Resting HRV as a trait marker of rumination in healthy individuals? A large cross-sectional analysis

Zefeng Li[1], Matias Pulopulos[2], Jens Allaert[1], Stefanie De Smet[3], Linde De wandel[1], Mitchel Kappen[1], Louise Puttevils[1], Lais Razza[1], Emmanuelle Schoonjans[1], Gert Vanhollebeke[1], Chris Baeken[4], Rudi De Raedt[5], and Marie-Anne Vanderhasselt[5]

[1]Ghent University Faculty of Medicine and Health Sciences
[2]Ghent University Faculty of Psychology and Educational Sciences
[3]UZ Gent
[4]Ghent University
[5]Affiliation not available

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Abstract

The tendency to ruminate (i.e., repetitive, self-referential, negative thoughts) is a maladaptive form of emotional regulation and represents a transdiagnostic vulnerability factor for stress-related psychopathology. Vagally-mediated heart rate variability (HRV), reflecting parasympathetic nervous system activity, is commonly used as a physiological marker of stress regulation. Past research has suggested a link between trait rumination and resting HRV at baseline; however, inconsistent results exist in healthy individuals. In this study, we investigated the association between the tendency to ruminate and resting HRV measured at baseline in a healthy population using a large cross-sectional dataset (N = 1189, 88% women; mean age = 21.55, ranging from 17 to 48 years old), which was obtained by combining samples of healthy individuals from different studies from our laboratory. The results showed no cross-sectional correlation between resting baseline HRV and trait rumination (confirmed by Bayesian analyses), even after controlling for important confounders such as gender, age, and depressive symptoms. Also, a nonlinear relationship was rejected. In summary, based on our results in a large sample of healthy individuals, baseline resting HRV is not a trait marker of the tendency to ruminate.

Introduction

Human consciousness flows continuously and spontaneously from one thought to the next. Sometimes thinking evolves into an endless stream of repetitive self-referential negative thoughts that are difficult to let go of (Tseng & Poppenk, 2020), defined as rumination. According to the Response Styles Theory, rumination is the focused attention on the symptoms of one's emotional distress and its possible causes and consequences, as opposed to its solutions (Nolen-Hoeksema, 1991; Nolen-Hoeksema et al., 2008). The habitual tendency to ruminate is considered a maladaptive form of emotional regulation and has been associated with a sustained physiological stress response that damages the hormonal, cardiovascular, and nervous systems, ultimately leading to observable physical and mental health problems (Aldao et al., 2010; Brosschot et al., 2006; Kubzansky et al., 1997). Rumination is one of the reasons responsible for incomplete cardiovascular recovery after stress exposure and is therefore associated with cardiovascular indices (Radstaak et al., 2011). Besides, even though the tendency to ruminate is a well-known predictor of the onset and maintenance of depression (McLaughlin et al., 2007; Nolen-Hoeksema et al., 2008), rumination is considered a more general transdiagnostic factor of vulnerability and outcome in stress-related psychopathology (e.g., alcohol abuse, eating disorder, anxiety; Caselli et al., 2010; Dondzilo et al., 2016; Wilkinson et al., 2013). Therefore, core

neurophysiological mechanisms underlying a tendency to ruminate are important to further understand the relationship between rumination and the development of future clinical symptoms and health problems.

The functional state of the Autonomic Nervous System (ANS), consisting of the sympathetic and parasympathetic systems, has been reported as an important neurophysiological mechanism associated with rumination (Ottaviani et al., 2016; Vanderhasselt & Ottaviani, 2021). More specifically, both branches of the ANS act on the sino-atrial node of the heart and result in a complex variation between consecutive heartbeats over time, defined as heart rate variability (HRV; Goldberger et al., 2001; Porges, 2001, 2007; Saul et al., 1990; Task Force, 1996). In the face of stressors, the inhibitory control of the parasympathetic (over the sympathetic) nervous system enables the regulation of physiological and psychological states, an ability that is considered key to behavioral adaptability to the environment (mainly via the vagus nerve; Thayer et al., 2012). This parasympathetic dominance is associated with higher HRV (Friedman, 2007; Grol & De Raedt, 2020; Nasso et al., 2019, 2020; Pulopulos et al., 2018). Higher HRV is regarded as an indicator of better emotional regulation and mental health (Brosschot et al., 2006; Perna et al., 2020; Reynard et al., 2011; Thayer & Lane, 2000). In addition, the heart and the brain are reciprocally connected via the ANS pathways. Thayer's neurovisceral integration model proposes a network of cortical and subcortical neural structures, known as the central autonomic network (CAN), which receives sensory input from the peripheral end organs such as the heart (Thayer & Lane, 2000). The neurovisceral integration model proposes that vagally-mediated HRV is a read-out of the bi-directional interaction between central and cardiovascular processes, with higher HRV denoting more self-regulation and adaptability (Thayer et al., 2009).

