Scholarly Journal of Psychology and Behavioral Sciences
DOI: 10.32474/SJPBS.2023.07.000271
ISSN: 2641-1768
Research Article

Respiratory Sinus Arrhythmia as a Predictor of Daily Emotion Regulation

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Received: October 25, 2023 **Published:** November 03, 2023

Abstract

Research indicates physiology may influence emotion regulation under stress. Respiratory sinus arrhythmia (RSA) is an index of parasympathetic nervous system activation, which may inform the use of certain regulation strategies. The current study examined the interactions between basal RSA (BRSA) and RSA reactivity to stress induction, and their relationship to emotion regulation. The purpose of our study was to investigate whether unique RSA interactions predicted the use of adaptive or maladaptive emotion regulation strategies in response to daily stressors. Participants recorded their BRSA and RSA reactivity under stress in a lab paradigm. They then completed ecological momentary assessments which measured emotion regulation in response to daily stressful events. We found that high BRSA predicted increased use of all regulation strategies (βs from 0.05 to 0.55, *ps* < .050). Lower reactivity was associated with increased rumination and suppression in the presence of high BRSA (βs from -0.06 to -0.12, *ps* < .001). We found evidence that suggests RSA reactivity may be better explained by a quadratic function than a linear (βs from 0.13 to 0.24, *ps* ≤ .001). Furthermore, we observed significant slope differences in RSA reactivity across most regulation strategies. Conclusions from our research were that that high BRSA consistently predicted an individual's tendency to use strategies to regulate emotions. Neither muted nor excessive RSA reactivity appeared to be adaptive, and high BRSA with low reactivity appeared to be associated with maladaptive regulation strategies. Finally, individuals with high BRSA exhibited different emotion regulation profiles than those with low BRSA.

Keywords: Respiratory sinus arrhythmia; Emotion regulation; Rumination; Suppression; Cognitive reappraisal; Problem solving

Introduction

Emotion regulation is closely associated with mental health outcomes; greater use of adaptive emotion regulation is correlated with reduced depression and increased psychological well-being [1]. Emotion regulation is defined as the processes involved in managing and adapting emotional reactions to reach a goal [2]. Adaptive emotion regulation strategies, including cognitive reappraisal and problem solving, have been shown to buffer the impacts of stress, decrease negative emotion, and promote psychological well-being [3-5]. Conversely, maladaptive emotion regulation strategies such as cognitive suppression and rumination have been associated with greater distress and the development of psychological disorders such as depression and anxiety [6,7]. Theory and research suggest that the deployment of emotion regulation strategies in response to daily stressors may be influenced by physiological self-regulation.

One marker of physiological self-regulation is respiratory sinus arrhythmia (RSA), theorized to be a reliable indicator of emotion regulatory capacity through the vagal nerve pathway [8]. RSA is an index of parasympathetic nervous system (PNS) activation and denotes the degree to which an individual may be modifying their physiological state in response to their environment. Although theory suggests both basal RSA (BRSA) and RSA reactivity to stress may impact how an individual will respond to environmental demands [9,10], less is known about the relationship between RSA and the deployment of adaptive or maladaptive emotion regulation strategies in daily life. The purpose of the current study is to examine the unique and joint effects of BRSA and RSA reactivity on emotion regulation in response to daily stressors.

Emotion Regulation

Emotion regulation has been defined as "the extrinsic and intrinsic processes responsible for monitoring, evaluating, and modifying emotional reactions, especially their intensive and temporal features, to accomplish one's goals" [2]. In some instances, emotion regulation involves dampening an emotional response while in other cases it boosts the reaction in terms of regularity, duration, or intensity [11]. Emotion regulation strategies are essential tools in managing one's reactions to life stressors and are associated with numerous positive mental health outcomes [1]. Adaptive emotion regulation strategies, such as cognitive reappraisal and problem solving, are linked to overall psychological well-being, positive affect, and decreased psychopathology [11,12]. Conversely, maladaptive emotion regulation strategies, such as suppression and rumination, are linked to internalizing and externalizing problems leading to increased psychopathology [13].

Rumination

Rumination is a strategy for managing emotions defined as repeated thinking about negative emotions and the causes and consequences associated with negative feelings [14]. This emotion regulation strategy is considered maladaptive because it amplifies the extent and intensity of depressed mood and is part of the criteria for major depressive disorder [15]. Rumination is associated with increased parasympathetic withdrawal and a corresponding decrease in parasympathetic activity [16,17]. Further research establishes a link between parasympathetic withdrawal in response to stressors and increased rumination [17]. Rumination is a well-known predictor of internalizing symptoms, and understanding which physiological profiles predict the tendency to ruminate may provide greater understanding for the susceptibility to psychopathology.

