQ-II scores greater than 0.73 *SD*s above the sample average. This threshold fell at the 78th percentile of AAAQ-II scores in the current sample.

PROCESS was also used to examine the pattern of the lnRMSSD-quadratic x AAQ-II interaction. As shown in Figure 5, at a low level of AAQ-II (i.e., -1 *SD*), the lnRMSSD-quadratic effect was not significant (B = -0.022 (*SE* = 0.056), p = .694). However, as expected, at a high level of AAQ-II (i.e., +1 *SD*), that effect was significantly positive (B = 0.090 (*SE* = 0.042), p = .034). Simple slopes across all observed scores on the AAQ-II were examined using the Johnson-Neyman technique. Results revealed that the lnRMSSD-quadratic effect was significantly positive for AAQ-II scores greater than 0.70 *SD*s above the sample average. This threshold fell at the 78th percentile of AAQ-II scores in the current sample.

Table 8 shows the results of a regression analysis which tested the moderating impact of AAQ-II scores on the associations between vmHRV and DASS-S scores. The overall model was significant ($R^2 = 0.400$, $p < 0.001$). AAQ-II total significantly predicted DASS-S at average levels of HRV (B (*SE*) = 0.666 (0.068), *sr* = .54, $p < 0.001$). Addition of the interactions between AAQ-II and the lnRMSSD-linear (B (*SE*) = 0.044(0.057), *sr* = .04, p = 0.436, $\Delta R^2 = 0.002$) and lnRMSSD-quadratic (B (*SE*) = -0.036 (0.037), *sr* = -.05, p = 0.335, $\Delta R^2 = 0.003$) terms of vmHRV did not significantly contribute to the model's predictive power. Therefore, the AAQ-II total did not significantly moderate the relationship between vmHRV and DASS-S. Inclusion of BMI and Respiration as covariates did not change these results (see Table 8).

As shown in Table 9, when DASS-S was added as a covariate to the model predicting DASS-D, the main effect of AAQ-II remained significant B (*SE*) = 0.342 (0.067), *sr* = .228, $p <$ 0.001). Also, both interaction terms (lnRMSSD-linear x AAQ-II: B (*SE*) = -0.139 (0.046), *sr* = -.135, p = .003, $\Delta R^2 = 0.018$; lnRMSSD-quadratic x AAQ-II: B (*SE*) = 0.071 (0.030), *sr* = .107, p = 0.017, $\Delta R^2 = 0.007$) remained significant. Inclusion of BMI and Respiration as covariates did not change these results (see Table 9).

Hypothesis 6: Moderating effect of experiential avoidance on the association between resting vmHRV and brooding rumination

Table 10 shows the results of a regression analysis which tested the moderating impact of AAQ-II scores on the associations between vmHRV and RRS-B. The overall model was significant ($R^2 = 0.466$, $p < 0.001$). Regarding the main effects, only AAQ-II total significantly predicted RRS-B (B (*SE*) = 0.672 (0.064), *sr* = 0.55, $p < 0.001$). Addition of the interactions between AAQ-II and both the lnRMSSD-linear (B (*SE*) = -0.007 (0.053), *sr* = -.01, $p = .903$, $\Delta R^2 < 0.001$) and lnRMSSD-quadratic (B (*SE*) = 0.071 (0.030), *sr* = 0.01, $p = 0.827$, $\Delta R^2 < 0.001$) terms did not significantly contribute to the model's predictive power. Probing further, at a low level of AAQ-II (i.e., -1 *SD*), the lnRMSSD-linear effect was not significant (B = -0.01 (*SE* = 0.084), $p = .908$). At a high level of AAQ-II (i.e., +1 *SD*), that effect was also not significant (B = -0.023 (*SE* = 0.069), $p = .742$). At a low level of AAQ-II (i.e., -1 *SD*), the lnRMSSD-quadratic effect was not significant (B = -.011 (*SE* = 0.058), $p = .850$). At a high level of AAQ-II (i.e., +1 *SD*), that effect was also not significant (B = 0.004 (*SE* = 0.044), $p = .924$). Furthermore, the Johnson-Neyman technique revealed no evidence of any effect of the quadratic term at any level of AAQ-II scores. Inclusion of BMI and Respiration as covariates did not change these results (see Table 10).

Hypothesis 7: Moderating effect of positive beliefs about rumination on the association between vmHRV and brooding rumination