Even though the association between rumination and vagally-mediated HRV has been widely studied, research remains inconsistent across the literature. Rumination can be separated into trait and state components, with the habitual tendency to ruminate in daily life referring to trait rumination, whereas state rumination is the act of ruminating elicited by discrete stressors (Key et al., 2008; Nolen-Hoeksema & Morrow, 1993). Most often, dynamic changes in HRV have been reported to examine the link between state rumination and stress reactivity after a laboratory induction (Ottaviani & Shapiro, 2011). In these studies, where individuals were put into a state of rumination in the laboratory - such as a video clip triggering stress, coping with fear sources that frighten the individual, or engaging in fearful or angry imagery or recall - a reduction of HRV was observed (Beauchaine et al., 2007; Castaneda & Segerstrom, 2004; El-Sheikh et al., 2011). Furthermore, in a meta-analysis reviewing 18 experimental studies, it was reported that perseverative cognition, including rumination and worry that share a commonality and are highly intercorrelated (Brosschot et al., 2006b; Fresco et al., 2002), was associated with lower HRV in healthy volunteers only on the state measures (Ottaviani et al., 2016). However, in contrast to the inverse association between stress-induced HRV and rumination response, questions remain regarding the association between resting (baseline) HRV and the tendency to ruminate in daily life (trait rumination). The habitual tendency to ruminate is known to be associated with chronic stress (inability to recover) and has been associated with a higher risk of cardiovascular disease (Busch et al., 2017; Schwartz et al., 2003). Importantly, the meta-analysis mentioned above reported that there was no association between HRV and the trait measure of perseverative cognition in the experimental study; however, the number of correlational studies (and the number of subjects) testing this association was relatively low (Ottaviani et al., 2016). Therefore, the relationship between resting HRV and trait rumination in healthy individuals remains unclear, as many studies focus on clinical populations or the HRV in response to induced rumination (i.e., a momentary, reactive state). Even though resting HRV is assumed to be a transdiagnostic and promising biomarker of mental health resilience (Beauchaine & Thayer, 2015; Perna et al., 2020), to the best of our knowledge, there is no study describing the association between resting-state HRV and trait rumination based on a large-scale and well-powered dataset in healthy individuals.

In this study, we use a large cross-sectional dataset of physiological and self-report (trait rumination and depression) data from our laboratory collected over a time span of 4 years (2017-2022) to investigate the association between resting HRV (i.e., measured during a baseline period) and the habitual tendency to ruminate in healthy individuals. We hypothesize that baseline HRV at rest will be negatively correlated with trait rumination as both high trait rumination and low HRV are risk factors for stress-related psychopathol-

ogy (Key et al., 2008; Larsen & Christenfeld, 2009). In addition, given that HRV is sensitive to various demographic variables, we will investigate whether HRV is associated with the tendency to ruminate after controlling for gender, age, and the level of depressive symptoms that are known to significantly influence HRV (Laborde et al., 2017). Moreover, a study has indicated that parasympathetic regulation of the heart through the vagus nerve might not have an unmitigated linear relationship with emotion (Kogan et al., 2013), so we also explore whether there is a non-linear relationship between HRV and emotion in our large cross-sectional data.

Methods

Participants

A group of 1245 healthy participants (197M/1048F) with a mean age of 21.55 (SD = 3.05, ranging from 17-48 years old) were included in our dataset. All subjects participated in 14 experiments in our laboratory, the specific experimental information is listed in the supplementary material (Allaert et al., 2021, 2022; De Smet et al., 2021; DeWandel et al., 2022; Pulopulos et al., 2020; Pulopulos et al., 2020). Although there were differences in the inclusion criteria from study to study, all studies excluded participants with cardiovascular disease and psychiatric disorders. All the experiments involved physiological data and questionnaires measurement. All studies were approved by the medical ethical board of Ghent university or the Ethical Committee from the Faculty of Psychology and Educational Sciences at Ghent University and were performed in accordance with the Declaration of Helsinki.