Suppression

Along with altering emotions or behaviors linked to emotions, emotion regulation strategies can also be used to alter cognitions associated with emotions. Cognitive suppression is defined as an attempt to clear one's mind from unwanted thoughts [18]. Individuals often engage in suppression to avoid negative emotionality following aversive thoughts [19]. Cognitive suppression is considered maladaptive because contrary to its goal, it can lead to increased intrusive, unwanted thoughts, resulting in greater distress [6]. Although utilized as a coping strategy, suppression negatively impacts an individual's mental health. It is linked to psychological disorders such as depression, anxiety, and obsessive-compulsive disorder [7]. Given the link between cognitive suppression and internalizing disorders, it is important to examine whether certain physiological indicators predict greater use of suppression. Select studies indicate suppression is linked to heightened sympathetic arousal and less heart rate variability in response to stress [20], but research is limited regarding the relationship between RSA and suppression.

Cognitive Reappraisal

Instead of inhibiting the emotional response, cognitive reappraisal is regulation strategy where an individual cognitively reframes a situation to alter its emotional impact [22]. This strategy is considered adaptive because it promotes down-regulation of negative emotions in response to a stressful event [23,4]. In contrast to suppression, individuals who utilize cognitive reappraisal as a coping strategy express greater positive emotion, less negative emotion, and more effective interpersonal functioning [24]. Overall, reappraisal predicts better psychological functioning and decreased symptoms of psychopathology [5]. Previous studies have found a robust association between increased RSA reactivity and cognitive reappraisal, indicating that RSA reactivity may predict the utilization of cognitive reappraisal strategies [25,26]. Davis and colleagues [26] found reappraisal promoted better parasympathetic regulation of fear for children who were exposed to a sad or scary film. The present study will examine if this association holds true in daily responses to negative events for undergraduate students.

Problem Solving

Problem solving is considered an adaptive emotion regulation tool because it is shown to reduce psychological distress and promote self-efficacy [27]. Unlike rumination where the individual perseverates on negative feelings without challenging them, problem solving attempts to make an adaptive change in the moment to better one's circumstances [14,28]. The ability to engage in problem solving also serves as a predictor for psychological wellbeing [29]. This may be due to an underlying mechanism in which problem solving buffers the impact of temporary and chronic stress [3]. Problem solving appears to serve as a protective factor for psychological wellbeing, consistent with the hypothesis that problem solving is related to the physiological mechanisms that help individuals regulate [30]. Indeed, research suggests higher resting RSA is associated with problem solving abilities, and in turn, higher emotion regulatory capacity [31]. Research exploring the connection between BRSA and RSA reactivity to problem solving, however, is limited.

RSA as a Physiological Index of Emotion Regulation

Prior research links RSA with emotional regulation and attentional control and posits this link to occur via the inhibitory processes of the autonomic nervous system (ANS) through the vagus nerve [32,33]. To further elucidate this mechanism, Thayer and colleagues proposed a neurovisceral integration model wherein the prefrontal cortex (PFC) and the central autonomic network (CAN) integrate environmental information with sensory inputs from end-organ tissues to influence RSA via the vagal nerve pathway [34-36]. The PFC and the CAN incorporate multiple executive, affective, and regulatory circuits which together exert a top-down influence on RSA. This relationship is reciprocal, such that the physiological state of the heart becomes one of the inputs to the CAN [34]. Thus, theory suggests that vagal influence on the sinoatrial node may be both a sequela and a driver of an individual's state of physiological self-regulation, and that high RSA represents their capacity to respond to their environment appropriately and adaptively [34,35].

Vagal influence is measured by recording cardiac QRS complexes and measuring the R-R interbeat intervals (IBI) in milliseconds (ms). The variation in IBI associated with the respiratory pattern is RSA and quantifies the PNS influence on cardiac activity [37]. Individuals with a responsive PNS which exerts robust influence on their heartrate through the vagus nerve exhibit vagal tone [38,34]. RSA as a marker for physiological self-regulation is measured under two conditions: at rest and under stress. Basal RSA indexes the degree of vagal tone at rest (also sometimes referred to as baseline RSA) while RSA reactivity is the extent to which vagal tone changes in response to a stimulus [39,40]. High BRSA indicates the vagal "brake" is applied and the individual is in a well-regulated state with the physiological capacity to mobilize additional resources in response to environmental stressors [41]. Research indicates high BRSA is associated with positive outcomes, including increased stress resiliency [42] and decreased depression [43]. In contrast, low BRSA may indicate low regulatory capacity, and research has shown that low BRSA is associated with negative outcomes such as increased anxiety [44], depression [45], and self-injury [46].