Table 11 shows the results of a regression analysis testing the moderating impact of PBRS-A scores on the associations between vmHRV and RRS-B scores. The overall model was significant ($R^2 = 0.062$, $p = .026$). Regarding the main effects, only PBRS-A scores significantly predicted RRS-B scores (B (*SE*) = 0.250 (0.085), *sr* = .20, *p* = .004). Addition of the interactions between PBRS-A and both the lnRMSSD-linear (B (*SE*) = -0.073 (0.073), *sr* = -.07, *p* = 0.312) and lnRMSSD-quadratic (B (*SE*) = -0.054 (0.050), *sr* = -.07, *p* = 0.286) terms did not significantly contribute to the model's predictive power. Therefore, the PBRS-A did not significantly moderate the relationship between vmHRV and RRS-B. Probing further, at a low level of PBRS-A (i.e., -1 *SD*), the lnRMSSD-linear effect was not significant (B = -0.018 (*SE* = 0.104), *p* = .859). At a high level of PBRS-A (i.e., +1 *SD*), that effect was also not significant (B = -0.166 (*SE* = 0.100), *p* = .088). The Johnson-Neyman technique revealed that the lnRMSSD-linear effect was negative and approached significance (.05 > *p* < .10) for PBRS-A scores greater than 0.27 *SD*s above the sample average and below 1.45 *SD*s above the average. To be clear, the effect above 1.45 *SD*s became increasingly negative but the widening confidence interval at the extremes of the effect meant it was no longer *p* < .10. At a low level of PBRS-A (i.e., -1 *SD*), the lnRMSSD-quadratic effect was not significant (B = 0.074 (*SE* = 0.063), *p* = .241). At a high level of PBRS-A (i.e., +1 *SD*), that effect was also not significant (B = -0.034 (*SE* = 0.075), *p* = .653). Furthermore, the Johnson-Neyman technique revealed no evidence of any effect of the quadratic term at any level of AAQ-II scores. Inclusion of BMI and Respiration as covariates did not change these results (see Table 11).

Chapter 4. Discussion

Implications

The current study aimed to replicate the findings of Spangler et al. (2021), in the service of providing further evidence to explain an atypical pattern of positive association between resting vmHRV and depressive symptom severity observed among women. That pattern was also expected to extend to difficulties in ER and brooding rumination. Overall, the current sample was similar to those used in Williams et al. (2018) and Spangler et al. (2021). All study samples were similar in size (n women = 204, 207, and 180 respectively) and included relatively young participants (mean age = 18.47 $\pm$ 0.76, 19.12 $\pm$ 1.65, and 19.59 $\pm$ 3.77 in years, respectively). Resting vmHRV of the current sample (mean lnRMSSD = 3.69, SD = 0.55) was similar to that of Spangler at al. (2021; mean lnRMSSD = 3.66, SD = 0.59). BMI of the current sample (mean = 24.22, SD = 4.78) was similar to that of Williams et al. (2018; mean = 23.09, SD = 5.03). Respiration (as indexed via Fast Fourier transformation of High Frequency Hertz; FFT HF Hz) of the current sample (mean = 0.237, SD = 0.09) was similar to that of Williams et al. (2018; mean = 0.260, SD = 0.057). Difficulties in ER in the current sample (DERS total mean = 91.61, SD = 23.05) was somewhat greater and more varied than that of Williams et al. (2018; mean = 83.55, SD = 19.33). Depressive symptom severity in the current sample (DASS-D mean = 9.40, SD = 7.94) was somewhat greater and less varied than that of Spangler et al. (2021; mean = 8.83, SD = 9.71).

Hypothesis 1 predicted that resting vmHRV would be associated in a concave, curvilinear fashion with ER, such that the correlation was negative among women with resting vmHRV in the lower half of the vmHRV distribution and positively associated among women in the upper half of the vmHRV distribution. Likewise, it was predicted, in Hypothesis 2, that resting vmHRV would be negatively correlated with depressive symptom severity among women with resting vmHRV in the lower half of the vmHRV distribution and positively associated among women in the upper half of the vmHRV distribution. Similarly, it was predicted, in Hypothesis 3, that resting vmHRV would be negatively correlated with brooding rumination among women with resting vmHRV in the lower half of the vmHRV distribution and positively associated among women in the upper half of the vmHRV distribution. These hypothesized concave quadratic associations would be in accordance with theories of disorders of overcontrol in which the tendency to exert excessive inhibitory control results in a maladaptive response pattern to stress. Results were not consistent with Hypothesis 1, and the typical negative relationship between resting vmHRV and difficulties in ER described in the findings of Williams, et al. 2018, was not significant. Results were not significantly changed when BMI and respiration were included as covariates.

Results were largely consistent with Hypothesis 2, replicating the findings of Spangler et al. (2021), as there was a significant positive quadratic association between vmHRV and depressive symptoms at high levels (above the 78th percentile) of experiential avoidance. In accordance with the findings of Spangler regarding negative affect, Hypothesis 2 also predicted that vmHRV would not be significantly associated with the stress subscale of the DASS, as it primarily represents symptoms of broad negative emotion. Results were consistent with this facet of Hypothesis 2. There was no significant association (linear or quadratic) between vmHRV and generalized stress/negative emotion. Furthermore, the concave quadratic association between vmHRV and depressive symptoms was strengthened when the stress subscale of the DASS was partialed out. Results were not significantly changed when BMI and respiration were included as covariates.

Results were not consistent with Hypothesis 3, and the expected negative relationship between resting vmHRV and brooding rumination was not significant. Results were not significantly changed when BMI and respiration were included as covariates. This result is consistent with the suggestion discussed in Spangler et al. (2021) that the nonlinear relationship between vmHRV and negative emotion is specific to the low positive affect and anhedonia commonly endorsed in depression, rather than representing more generalized negative emotion. Brooding rumination has generally been found to correlate more strongly with high levels of negative affect than low levels of positive affect.