Questionnaires

Rumination. The Ruminative Response Scale (RRS) is administered to measure the degree of ruminative thinking styles of individuals (Nolen-Hoeksema & Morrow, 1991; Dutch translation by Raes et al., 2007). The RRS consists of 22 items describing how participants respond to a depressed mood, related to focusing on the self, symptoms, and the origin and consequences of the distress. This self-report questionnaire asks participants to respond on a 4-point Likert scale rating the frequency with which they generally think or do certain things when they feel sad, down, or depressed (i.e., 1 = almost never, 2 = sometimes, 3 = often, 4 = most of the time). The questionnaire also consists of two subscales: brooding and reflection. Brooding means a passive comparison of one's current situation with some unachieved work, and reflection means a purposeful turning inward to engage in cognitive problem-solving to alleviate one's depressive symptoms (Treynor et al., 2003). General Cronbach's alphas of RRS were .92, .78, and .75 for the RRS total scale, and the brooding and reflection subscales, respectively (Schoofs et al., 2010). All reported Cronbach's alphas are cited from previously executed validation studies and not from the current dataset, including the depression questionnaires below. 1150 participants in the dataset had RRS scores available.

Depression. Three different questionnaires were used to evaluate the presence of depressive symptoms, namely the Beck Depression Inventory (BDI)-II (Beck et al., 1996; Dutch version Van der Does, 2002), The Mood and Anxiety Symptoms Questionnaire (MASQ) (Wardenaar et al., 2010), and the depression subscale of the Depression, Anxiety, and Stress Scale (DASS-21) (de Beurs et al., 2001; Henry & Crawford, 2005). Given that the studies used three different questionnaires to assess depression, a standardized Z score was computed to increase the total sample size for our dataset ($\text{Depression}_{\text{Standardized}}$).

Beck Depression Inventory-II. The BDI-II is administered to evaluate depressive symptoms. The BDI-II is a widely used self-report questionnaire consisting of 21 multiples-choice format items (4-point scale), to assess the presence and severity of cognitive, motivational, affective, and somatic symptoms of depression in the past two weeks. Past reports demonstrated established reliability and validity in clinical and non-clinical samples, with Cronbach's alpha of .92 and .93 in a psychiatric and student population, respectively (Alexandrowicz et al., 2014). 288 participants in the dataset had BDI-II scores available.

Mood and Anxiety Symptoms Questionnaire. The MASQ is one of the common use self-reported questionnaires to assess symptoms of depression and anxiety. The questionnaire is designed to measure a tripartite model of anxiety and depression, which assumes that symptoms of depression and anxiety can be described

in three dimensions. "General Distress" includes general symptoms of psychological distress, "Anhedonic Depression" describes a lack of positive emotions and loss of energy, and "Anxiety Arousal" describes symptoms of excessive physical arousal (Watson et al., 1995). The MASQ used in this study consists of 30 items in the Dutch version with each item scored on a 5-point Likert scale (i.e., 1 = not at all, 2 = a little, 3 = moderately, 4 = quite a bit, 5 = extremely) in the past week (including today). Cronbach's alpha of Anhedonic Depression was from .93 to .95 (Wardenaar et al., 2010). 218 participants in the dataset had MASQ scores available.

Depression, Anxiety, and Stress Scale. The DASS measures the presence of depressive symptoms, anxiety, and stress in the past 7 days. The DASS consists of 21 items rated on a 4-Point Likert scale (0 = Not at all or never applicable, 1 = A little or sometimes applicable, 2 = Proper or often applicable, 3 = Very sure or mostly applicable) and widely used in clinical settings to assist in diagnosis and outcome monitoring and in non-clinical settings as a mental health screening. The scale has three subscales, depression, anxiety, and stress, each containing seven items, The higher the score, the higher the level of negative emotions. The Cronbach's alpha of the DASS-21 was .88 for the depression scale and .93 for the total scale (Henry & Crawford, 2005). 459 participants in the dataset had DASS scores available.