While the literature offers a consistent view of the association between high BRSA and positive psychological outcomes, it is less consistent about whether high or low RSA reactivity is most adaptive [39]. Theory suggests the ability to apply and withdraw the vagal brake is necessary to allow an individual to respond to stressors, while failing to do so indicates an inability to adaptively respond to the environment [41]. However, research is unclear as to what amount of RSA reactivity to stress is adaptive and at what point muted or excessive reactivity becomes maladaptive [39]. Studies indicate high RSA reactivity is associated with parasuicidal behavior [46] as well as depression and nonsuicidal self-injury [30]. However, high RSA reactivity is also associated with adaptive outcomes, such as fewer internalizing and externalizing problems [47]. Like high RSA reactivity, low RSA reactivity is also associated with maladaptive outcomes such as generalized anxiety disorder [48] and externalizing symptoms [49]. Overall, the data suggests both high and low RSA reactivity may result in maladaptive outcomes, but more research is needed to better elucidate under what conditions high or low RSA reactivity becomes maladaptive.

In addition to examining the unique effects of BRSA and RSA reactivity on psychological functioning, recent research highlights the importance of their joint effects to obtain a clearer picture of the role of RSA in emotion regulation [50,51]. The research suggests one's physiological starting point may impact the adaptiveness of one's reactivity. High BRSA may suggest greater capacity to initiate adaptive reactions to stress [42,43]. Both high and low RSA reactivity can lead to maladaptive outcomes, suggesting moderate RSA reactivity may be most flexible and adaptive [9,53]. Taken together, it appears high BRSA combined with moderate reactivity may be associated with adaptive outcomes, while low BRSA, either independently or in combination with low or high reactivity, may lead to maladaptive outcomes. Consistent with this postulation, prior research has found the joint effects of high BRSA with high RSA reactivity predict depression symptoms [51] and dysregulated behavior [50]. Furthermore, low BRSA and high reactivity is associated with poor emotion regulation and numerous psychopathologies [54]. The present study further investigates RSA as an indicator of emotion regulatory capacity and attempts to clarify the conditions under which high and low levels of BRSA and RSA reactivity are either adaptive or maladaptive.

Present Study

In our present study, we examined the relationships between RSA and emotional regulation in response to daily stressors. We hypothesized that high BRSA would predict more use of adaptive and less use of maladaptive emotion regulations strategies in response to daily stressors (H_1). We further hypothesized a quadratic effect of RSA reactivity such that excessively low *or* high levels of RSA reactivity would predict greater use of maladaptive emotion regulation strategies (H_2). We postulated that RSA reactivity and BRSA would interact such that moderate RSA reactivity in the presence of high BRSA would be associated with greater use of adaptive and less use of maladaptive emotion regulation strategies (H_3). Conversely, we expected either low *or* high RSA reactivity in the presence of low BRSA to be associated with greater use of maladaptive and less use of adaptive emotion regulation strategies (H_4). The design of this research study allowed us to examine the relationship between RSA and emotion regulation by linking the physiological data on each participant to the strategies they employed daily in response to stressors.

Materials and Methods

Participants

Participants were recruited via flyers and email for a larger study which ran from October 2015 to March 2020 from a private liberal arts university in the U.S. Pacific Northwest. Due to the public nature of the recruiting process, it is not possible to calculate the number of individuals who were exposed to the study but chose not to participate. In total, 659 participants provided informed consent and completed the larger study. The research conducted in this study was approved by the university institutional review board and conducted in accordance with the ethical standards in the 1964 Declaration of Helsinki. For the purposes of this study, sex was recorded as the self-reported sex assigned at birth. The final participant pool (N = 169, 90.5% female) consisted of undergraduates ages 18-39 (M = 19.48, SD = 1.96). Demographics of the study participants are displayed in Table 1. Participants were eligible for the study if they were at least 18 years old and enrolled in the university's general psychology course. Respondents were excluded if they were under 18 years old or had participated in the research study during previous quarters.