Hypothesis 4 predicted that experiential avoidance would moderate the association between resting vmHRV and difficulties in ER. Specifically, vmHRV was expected to be positively associated with emotion regulation difficulties among individuals who strongly endorsed a goal of experiential avoidance and negatively associated among individuals who endorsed lower levels of experiential avoidance. Similarly, Hypothesis 5 predicted that experiential avoidance would moderate the association between resting vmHRV and depressive symptoms such that vmHRV would be positively associated with depressive symptoms among individuals who strongly endorsed a goal of experiential avoidance and negatively associated among individuals who endorsed lower levels of experiential avoidance. Also, Hypothesis 6 predicted that experiential avoidance would moderate the association between resting vmHRV and brooding rumination such that vmHRV would be positively associated with brooding rumination among individuals who strongly endorsed a goal of experiential avoidance and negatively associated among individuals who endorsed lower levels of experiential avoidance. In keeping with theories of disorders of overcontrol, these patterns of data would provide additional evidence for a pathway by which tendency toward experiential avoidance, may drive women with high resting vmHRV to engage in maladaptive coping which exacerbates difficulties in ER and symptoms of depression.

Results were not consistent with Hypothesis 4. While experiential avoidance significantly predicted difficulties in ER, it did not significantly moderate the relationship between vmHRV and difficulties in ER. Results were, however, consistent with Hypothesis 5, as experiential avoidance moderated the association between vmHRV and depressive symptoms, specifically when negative affect was partialed out. Results were not consistent with Hypothesis 6. While experiential avoidance significantly predicted brooding rumination, it did not significantly moderate the relationship between vmHRV and brooding rumination. Results were not significantly changed when BMI and respiration were included as covariates. Thus, BMI and respiration were omitted from reported analyses to conserve degrees of freedom. These findings provide support for the proposed framework by which women with relatively high capacity for inhibitory control experience greater depressive symptoms via engagement in experiential avoidance. Moreover, results of predictions 4, 5, and 6 further demonstrate that the curvilinear relationship between vmHRV and negative emotion is specific to depressive symptom presentation and may not extend to difficulties in ER or brooding rumination.

Hypothesis 7 predicted that the association between vmHRV and brooding rumination would be moderated by the strength of positive beliefs about rumination. Specifically, individuals with higher levels of vmHRV would be more likely to report brooding rumination if they strongly believe that rumination is beneficial. In contrast, higher vmHRV should predict lower levels of brooding rumination among individuals who do not believe rumination is beneficial. Results were not consistent with Hypothesis 7. While endorsing positive beliefs about rumination predicted engagement in brooding rumination, it did not significantly moderate the effect of vmHRV on brooding rumination. Results were not significantly changed when BMI and respiration were included as covariates. Thus, BMI and respiration were omitted from reported analyses to conserve degrees of freedom. This finding provides further support for the idea that an atypical pathway to rumination is possible whereby women with high inhibitory believe repetitive thought to be beneficial and engage in such strategies (i.e., rumination) with the intention to reach valued goals (e.g., avoidance of negative experiences).

Limitations and Future Directions

As in the data analytics strategy above, age, race, and ethnicity have all been purported in the literature as important covariates when examining individual differences in vmHRV. The current study was limited by homogeneity of its sample, which was collected exclusively among college students. For example, the sample of participants were relatively young, predominantly White or European American, and not Hispanic or Latinx. It is possible that results would not generalize to a more diverse sample including older adults and/or individuals identifying as belonging to other races or ethnicities. This study was also limited by missing data, as many participants did not disclose race, ethnicity, or menstrual cycle information and therefore power to test these covariates was not sufficient. Future research should examine these hypotheses among a more heterogeneous sample and explore the moderating effects of age, race, ethnicity, and menstruation on the curvilinear association between vmHRV and depression. For example, future studies may benefit from examining these constructs in a community sample or across populations of differing backgrounds and identities.

It is also worth noting that despite attempts to oversample individuals with relatively higher depressive symptoms. The resulting group of participants, on average, did not report elevated or clinically significant levels of depressive symptoms. Future studies may benefit from examining the present hypotheses among populations with more variation in experience of depressive symptoms (e.g., psychological clinic outpatients or broader community samples).

The cross-sectional design of the current study limited its ability to determine directionality and causality. Longitudinal study designs would further the current understanding of the temporal relationships between greater inhibitory capacity, as indexed by vmHRV, depressive symptoms, and maladaptive coping strategies such as experiential avoidance and brooding rumination.

It is important to acknowledge that the data collection for this study occurred during the Covid-19 viral pandemic (specifically, August to November of 2021). Consideration must be given to the impact of this ongoing, worldwide disruption on these results. For example, it is possible that individuals who are less prone to health issues in general, including depression, self-selected into the study and those more likely to be experiencing heightened depressive symptoms (and also more prone to engage in experiential avoidance) opted out in order to avoid contracting Covid-19 and/or experiencing distress associated with interacting in an in-person laboratory session following several months in lockdown/isolation.

Conclusion

The present study aimed to reconcile seemingly conflicting reports of both negative (typical pattern) and positive (atypical pattern) associations between vmHRV and negative emotion. Despite limitations, the current investigation reinforces and extends understanding of the complex relationships between self-regulatory capacity, coping, and experience of emotion. Collectively, the present findings are largely consistent with the hypotheses and conclusions of Spangler et al. (2021). The resulting concave curvilinear association provides support for an atypical pattern by which depressive symptoms are characterized by high resting vmHRV for women at the upper half of the distribution of vmHRV. Furthermore, the present investigation strengthens the evidence that this atypical pattern is unique to depressive symptoms, rather than general to broader negative affect, among women and builds upon previous research by showing that high experiential avoidance moderates this relationship. The current study also linked endorsement of positive beliefs about worry to greater experiential avoidance as a potential explanation for why women may, at least initially, intentionally exert their self-regulatory capacity to engage in maladaptive ER responses despite exhibiting higher average vmHRV.