Physiological assessment of baseline HRV

Data were acquired using two different kinds of devices: BiopacMP150/160 (Biopac Systems Inc., California, USA), and Polar (Polar V800 H7 & H10, Kempele, Finland), at a sampling frequency of 1000 Hz for all devices. The electrocardiogram (ECG) electrode placements were corresponding to each device's instruction manual. There were two different baseline conditions in the samples of this study: 1) Rest, sitting upright in a chair with palm up and eyes open naturally (72.3 % of the total sample); 2) Vanilla, also sitting upright in a chair and reading magazines (27.6 % of the total sample). Data collection was performed in a controlled environment. All data included baseline measurement for 5 or 10 minutes to calculate resting-state HRV. For the data which lasted 5 minutes, we calculated the mean values of the time intervals between R peaks over the 5 minutes. For the data which lasted 10 minutes, we used the last 5 minutes of cardio data because the last 5 minutes of heart rate were more stable and had fewer artifacts than those of the first 5 minutes.

Data pre-processing

PhysioDataToolbox (Version 0.6.3), a MATLAB-based (MATLAB 2020b Component Runtime (v9.9)) application, was used to pre-process data from Biopac (Sjak-Shie, 2022). All data were formatted and imported into the toolbox, and then the ECG signal analyzer and HRV analyzer in the toolbox were used. The ECG signal analyzer treated the raw ECG data with a 1 Hz high-pass filter, a 50 Hz low-pass filter, and 1x signal gain. Then the ECG analyzer detected R-peak with the feature of 0.5 mV minimum R-peak, 0.3 s minimum distance between R-peak, 0.3 s minimum interbeat interval value, and 2 s maximum interbeat interval value. Baseline epochs with 5 or 10 minutes were defined according to the procedures of different experiments. After the R-peaks detection, the ECG data were visually inspected and manually corrected to remove ectopic beats, artifacts, and misidentified R-peaks singly. We extracted the root mean square of continuous heartbeat interval difference (RMSSD) to assess heart rate variability in time domains for the baseline epoch. Although some frequency-domain metrics such as high-frequency power also reflect parasympathetic activity, RMSSD is more correlated with vagal regulation and is less affected by respiratory and motor artifacts (Penttilä et al., 2001). The data from Polar, which only measures the intervals between two R-peaks in a consecutive period, were different from the data from Biopac which contains the whole heartbeat cycles and intervals. As such, we analyzed these data via Artiifact and Kubios 3.0.2 (Kaufmann et al., 2011; Tarvainen et al., 2002, 2014). The published polar data were adopted directly from three studies from our lab (Pulopulos et al., 2020a; Pulopulos et al., 2020b).

Data analysis

The SPSS software for Windows (IBM SPSS Statistics 27) was used for descriptive, correlation, and regression analysis. First, HRV values that differed from the mean value by more than three standard deviations were removed. Then, we performed an overall descriptive analysis of the HRV, questionnaire scores, and

demographic information (age, gender).

Pearson correlation was used to calculate the correlation coefficient between HRV, questionnaire scores, and age. Independent sample t-tests were used to examine gender differences in HRV and questionnaire scores and the effects of baseline type (i.e., resting and vanilla) on HRV. Observed power was estimated by retrospective power analysis to evaluate the statistical reliability whereas higher power indicates less probability of type II error. Then, two linear regression analyses were conducted with HRV as the dependent variable. In model 1, we included RRS_{total} as the independent variable and age, gender, and $Depression_{standardized}$ as control variables. In model 2, we included Brooding and Reflection together with the control variables (age, gender, and $Depression_{standardized}$). To explore whether there is a non-linear effect between HRV and rumination or depression as reported by previous studies, we conducted curve estimations under regression analyses in SPSS with HRV as the dependent variable; RRS_{total}, Brooding, Reflection, the scores from BDI-II, $MASQ_{depression}$, $DASS_{depression}$, and $Depression_{standardized}$ as independent variables. One independent variable was included for each estimation.

Results

Sample characteristics

Table 1 reports descriptive statistics for the HRV index, the subdimensions of the RRS, the three depression questionnaires, and $Depression_{standardized}$. After removing the samples that had physiological data with poor quality or with values higher than three standard deviations above the mean, a total of 1189 participants were finally included. The sample sizes vary somewhat per variable due to the different types of questionnaires collected in different experiments.