Table 1: Descriptive Statistics of the Sample

Demographic	*N*	%	*M*	*SD*
Age			19.48	1.96
Sex				
Male	16	9.5		
Female	153	90.5		
Race				
Caucasian	98	58		
Asian	25	14.8		
African American	7	4.1		
Pacific Islander	7	4.1		
Other	10	5.9		

Sample Size, Power, and Precision

In multilevel modeling (MLM), it is difficult to calculate the precise sample size necessary to achieve sufficient power within the study. In MLM, power is a function of the effect size, intraclass correlation, number of repeated measures (units) and the number of participants [55]. In a review of the literature, estimates on the required sample size for a sufficiently powered MLM study vary. McCoach states 30 clusters may be adequate but recommends a minimum of 100 clusters while others estimate over 200 clusters are necessary to detect small and cross-level interaction effects [56]. Therefore, we performed a summary- statistics-based power analysis [57] which suggested a minimum sample size of 149 clusters to achieve a power of .80 and an α level of .05. Our sample ranged from 162 to 169 clusters for three of the four outcome variables and so we believe our study to be sufficiently powered. However, as only 61 clusters were available to analyze data on cognitive reappraisal, we believe we may be slightly underpowered on this outcome variable (Table 2).

Table 2: Fixed Effects of RSA levels.

Emotion Regulation Strategy	β	*SE*	*t*	*p*
Age				
Rumination	0.022	0.007	3.362	***
Suppression	0.052	0.007	7.900	***
Cognitive Reappraisal	0.006	0.011	0.542	.588
Problem Solving	0.004	0.009	0.512	.609
BRSA				
Rumination	0.047	0.018	2.560	.011
Suppression	0.164	0.018	9.032	***
Cognitive Reappraisal	0.232	0.057	4.039	***
Problem Solving	0.051	0.024	2.165	.030
RSA-R				
Rumination	0.204	0.084	2.425	.015
Suppression	0.548	0.085	6.466	***
Cognitive Reappraisal	0.200	0.256	0.784	.433
Problem Solving	-0.017	0.110	-0.157	.876
BRSA x RSA-R				
Rumination	-0.057	0.014	-4.001	***
Suppression	-0.123	0.014	-8.545	***
Cognitive Reappraisal	-0.104	0.040	-2.584	.010
Problem Solving	0.025	0.019	1.312	.190

Quadratic RSA-R				
Rumination	0.134	0.032	4.196	***
Suppression	0.227	0.032	7.030	***
Cognitive Reappraisal	0.238	0.074	3.198	.001
Problem Solving	-0.039	0.042	-0.935	.350
BRSA x quadratic RSA-R				
Rumination	-0.006	0.002	-3.459	***
Suppression	-0.010	0.002	-5.399	***
Cognitive Reappraisal	-0.009	0.005	-1.917	.056
Problem Solving	-0.001	0.002	-0.609	.543
Sex				
Rumination	0.122	0.040	3.047	.002
Suppression	-0.197	0.040	-4.846	***
Cognitive Reappraisal	-0.747	0.093	-8.007	***
Problem Solving	-0.329	0.053	-6.202	***
Note. $N = 169$ (Rumination $n = 162$, Suppression $n = 169$, Cognitive Reappraisal $n = 61$, Problem Solving $n = 169$).				
***$p < .001$.				

Research Design

All participants completed an online baseline questionnaire on Qualtrics (https://www.qualtrics.com) which included measures of trait affect and trait depression. Participants then conducted a laboratory visit where researchers collected physiological data at baseline and under stress. During the baseline paradigm participants viewed relaxing nature scenes before participating in a stress induction task. In the stress induction task, participants were briefed they would be given two minutes to prepare a speech about why they were a good friend. Participants were told they may or may not be required to give the speech to the researcher, and a coin toss would be utilized to determine whether or not they were required to give the speech. Then, each participant was instructed to type their speech on the computer. Participants did not know whether they had to give the speech or not until the end of the experiment. The stress induction task utilized deception in that no participants were actually required to give the speech. We performed a manipulation check on the stressor task with a paired sample *t*-test comparing negative affect (NA) scores recorded prior to and after the stressor. Scores demonstrated significant change in the expected direction, $t(146) = -7.05$, $p < .001$. Additionally, during the stressor task RSA declined on average as expected with a mean withdrawal greater than zero, $M = 1.11$, $SD = 0.90$, $t(168) = 16.15$, $p < .001$. After the lab visit, participants completed 42 ecological momentary assessments (EMAs) over seven days, consisting of six questionnaires per day randomly assigned between the hours of 9:00 AM and 8:00 PM. Each questionnaire prompted the participant to describe the worst event that happened to them in the past hour, and to keep this event in mind while completing the questionnaire. On each outcome variable, participants indicated the frequency of how they responded to negative events on a scale of 1 (*I didn't do this at all)* to 4 (*I did this a lot)*, or 99 (*I choose NOT to respond*). Each participant completed the baseline questionnaire, lab visit, and EMA questionnaires over the course of ten weeks (the duration of one undergraduate quarter). All participants received either course credit or monetary compensation ($10) for completing the study.