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Appendix A: Tables

Table 1. Descriptive Statistics

	Mean	Standard Deviation
Age	18.47	0.76
BMI	24.22	4.78
Respiration	0.237	0.09
lnRMSSD	3.69	0.55
DERS total	91.61	23.05
DASS-D	9.40	8.49
DASS-S	13.43	7.94
AAQ-II total	24.19	8.80
RRS-B	12.67	3.57
PBRS-A total	26.66	5.06

N = 204 for all variables except Age (N= 193) and PBR-A (N=203)
Age (years); BMI, body mass index (weight in pounds/height in inches squared); Respiration, Fast Fourier transformation of High Frequency Hertz (FFT HF Hz); lnRMSSD, natural logarithm of the root mean square of successive differences (milliseconds); DERS total, Difficulties in Emotion Regulation Scale total score; DASS-D, Depression Subscale score of the Depression Anxiety Stress Scale; DASS-S, Stress Subscale score of the Depression Anxiety Stress ScaleAAQ-II, Revised Acceptance and Action Questionnaire total score; RRS-B, Ruminative Response Scale Brooding subscale score; PBRS-A total, Adapted Positive Beliefs about Rumination Scale total score
Sample self-identified as Female, 66.1 % Caucasian/White, and 92.7% non-Hispanic/Latin

Table 2. Zero-order Correlations

	lnRMSSD	DERS total	DASS-D	DASS-S	AAQ-II total	RRS-B	PBRS-A total	BMI	Respiration
lnRMSSD	–								
DERS total	-0.041	–							
DASS-D	-0.148*	0.615**	–						
DASS-S	-0.024	0.656**	0.678**	–					
AAQ-II total	-0.114	0.766**	0.688*	0.628**	–				
RRS-B	-0.098	0.620**	0.617**	0.606**	0.682**	–			
PBRS-A total	0.026	0.113	0.124	0.128	0.168*	0.206**	–		
BMI	-0.104	0.080	0.160*	-0.104	0.085	0.096	-0.016	–	
Respiration	0.057	-0.084	-0.076	0.057	-0.064	-0.065	0.016	0.054	–

lnRMSSD, natural logarithm of the root mean square of successive differences (milliseconds); DERS total, Difficulties in Emotion Regulation Scale total score; DASS-D, Depression Subscale score of the Depression Anxiety Stress Scale; AAQ-II, Revised Acceptance and Action Questionnaire total score; RRS-B, Ruminative Response Scale Brooding subscale score; PBRS-A total, Adapted Positive Beliefs about Rumination Scale total score
** correlation is significant at the 0.01 level (2-tailed)
* correlation is significant at the 0.05 level (2-tailed)

Table 3. Summary of regression models predicting difficulties in ER and depressive symptoms from vmHRV (with and without BMI and respiration as covariates)

	DERS total				DASS-D			
Variable	R^2	B (*SE*)	*sr*	*p* value	R^2	B (*SE*)	*sr*	*p* value
	0.002			.801	0.045			.010
Constant		-0.015 (0.083)				-0.101 (0.085)		.223
lnRMSSD-linear		-0.040 (0.069)	-.04	.573		-0.141 (0.071)	-.14	.043
lnRMSSD-quadratic		0.016 (0.047)	.02	.745		0.102 (0.048)	.15	.030
Variable	R^2	B (*SE*)	*sr*	*p* value	R^2	B (*SE*)	*sr*	*p* value
	0.015			0.551	0.067			0.007
Constant		-0.190 (0.400)		0.635		-0.593 (0.389)		0.129
lnRMSSD-linear		-0.027 (0.071)	-0.027	0.704		-0.123 (0.069)	-0.122	0.077
lnRMSSD-quadratic		0.009 (0.048)	0.014	0.845		0.092 (0.046)	0.136	0.049
BMI		0.017 (0.015)	0.079	0.261		0.029 (0.014)	0.136	0.049
respiration		-0.954 (0.781)	-0.086	0.223		-0.819 (0.760)	-0.074	0.282

Table 4. Summary of regression models predicting DASS-S from vmHRV and DASS-D with DASS-S partialled out.

	DASS-S				DASS-D Controlling for DASS-S			
Variable	R^2	B (*SE*)	*sr*	*p* value	R^2	B (*SE*)	*sr*	*p* value
	0.004			.642	0.489			< .001
Constant		-0.041 (0.085)		.625		-0.074 (0.061)		.227
lnRMSSD-linear		-0.021 (0.070)	-.02	.762		-0.126 (0.051)	-.13	.013
lnRMSSD-quadratic		0.042 (0.034)	.06	.381		0.074 (0.034)	.11	.031
DASS-S		-	-	-		0.668 (0.051)	.67	< .001
Variable	R^2	B (*SE*)	*sr*	*p* value	R^2	B (*SE*)	*sr*	*p* value
	0.008			.812	0.505			< .001
Constant		0.010 (.402)		.979		-0.600 (0.284)		.036
lnRMSSD-linear		-0.016 (0.071)	-.02	.820		-0.112 (0.050)	-.11	.027
lnRMSSD-quadratic		0.040 (0.048)	.06	.406		0.065 (0.034)	.10	.055
BMI		0.004 (0.015)	.02	.784		0.026 (0.011)	.12	.015
respiration		-0.631 (0.784)	-.06	.422		-0.400 (0.556)	-.04	.473
DASS-S		-	-	-		0.664 (0.050)	.66	< .001

Table 5. Regression analysis predicting RRS-Brooding (with and without BMI and respiration as covariates).