Table 1 places here, please.

Correlation analyses

As shown in Table 2, HRV was not significantly correlated with RRS_{total}, Brooding, Reflection, BDI-II, $MASQ_{depression}$, or $DASS_{depression}$, nor with $Depression_{standardized}$. However, RRS_{total}, Brooding, and Reflection were significantly correlated with BDI-II, $MASQ_{depression}$, and $DASS_{depression}$, and $Depression_{standardized}$, indicating that the tendency to ruminate was associated with higher levels of depression symptoms. There was a significantly negative correlation between age and RRS_{total}, Brooding, and Reflection, which means that the tendency to ruminate gradually decreased with the increase of age. Similarly, age was negatively correlated with BDI-II and $Depression_{standardized}$, respectively. The analyses with gender as the grouping variable found that the HRV was lower in women than in men (t (233.162) = 2.399, p = .017), and the RRS_{total} (t (1148) = -3.618, $p < .001$), Brooding (t (1148) = -3.649, $p < .001$) and Reflection (t (1148) = -2.895, $p < .001$) were higher in women than in men, but there were no differences in BDI-II (t (342) = -1.006, p = .315), $DASS_{depression}$ (t (457) = .415, p = .678) and $Depression_{standardized}$ (t (1019) = -.403,p = .687). Sex differences in depression could not be investigated using the $MASQ_{depression}$ because all the participants were female. In addition, there was a significant difference in HRV between the types of physiological baseline measurement (t (1187) = -2.060, p = .040), showing lower HRV during resting baseline than during Vanilla baseline.

Table 2 places here, please.

Regression analysis

None of the linear models with RRS_{total}, brooding, and reflection with and without covariates (age, gender, and $Depression_{standardized}$) were statistically significant (see Table 3).

Table 3 places here, please.

Based on the frequentists approach showing non-significant regard to HRV, rumination, and depression, which thereby failed to reject the null hypothesis, Bayesian factor analyses (using JASP 0.16.3) were conducted to assess the likelihood of a correct null hypothesis (Quintana & Williams, 2018). Bayesian factor analysis is a

development and alternative to testing the null hypotheses significance test. The Bayesian framework allows for the probabilistic description of parameters and hypotheses and can quantify the degree to which the data favors the null hypothesis (H0) or the alternative hypothesis (H1) (Gelman et al., 2014; McElreath, 2020). The H1 is that HRV is negatively correlated to rumination. The H0 rejects these correlations. In this study, we use Bayes factor 10 (BF_{10}) which measures the degree to which H1 is supported by data compared with the H0. When the BF is higher than 1, the evidence is in favor of H1. The larger the factor, the higher the probability of the evidence in favor of H1. On the contrary, when the BF is less than 1, the evidence is in favor of H0. The smaller the factor, the higher the probability of the evidence in favor of H0.

Bayesian analysis showed that there was strong evidence supporting no correlations between HRV and RRS_{total}(BF_{10} = 0.152), Brooding (BF_{10} = 0.061), and Reflection (BF_{10} = 0.41), because the BF_{10} were less than 1.

Table 4 places here, please.

For non-linear effects, we created a linear term and a quadratic term for each variable in the equation to do a curve estimate. Significant linear and quadratic effects of Reflection and a significant quadratic effect of $MASQ_{depression}$ on HRV were observed. No other quadratic effect was found between HRV with rumination and depression (see Table 4).

Discussion

In this study, we aimed to explore whether baseline vagally-mediated HRV (measured via RMSSD) is a marker of the habitual tendency to ruminate, which is a maladaptive thought process that makes individuals vulnerable to mental disorders (measured by the RRS), in a large sample of healthy individuals. Based on our data from over 1100 volunteers, no evidence is found for the relationship between baseline vagally-mediated HRV at rest and rumination.