Measures and Covariates

Respiratory Sinus Arrhythmia

RSA data were gathered via pre-gelled disposable Ag/AgCl electrodes placed on the chest, back and abdomen using a Lead II configuration. Electrocardiogram (ECG) signals were continuously sampled at a gain of 1000 Hz using the Biopac MP150 Data Acquisition System and recorded using AcqKnowledge 4.4 software (Biopac Systems, Inc., Goleta, CA). Researchers analyzed the data in the MindWare Technologies (Gahanna, OH) heartrate variability (HRV) 3.1.3 computer application which calculated R-R IBI using the high frequency heartrate variability method [58]. HF-HRV calculates RSA in the frequency domain by transforming the signal via a fast Fourier transformation, then isolating the respiratory frequency band. We set the parameters from 0.15 to 0.40 Hz as suggested by the Task Force of the European Society of Cardiology and The North American Society of Pacing Electrophysiology [59]. We recorded respiration by measuring the impedance change (dZ/dt) through electrodes placed at the jugular notch and just inferior to the xiphoid process of the sternum. The dZ/dt signal was sampled at 50 kHz, and respiration rate was extracted from the dZ/dt signal in accordance with the methodology reported in the literature [60]. Trained graduate students then visually screened, scored, and manually corrected the datafiles as needed. RSA was scored in 30-second epochs, then averaged across four minutes for the baseline task and across two minutes for the stress induction task.

We calculated BRSA as the mean difference in milliseconds (ms) between heartrates on inhalation and exhalation over the duration of the four-minute baseline task. We calculated RSA under stress as the mean difference between heartrates on inhalation and exhalation over the duration of the two-minute stressor task. We then obtained RSA reactivity by subtracting each participant's stressor RSA value from their BRSA value; positive reactivity values reflected RSA withdrawal (e.g., RSA declined from baseline to stress), and negative reactivity values reflected RSA augmentation (e.g., RSA increased from baseline to stress). Basal RSA values were normally distributed with a skew of 0.01 and a kurtosis of -0.19. We categorized these values into either "low" (range of 1.58ms to 6.55ms, bottom 50th percentile) or "high" (range of 6.55ms to 11.62ms, top 50th percentile) groups. RSA reactivity values were normally distributed with a skew of 0.19 and kurtosis of 0.38. We categorized these values into four groups. The "augmented" group included all participants with negative values (-2.61ms to 0.00ms) and comprised only 9.5% of the sample. Participants with RSA withdrawal were categorized into "low" (values from 0.00ms to 0.85ms, bottom 33rd percentile), "moderate" (values from 0.85ms to 1.50ms, middle 33rd percentile) or "high" (values from 1.50ms to 4.68ms, top 33rd percentile) groups.

Physiological data were screened to eliminate extreme outliers according to the interquartile range (IQR) rule. The commonly used range of Q_1 -1.5*IQR to Q_3 +1.5*IQR classified numerous observations as outliers, however we believe these observations simply represented normal physiological variation. Thus, we modified the range to Q_1-3*IQR to Q_3 +3*IQR and included all participants with BRSA values ranging from 1.58ms to 11.62ms and RSA reactivity values from -2.61ms to + 4.78ms for analyses. We removed one participant due to BRSA of less than 1.58ms. Additionally, we removed four hundred and seventy-three participants who had not completed the outcome variables of interest, five participants who lacked sufficient physiological data to calculate RSA values, and eleven participants who were missing a required variable (age or sex).

Rumination

We assessed rumination using the brooding subscale of the Ruminative Response Scale (RRS) [61]. The brooding subscale consists of five items and assesses the participants' tendency to ruminate on negative emotion. Participants were prompted to recall their worst event in the past hour, and with that event in mind to rate how frequently they respond to negative events on items such as: "When you are thinking about this event, how much did you think 'What I am doing to deserve this'" and "When you are thinking about this event, how much did you think 'Why do I always react this way'" Higher scores indicate greater use of rumination. The internal consistencies of the brooding subscale of the RRS for the current study ranged from α = .52 to α = .93 (*M* = .78) across the 42 EMAs.

Suppression

We assessed suppression using the thought suppression subscale of the White Bear Suppression Inventory (WBSI) [62]. The thought suppression subscale consists of six items designed to measure the extent to which respondents engage in suppressing unwanted thoughts. Participants were prompted to recall their worst event in the past hour, and with that event in mind to rate how frequently they respond to negative events on items such as: "When you are thinking about this event, how much did you have thoughts that [you] cannot stop" or "When you are thinking about this event, how much did you have thoughts that [you] try to avoid." Higher scores indicate greater use of thought suppression strategies. The internal consistencies of the thought suppression subscale of the WBSI for the current study ranged from α = .90 to α = .97 (*M* = .93) across the 42 EMAs.