	RRS-Brooding Score			
Variable	R^2	B (*SE*)	*sr*	*p* value
	0.012			.298
Constant		-0.033 (0.084)		.693
lnRMSSD-linear		-0.095 (0.070)	-.10	.177
lnRMSSD-quadratic		0.033 (0.047)	.05	.480
With Covariates (BMI and Respiration)	R^2	B (*SE*)	*sr*	*p* value
	0.023			.327
Constant		-0.298 (0.399)		.693
lnRMSSD-linear		-0.083 (0.071)	-.08	.242
lnRMSSD-quadratic		0.027 (0.048)	.04	.570
BMI		0.018 (0.015)	.09	.221
Respiration		-0.717 (0.778)	-0.06	.358

Table 6. Regression analysis predicting DERS scores (with and without BMI and respiration as covariates)

	DERS Score			
Variable	R^2	B (*SE*)	*sr*	*p* value
	0.594			< 0.001
Constant		0.017 (0.055)		0.763
lnRMSSD-linear		0.029 (0.048)	0.027	0.552
lnRMSSD-quadratic		-0.007 (0.033)	-0.010	0.827
AAQ-II total score		0.801 (0.056)	0.651	< 0.001
AAQ-II total score x lnRMSSD-linear		0.051 (0.047)	0.050	0.275
AAQ-II total score x lnRMSSD-quadratic		-0.030 (0.030)	0.045	0.322
With Covariates (BMI and Respiration)	R^2	B (*SE*)	*sr*	*p* value
	0.596			< 0.001
Constant		-0.052 (0.263)		0.844
lnRMSSD-linear		0.033 (0.048)	0.031	0.493
lnRMSSD-quadratic		-0.009 (0.033)	-0.013	0.781
AAQ-II total score		0.796 (0.056)	0.643	< 0.001
AAQ-II total score x lnRMSSD-linear		0.052 (0.047)	0.051	0.264
AAQ-II total score x lnRMSSD-quadratic		-0.030 (0.031)	-0.044	0.330
BMI		0.007 (0.010)	0.032	0.487
Respiration		-0.395 (0.509)	-0.035	0.438

Table 7. Regression analysis predicting DASS-D scores (with and without BMI and respiration as covariates)

	DASS-D Score			
Variable	R^2	B (*SE*)	*sr*	*p* value
	0.504			< 0.001
Constant		-0.054 (0.061)		0.376
lnRMSSD-linear		-0.031 (0.053)	-0.029	0.565
lnRMSSD-quadratic		0.034 (0.037)	0.046	0.359
AAQ-II total score		0.625 (0.062)	0.509	< 0.001
AAQ-II total score x lnRMSSD-linear		-0.120 (0.051)	-0.117	0.021
AAQ-II total score x lnRMSSD-quadratic		0.056 (0.033)	0.084	0.094
With Covariates (BMI and Respiration)	R^2	B (*SE*)	*sr*	*p* value
	0.511			< 0.001
Constant		-0.348 (0.290)		0.231
lnRMSSD-linear		-0.023 (0.053)	-0.022	0.661
lnRMSSD-quadratic		0.030 (0.037)	0.041	0.414
AAQ-II total score		0.622 (0.062)	0.502	< 0.001
AAQ-II total score x lnRMSSD-linear		-0.116 (0.051)	-0.113	0.025
AAQ-II total score x lnRMSSD-quadratic		0.052 (0.034)	0.077	0.127
BMI		0.017 (0.012)	0.077	0.122
Respiration		-0.435 (0.560)	-0.039	0.438

Table 8. Regression analysis predicting DASS-S scores (with and without BMI and respiration as covariates)

	DASS-S Score			
Variable	R^2	B (*SE*)	*sr*	*p* value
	0.400			
Constant		-0.017 (0.067)		.803
lnRMSSD-linear		0.030 (0.058)	.03	.607
lnRMSSD-quadratic		0.026 (0.040)	.04	.520
AAQ-II total score		0.666 (0.068)	.54	< .001
AAQ-II total score x lnRMSSD-linear		0.044 (0.057)	.04	.436
AAQ-II total score x lnRMSSD-quadratic		-0.035 (0.037)	-.05	.335
With Covariates (BMI and Respiration)	R^2	B (*SE*)	*sr*	*p* value
	0.401			
Constant		0.11 (0.320)		.729
lnRMSSD-linear		0.030 (0.059)	.03	.607
lnRMSSD-quadratic		0.026 (0.040)	.04	.518
AAQ-II total score		0.663 (0.068)	.54	.628
AAQ-II total score x lnRMSSD-linear		0.043 (0.057)	.04	.448
AAQ-II total score x lnRMSSD-quadratic		-0.032 (0.037)	-.04	.386
BMI		-0.004 (0.012)	-.02	.749
Respiration		-0.155 (0.619)	-.01	.802

Table 9. Regression analysis predicting depressive symptom severity with DASS-S partialed out (with and without BMI and respiration as covariates)