Reduced resting HRV has been reported in various forms of psychopathology (Chalmers et al., 2014; Faurholt-Jepsen et al., 2017; Tak et al., 2009), and the association between reduced HRV with trait rumination has been reported in clinical and experimental studies (Johnson et al., 2014; McLaughlin & Nolen-Hoeksema, 2011). For example, a correlational study consisting of 117 women (55 recovered from depression and 56 healthy controls) found a significant relation between brooding, a maladaptive form of rumination, and HRV, such that women reporting higher levels of brooding exhibited lower levels of HRV (Woody et al., 2014). Another study monitored HRV in 52 healthy volunteers throughout the day and found that the tendency to worry (another perseverative cognition, highly correlated to rumination) was associated with lower HRV (Brosschot et al., 2007; Fresco et al., 2002). In line with these results, the seminal neurovisceral integration model proposes that in healthy individuals, the prefrontal cortex is in control over subcortical areas, resulting in tonic inhibitory control of the parasympathetic branch of the ANS (i.e., higher HRV; Thayer & Lane, 2009). As a result, these neural and autonomic regulations result in less viscous cycles of ruminative thoughts and turn higher resting HRV (Song et al., 2022). However, in the current study, this association between the tendency to ruminate and baseline vagally-mediated HRV measured at rest cannot be observed in healthy individuals, even after controlling for gender, age, and the level of depressive symptoms. Moreover, Bayesian analyses showed a higher likelihood of no association between HRV. Finally, our results exclude a non-linear relationship between HRV with rumination and the level of depressive symptoms, which is in line with a prior study that cannot find a linear or non-linear effect of baseline resting HRV on positive emotion and depression (Silvia et al., 2014).

A meta-analysis reviewing the relationship between physiological concomitants with perseverative cognition found that maladaptive thought processes (including rumination and worry) were associated with decreased HRV in 8 correlational studies, but the literature was insufficient to conclude whether this association existed specifically for both traits (i.e., habitual tendency) and state (i.e., momentary) rumination (Ottaviani et al., 2016). Two studies focused on the relationship between the tendency to ruminate and HRV recovery in children aged 7-14 and reported inconsistent results (Sample size: 100 and 103; Borelli et al., 2014; Gentzler et al., 2013). One study found a negative correlation between resting HRV and emotion regulation, as

measured by the difficulties in emotion regulation scale, in 198 undergraduate students (Rankin et al., 2014). Only two studies described in the previous paragraph specifically focused on trait rumination, worry, and resting HRV and reported significant negative associations (Brosschot et al., 2007; Woody et al., 2014). The remaining three studies (of the 8 studies included in the meta-analysis) were all related to instantaneous changes in HRV or state rumination and worry showing significant results but in the context of laboratory-based operation cannot generalize to the effects of chronic stress in everyday life (Cash et al., 2013; Gazelle & Druhen, 2009; Mezulis et al., 2014). Thus, existing studies either have focused on all-female samples and include depression risk rather than completely healthy controls, conclusions were drawn from young school children, or the sample size was relatively low. In addition, although an overlap, there is still distinguishing characteristic of rumination and worry (Nolen-Hoeksema et al., 2008). Therefore, the finding of this study, based on a large sample size and a young healthy population with a wider age range, suggests that the tendency to ruminate is not associated with lower HRV in healthy individuals.

Some characteristics of our study can, at least in part, explain the null association between HRV and rumination. Although the participants in the current dataset report a wide range of habitual tendencies towards rumination, they are healthy young individuals without mental diseases. Thus, it is possible that the association between resting HRV and rumination is more robust in individuals who have impaired parasympathetic control due to long-term stress exposure or who suffer from stress-related mental disorders. As a systematic review suggests, individuals who reported childhood adversity (retrospect of the past, a ruminative thought) have no significant overall association with resting HRV, whereas the clinical sample, as significant moderators, may have small significant association under specific circumstances (Wesarg et al., 2022). These might provide an explanation for the absent association between trait rumination and resting HRV in the current large sample of healthy individuals. Also, HRV was measured during a resting period, and no stress or ruminative processes were induced. Thus, another explanation could be that the negative correlation is more related to state (i.e., at that moment) rumination and acute changes in HRV under experimental induction paradigms rather than in a resting phase (Ottaviani et al., 2016). In sum, based on our findings, resting vagally-mediated HRV cannot be regarded as an index of the tendency to ruminate, and thus a vulnerability factor in trait rumination, in healthy individuals.