Cognitive reappraisal

We assessed cognitive reappraisal using a modified three-item cognitive reappraisal subscale of the Emotion Regulation Questionnaire (ERQ) [24]. Participants were prompted to recall their worst event in the past hour, and with that event in mind to rate how frequently they respond to negative events on items such as: "When this worst event happened, I thought about something different to feel less bad" or "When this worst event happened, I made myself think about it in a way that helps me feel better." Higher scores indicated greater use of cognitive reappraisal. The internal consistencies of the modified cognitive reappraisal subscale for the current study ranged from α = .69 to α = .96 (*M* = .86) across the 42 EMAs.

Problem solving

We assessed problem solving using a modified four-item problem solving/behavioral coping subscale of the Good Behavioral Self-Control Measure (GBSCM) [24]. Participants were prompted to recall their worst event in the past hour, and with that event in mind to rate how frequently they respond to negative events on items such as: "When you are thinking about this event, how much did you do something to try to solve the problem" or "When you are thinking about this event, how much did you think of different ways to take care of it." Higher scores indicate greater use of problem solving strategies. The internal consistencies of the modified problem solving subscale for the current study ranged from α = .86 to α = .96 (*M* = .92) across the 42 EMAs.

Data Analysis

Data were analyzed using multilevel modeling in Hierarchical Linear Modeling (HLM 7.03; [64]), demographics and Johnsen-Neyman intervals were calculated in SPSS 28.0.1.1 using the PROCESS version 4.3 macro for SPSS [65,66]. Analyzing data in HLM allowed us to use a longitudinal, multi-wave approach which considered within-participant variability in emotion regulation across assessments. Furthermore, HLM also takes into account the variation between individuals as a function of differences in RSA. All intercepts and slopes were allowed to vary randomly so that within-person variability was appropriately accounted for.

Rumination, suppression, cognitive reappraisal, and problem solving scores were calculated and entered as level-one variables along with a time sequence indicator (notification number). We calculated quadratic RSA reactivity by multiplying the RSA reactivity by itself. We then calculated a linear interaction term by multiplying BRSA by RSA reactivity, followed by a calculating a quadratic interaction term by multiplying BRSA by quadratic reactivity. Age, sex, trait negative affect, BRSA, RSA reactivity, linear RSA interaction, quadratic RSA reactivity, and the quadratic RSA interaction were entered sequentially in hierarchal models as level-two variables.

Results

Rumination

We observed significant main effects of age, BRSA, and RSA reactivity such that as these variables increased, so did rumination. Our quadratic RSA reactivity term proved significant, as did both the linear and quadratic interaction terms. In our sample, females endorsed increased rumination as compared to males. Random effects for rumination in our model were $\chi^2(157) = 252.47$, $p < .001$.

Suppression

The pattern of results observed in looking at suppression were similar to those of rumination. Age, BRSA, and RSA reactivity all predicted increased suppression. The quadratic RSA reactivity term as well as both liner and quadratic interactions all proved significant. In our sample, males endorsed higher levels of suppression and the random effects were $\chi^2(163) = 250.07$, $p < .001$.

Cognitive Reappraisal

Basal RSA significantly predicted cognitive reappraisal such that as BRSA increased, so did reappraisal. Linear RSA reactivity did not predict increased reappraisal, however quadratic RSA reactivity did. We observed a significant interaction between BRSA and linear RSA reactivity, and the interaction with quadratic RSA reactivity was significant at the $p < .100$ level. In our sample, males endorsed higher levels of reappraisal and the random effects were $\chi^2(56) = 42.14$, $p > .500$.

Problem Solving

Basal RSA significantly predicted problem solving, however liner RSA reactivity did not. Quadratic RSA reactivity and both interaction terms also failed to achieve significance. In our sample, males endorsed higher levels of problem solving. The random effects for problem solving in this model were $\chi^2(163) = 200.27$, $p = .025$.