	DASS-D Score			
Variable	R^2	B (*SE*)	*sr*	*p* value
	0.613			< 0.001
Constant		-0.047 (0.054)		.385
lnRMSSD-linear		-0.043 (0.047)	-.041	.357
lnRMSSD-quadratic		0.023 (0.032)	.031	.486
AAQ-II total score		0.342 (0.067)	.228	< 0.001
AAQ-II total score x lnRMSSD-linear		-0.139 (0.046)	-.135	.003
AAQ-II total score x lnRMSSD-quadratic		0.071 (0.030)	.107	.017
DASS-S		0.426 (0.057)	.330	< 0.001
With Covariates (BMI and Respiration)	R^2	B (*SE*)	*sr*	*p* value
	0.621			< 0.001
Constant		-0.396 (0.255)		.126
lnRMSSD-linear		-0.036 (0.047)	-.034	.448
lnRMSSD-quadratic		0.019 (0.032)	.026	.563
AAQ-II total score		0.338 (0.066)	.225	< 0.001
AAQ-II total score x lnRMSSD-linear		-0.135 (0.045)	-.131	.003
AAQ-II total score x lnRMSSD-quadratic		0.066 (0.030)	.097	.029
DASS-S		0.428 (0.057)	.331	< .001
BMI		0.018 (0.009)	.085	0.055
Respiration		-0.368 (0.494)	-.033	0.457

Table 10. Regression analysis predicting RRS-Brooding (with and without BMI and respiration as covariates).

	RRS-Brooding Score			
Variable	R^2	B (*SE*)	*sr*	*p* value
	0.466			< .001
Constant		0.002 (0.063)		.977
lnRMSSD-linear		-0.016 (0.055)	-.02	.769
lnRMSSD-quadratic		-0.003 (0.038)	-.01	.928
AAQ-II total score		0.672 (0.064)	.55	< 0.001
AAQ-II total score x lnRMSSD-linear		-0.007 (0.053)	-.01	.903
AAQ-II total score x lnRMSSD-quadratic		0.071 (0.030)	.01	.827
With Covariates (BMI and Respiration)	R^2	B (*SE*)	*sr*	*p* value
	0.468			< 0.001
Constant		-0.124 (0.302)		.977
lnRMSSD-linear		-0.012 (0.055)	-.01	.826
lnRMSSD-quadratic		-0.005 (0.054)	-.01	.888
AAQ-II total score		0.670 (0.065)	.54	< 0.001
AAQ-II total score x lnRMSSD-linear		-0.005 (0.054)	-.01	.929
AAQ-II total score x lnRMSSD-quadratic		0.006 (0.035)	.01	.863
BMI		0.008 (0.011)	.04	.476
Respiration		-0.275 (0.584)	-.03	.638

Table 11. Regression analysis predicting RRS-Brooding with vmHRV and positive beliefs about rumination (PBRS-A; with and without BMI and respiration as covariates)

	RRS-Brooding Score			
Variable	R^2	B (*SE*)	*sr*	*p* value
	0.062			.026
Constant		-0.013 (0.084)		.878
lnRMSSD-linear		-0.092 (0.070)	-.09	.187
lnRMSSD-quadratic		0.02 (0.047)	.03	.671
PBRS-A		0.250 (0.085)	.20	.004
PBRS-A x lnRMSSD-linear		-0.073 (0.073)	-.07	.312
PBRS-A x lnRMSSD-quadratic		-0.054 (0.050)	-.07	.286
With Covariates (BMI and Respiration)	R^2	B (*SE*)	*sr*	*p* value
	0.074			.033
Constant		-0.300 (0.392)		.878
lnRMSSD-linear		-0.080 (0.070)	-.08	.256
lnRMSSD-quadratic		0.013 (0.048)	.02	.787
PBRS-A		0.255 (0.085)	.21	.003
PBRS-A x lnRMSSD-linear		-0.072 (0.072)	-.07	.318
PBRS-A x lnRMSSD-quadratic		-0.056 (0.050)	-.08	.269
BMI		0.019 (0.015)	.09	.187
Respiration		-0.734 (0.766)	-.07	.339