Overall, despite an absent correlation between baseline HRV measured during rest, associations between other variables are in line with the literature. The results of our large-scale cross-sectional dataset show that the resting HRV of males was slightly higher than that of females (Hamidovic et al., 2020). Furthermore, sex differences were found in the rumination scores (females scoring higher as compared to males), but not in the questionnaires regarding depressive symptoms. In addition, our results also show that, based on a limited age range, there was a significant negative correlation between age and rumination scores, as well as age and BDI-II scores, indicating that with the increase in age, people experience fewer symptoms of rumination and depression. This observation is in line with prior studies reporting that older people show a decrease in processing negative stimuli and thus show a positive effect on emotion (Nashiro et al., 2012). Rumination and depression were also highly correlated, as previous studies suggested that rumination is a potential risk factor for depression and can prolong and intensify depressive symptoms (Nolen-Hoeksema et al., 1997; Spasojević & Alloy, 2001). Overall, these findings indicate that the association between rumination and related psychological constructs is consistent with those reported in the previous literature, showing the validity of our data.

Accurate baseline measurements are critical to measuring the impact of cognitive tasks or group designations. At the resting baseline phase, participants usually sit with their knees at a 90° angle, both feet flat on the floor, hands on thighs, and no psychological tasks. This protocol involves inevitable mind wandering, disruptive thoughts, or difficulty sitting still for some participants. A popular alternative to this forced relaxation could be vanilla baseline, where participants must perform a task that requires sustained attention but a minimal cognitive load (such as reading a magazine or coloring). Importantly, our results show that different baseline types influenced resting HRV, denoting that the HRV values during a vanilla baseline were higher as compared to a baseline in rest. Further studies should consider baseline type depending on specific experimental tasks and purpose, while there is no simple answer to defining an appropriate baseline measurement.

Some limitations of our study should be considered. It is important to mention that the sex ratio in this study is not balanced and that sex itself affects HRV, which may impede the broad applicability of our results. Body mass index is also associated with HRV, but it was not measured in some of our experiments. In addition, the measurement of trait rumination and resting HRV was inconsistent in time and space. The trait rumination questionnaire was generally completed online (before the experiment), while HRV was measured in a laboratory environment, and generally not on the same day. Moreover, as all the participants were recruited in the same lab, we cannot rule out the possibility of subjects that participated in multiple experiments. All the above factors might contribute to the observed results.

To conclude, this is the first study using a large cross-sectional dataset to examine the relationship between baseline resting HRV and trait rumination in healthy individuals. The results indicate that there is no association between HRV under a specific condition, namely baseline resting, and the tendency to ruminate in daily life, based on a sample of more than thousands of adults. Thus, vagally-mediated HRV at rest could not be regarded as a marker of trait rumination in healthy individuals.

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Reference

Aldao, A., Nolen-Hoeksema, S., & Schweizer, S. (2010). Emotion-regulation strategies across psychopathology: A meta-analytic review. *Clinical Psychology Review* , *30* (2), 217–237.

Alexandrowicz, R. W., Fritzsche, S., & Keller, F. (2014). Die Anwendbarkeit des BDI-II in klinischen und nichtklinischen Populationen aus psychometrischer Sicht. Eine vergleichende Analyse mit dem Rasch-Modell. *Neuropsychiatrie* , *28* (2), 63–73.

Allaert, J., De Raedt, R., Sanchez-Lopez, A., Baeken, C., & Vanderhasselt, M.-A. (2022). Mind the social feedback: Effects of tDCS applied to the left DLPFC on psychophysiological responses during the anticipation and reception of social evaluations. *Social Cognitive and Affective Neuroscience* , *17* (1), 131–141.

Allaert, J., De Raedt, R., van Der Veen, F. M., Baeken, C., & Vanderhasselt, M.-A. (2021). Prefrontal tDCS attenuates counterfactual thinking in female individuals prone to self-critical rumination.*Scientific Reports* , *11* (1), 1–14.

Beauchaine, T. P., Gatzke-Kopp, L., & Mead, H. K. (2007). Polyvagal theory and developmental psychopathology: Emotion dysregulation and conduct problems from preschool to adolescence. *Biological Psychology* , *74* (2), 174–184.

Beauchaine, T. P., & Thayer, J. F. (2015). Heart rate variability as a transdiagnostic biomarker of psychopathology. *International Journal of Psychophysiology* , *98* (2), 338–350.