Post Hoc Analyses

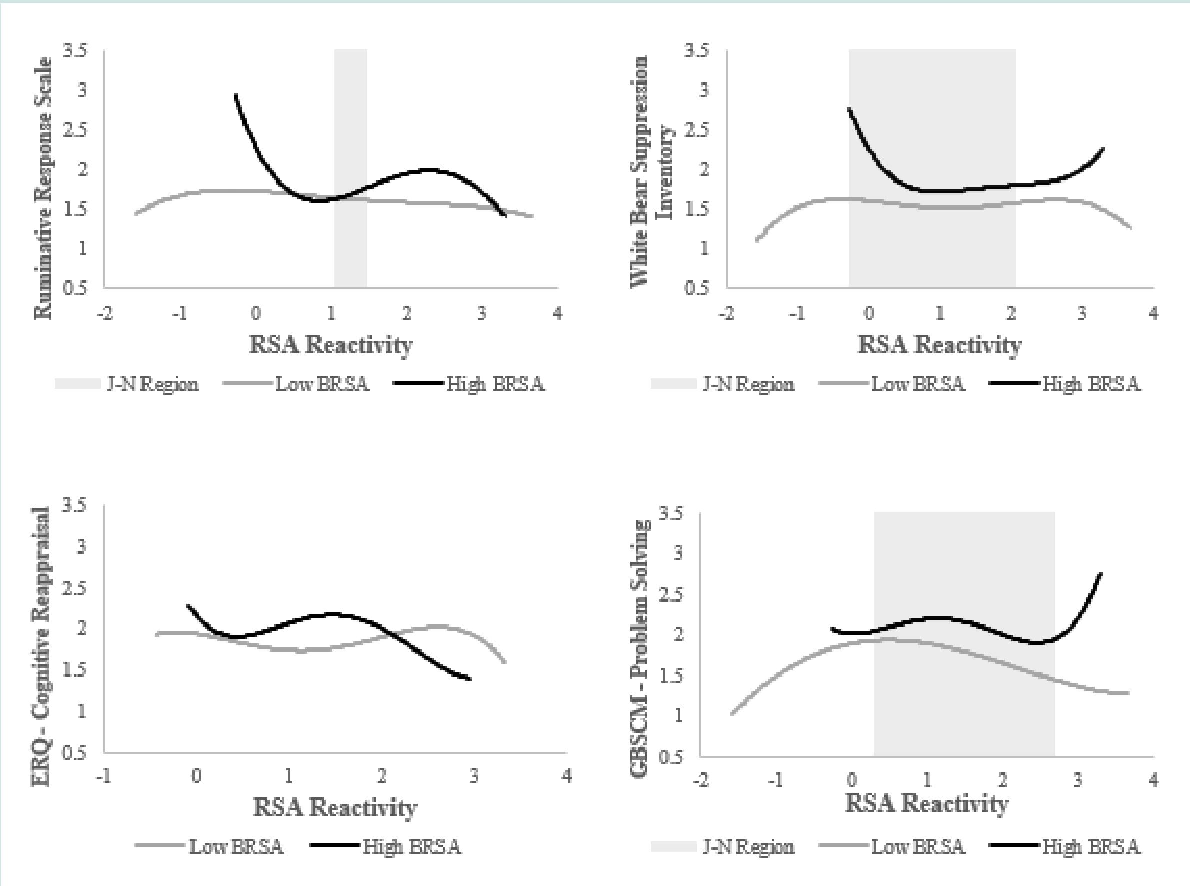

Figure 1: Trendlines of Emotion Regulation Strategies in Response to Daily Worst Event as a Function of RSA Group with Johnsen-Neyman (J-N) regions plotted.

We found BRSA and RSA reactivity to be moderately correlated, $r(169) = .314$, $p < .001$ (Figure 1), thus we further examined the interaction by graphing each emotion regulation strategy as a function of these variables with Johnsen-Neyman regression analyses. Results indicated RSA reactivity was significantly different between the low and high BRSA cohorts in three of the four outcome variables. The Johnsen-Neyman range of significant differences of RSA reactivity were between 1.03ms and 1.45ms for rumination, -0.23ms to 2.04ms for suppression, and 0.26ms to 2.72ms for problem solving.

Discussion

Prior research links high BRSA with positive mental health outcomes, and low BRSA with negative mental health outcomes [42-46]. Contrary to our expectations, we found high BRSA predicted increased use of all emotion regulation strategies, not only adaptive strategies. A possible explanation may be that high BRSA predicts an individual's overall tendency to seek and use regulation strategies in general, and the strategies they choose are influenced by other factors outside the scope of this study.

By contrast, RSA reactivity is not as clearly associated with positive or negative mental health outcomes, and the ranges of values which researchers consider "high" or "low" reactivity are ill-defined in the literature [39]. Therefore, we hypothesized a quadratic function of RSA reactivity such that high *or* low levels in our sample would prove maladaptive and moderate levels to be adaptive. We saw some evidence of this in graphing the data trend lines (Figure 1), and that the quadratic RSA reactivity term was significant with all strategies except problem solving. As our sample consisted overwhelmingly of young adult females in relatively good health, we suspect we may have seen only a subset of the RSA variation present in the population. This constrained range of variability may have obscured the true nature of the investigated relationships. Future studies with different sample demographics may help determine if a quadratic RSA reactivity is indeed a consistent predictor of emotion regulation.