Appendix B: Figures

Figure 1. Association between resting vmHRV and ER difficulties

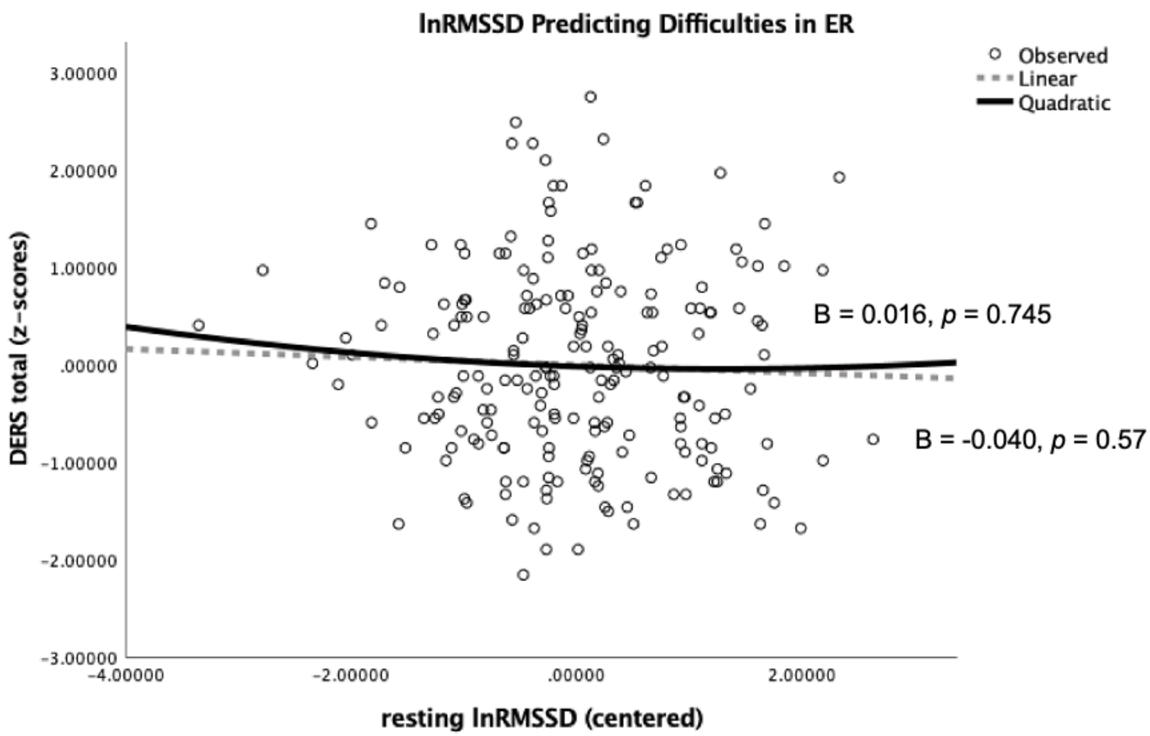

Figure 2. Association between resting vmHRV and depressive symptoms

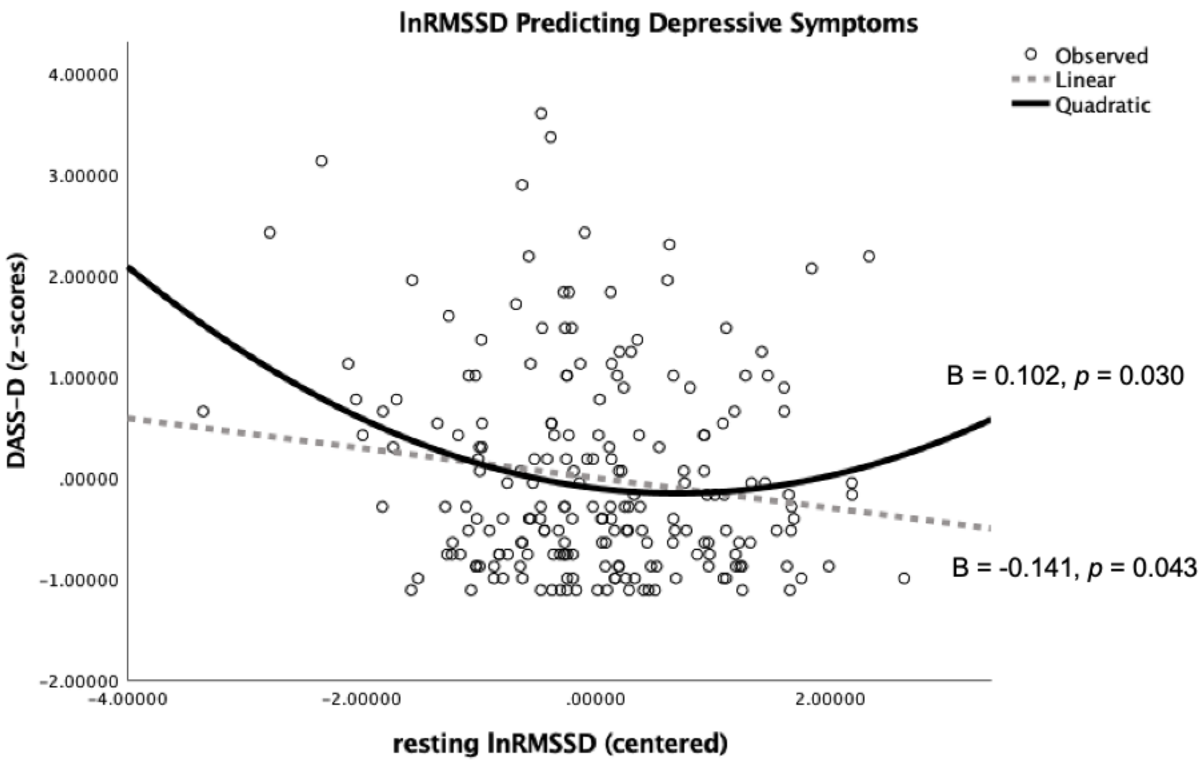

Figure 3. Association between resting vmHRV and brooding rumination

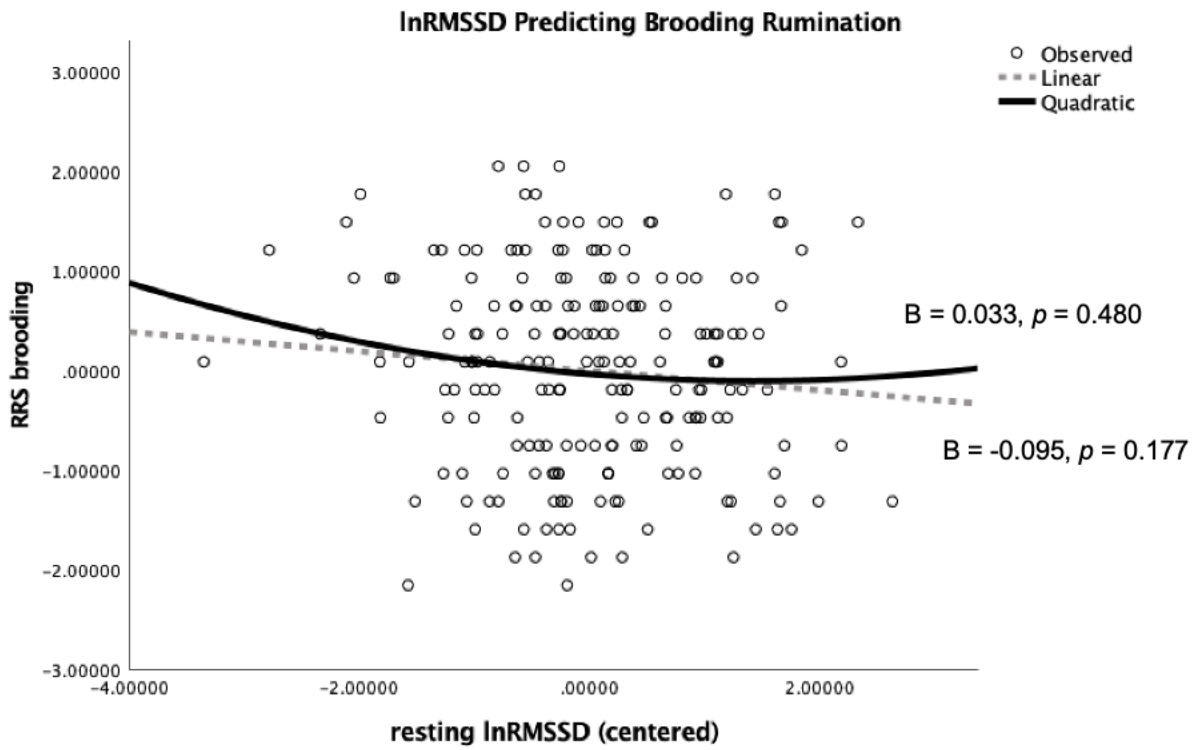

Figure 4. vmHRV-linear interaction with experiential avoidance (AAQ-II) to predict depressive symptoms (DASS-D)

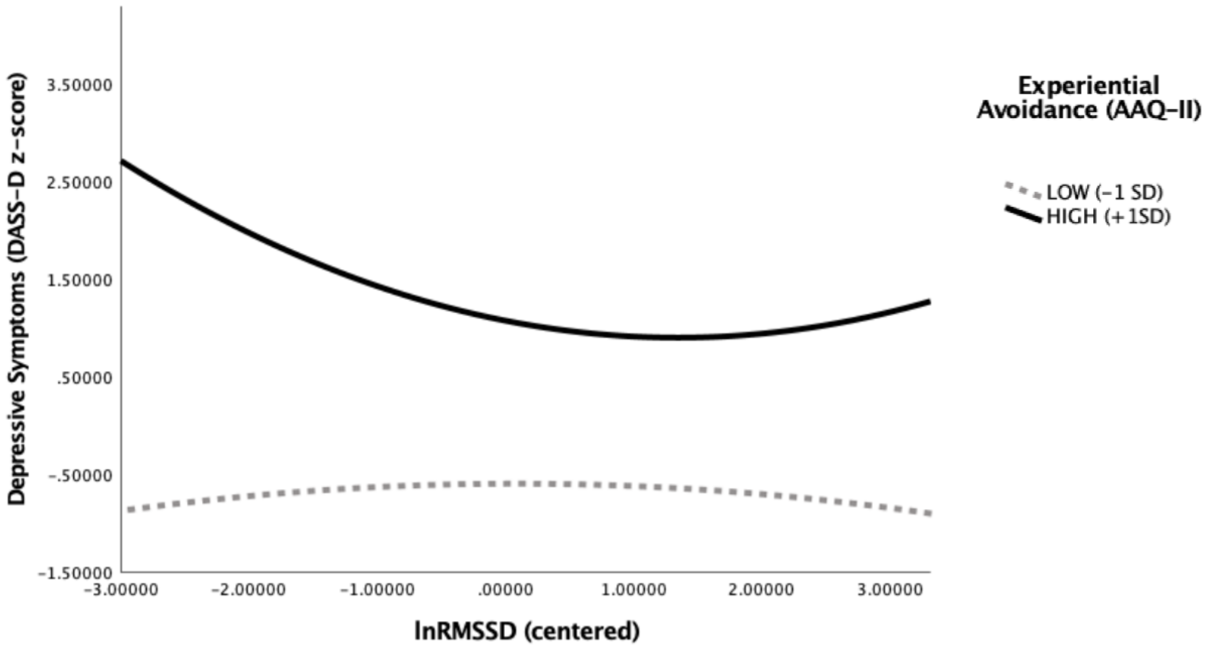

Figure 5. vmHRV-quadratic interaction with experiential avoidance (AAQ-II) to predict depressive symptoms (DASS-D)