The literature has established a link between low RSA reactivity, anxiety, and externalizing symptoms [48,49]. Concurrently, other research found augmented RSA reactivity is associated with dysregulated physiological responses (e.g., fainting when exposed to blood-injection-injury stimuli; [67]). We observed that individuals with high BRSA and very low (augmented) RSA reactivity demonstrated elevated levels of both rumination and suppression (Figure 1). Furthermore, rumination and suppression have been identified as transdiagnostic risk factors for psychological distress and pathology [68,69]. Our findings would seem to suggest RSA augmentation under stress potentially could be a physiological predictor for emotional dysregulation, similar to physiological dysregulation, especially in the presence of high BRSA. Notably, the majority of augmented RSA reactivity cases (81%) and the more extreme (negative) values were observed in individuals with low BRSA. That we did not see elevated use of rumination and suppression in those with low BRSA and augmented reactivity may indicate that this relationship is moderated by BRSA.

Across three of our outcome variables, we observed a region of statistically significant difference in RSA reactivity between the high and low BRSA groups. These findings provide further evidence for an interaction effect between BRSA and RSA reactivity that influences emotion regulation. We did not see this relationship in cognitive reappraisal, however, less than half of our participants generated data for this outcome variable due to its later inclusion in the study. Therefore, we believe it is premature to draw a firm conclusion about the nature of this relationship in cognitive reappraisal.

We observed several limitations in our study which most likely constrained our external validity. Our undergraduate sample was fairly homogenous in terms of age, race, and sex. This may have contributed to a lack of variability in RSA values, which may not be reflective of the general population. In turn, we must exercise caution generalizing these findings to individuals who do not meet these demographic characteristics. Additionally, we used a stressor task of preparing a speech. While our manipulation checks indicated this stressor was effective, college students typically are required to give speeches as part of their academic training. Thus, we anticipate our sample may have experienced a muted stress response with a narrower range of RSA reactivity than a sample not similarly conditioned.

Considering these limitations, future directions should examine RSA in more diverse samples to investigate whether similar findings in emotion regulation emerge across clinical and community samples. Additional representation in age, sex, and mental health status will provide greater RSA variability and external validity. Moreover, introducing alternative stressor tasks in the procedure, such as tasking the participant with complex arithmetic or reasoning tasks while recording their physiological responding, may elicit different physiological responses and increase the generalizability of these findings across different types of stressors [70-72]. Other procedural changes could explore whether particular interventions, such as a gratitude exercise, could alter one's ability to respond to daily stressors and influence the emotion regulation strategies they utilize. Our research presents evidence suggesting some individuals demonstrate RSA augmentation rather than withdrawal in response to a stressor task, and that an augmented response is associated with greater use of the maladaptive emotion regulation strategies of rumination and suppression.

Conclusions

The purpose of this study was to examine the unique and joint effects of BRSA and RSA reactivity on state emotion regulation in response to stressors. We used a longitudinal EMA design to examine the relationship between RSA and emotion regulation. This allowed us to link the physiological data from each participant to the strategies they employed in response to daily stressors. This study substantiates past research linking RSA to emotion regulation strategies; furthermore, it provides evidence to suggest the interaction between BRSA and RSA reactivity is an important factor in explaining daily emotion regulation. Exploring the interaction effects highlighted the moderating effect of BRSA on certain emotion regulation strategies. Our results suggest augmented RSA reactivity in the presence of high BRSA may predict an individual's tendency to use maladaptive strategies, however more studies are needed in order to examine whether these effects extend to other populations and different stressors. Future research could also examine whether these results generalize to other emotion regulation strategies other than the four examined here.

Author Acknowledgments

Conceptualization, A.M.; Data Curation, A.M. and K.S.; Formal Analysis M.C. and K.S.; Investigation, M.C. and K.S.; Methodology, A.M.; Project Administration, A.M.; Resources, A.M.; Supervision, A.M.; Validation, K.S.; Visualization, M.C. and K.S.; Writing - Original Draft Preparation, M.C. and K.S.; Writing - Review & Editing, A.M. and K.S. The author(s) did not use generative AI technologies for preparation of this work.

Conflicts of Interest

The authors declare no conflicts of interest.

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DOI: 10.32474/SJPBS.2023.07.000271