Beck, A. T., Steer, R. A., & Brown, G. K. (1996). *Beck depression inventory (BDI-II)* (Vol. 10, Issue 3). Pearson London, UK.

Borelli, J. L., Hilt, L. M., West, J. L., Weekes, N. Y., & Gonzalez, M. C. (2014). School-aged children's depressive rumination is associated with their reactivity to sadness but not fear. *Journal of Clinical Child & Adolescent Psychology* , *43* (5), 799–812.

Brosschot, J. F., Gerin, W., & Thayer, J. F. (2006a). The perseverative cognition hypothesis: A review of worry, prolonged stress-related physiological activation, and health. *Journal of Psychosomatic Research* , *60* (2), 113–124.

Brosschot, J. F., Gerin, W., & Thayer, J. F. (2006b). The perseverative cognition hypothesis: A review of worry, prolonged stress-related physiological activation, and health. *Journal of Psychosomatic Research* , *60* (2), 113–124.

Brosschot, J. F., Van Dijk, E., & Thayer, J. F. (2007). Daily worry is related to low heart rate variability during waking and the subsequent nocturnal sleep period. *International Journal of Psychophysiology* , *63* (1), 39–47.

Busch, L. Y., Pössel, P., & Valentine, J. C. (2017). Meta-analyses of cardiovascular reactivity to rumination: A possible mechanism linking depression and hostility to cardiovascular disease. *Psychological Bulletin* , *143* (12), 1378.

Caselli, G., Ferretti, C., Leoni, M., Rebecchi, D., Rovetto, F., & Spada, M. M. (2010). Rumination as a predictor of drinking behaviour in alcohol abusers: A prospective study. *Addiction* , *105* (6), 1041–1048.

Cash, C. S., Patel, A. I., Williams, D. P., & Thayer, J. F. (2013). Greater heart rate variability during a negative emotion induction is associated with lower trait rumination and anxiety.*Psychophysiology* , *50* , S37.

Castaneda, J. O., & Segerstrom, S. C. (2004). Effect of stimulus type and worry on physiological response to fear. *Journal of Anxiety Disorders* , *18* (6), 809–823.

Chalmers, J. A., Quintana, D. S., Abbott, M. J.-A., & Kemp, A. H. (2014). Anxiety disorders are associated with reduced heart rate variability: A meta-analysis. *Frontiers in Psychiatry* , *5* , 80.

de Beurs, E., Van Dyck, R., Marquenie, L. A., Lange, A., & Blonk, R. W. (2001). De DASS: een vragenlijst voor het meten van depressie, angst en stress. *Gedragstherapie* , *34* (1), 35–54.

De Smet, S., Baeken, C., De Raedt, R., Pulopulos, M. M., Razza, L. B., Van Damme, S., De Witte, S., Brunoni, A. R., & Vanderhasselt, M.-A. (2021). Effects of combined theta burst stimulation and transcranial direct current stimulation of the dorsolateral prefrontal cortex on stress. *Clinical Neurophysiology* , *132* (5), 1116–1125.

DeWandel, L., DeSmet, S., M Pulopulos, M., Lemmens, G., Hidalgo, V., Salvador, A., Vanderhasselt, M.-A., Pruessner, J., & Baeken, C. (2022). THE EFFECTS OF TRANSCRANIAL DIRECT CURRENT STIMULATION ON EPISODIC FUTURE THINKING FOLLOWING ACUTE PSYCHOSOCIAL STRESS. *Psychiatria Danubina* , *34* (suppl 3), 42–42.

Dondzilo, L., Rieger, E., Palermo, R., Byrne, S., & Bell, J. (2016). Association between rumination factors and eating disorder behaviours in young women. *Advances in Eating Disorders* , *4* (1), 84–98.

El-Sheikh, M., Hinnant, J. B., & Erath, S. (2011). Developmental trajectories of delinquency symptoms in childhood: The role of marital conflict and autonomic nervous system activity. *Journal of Abnormal Psychology* , *120* (1), 16.

Faurholt-Jepsen, M., Kessing, L. V., & Munkholm, K. (2017). Heart rate variability in bipolar disorder: A systematic review and meta-analysis.*Neuroscience & Biobehavioral Reviews* , *73* , 68–80.

Fresco, D. M., Frankel, A. N., Mennin, D. S., Turk, C. L., & Heimberg, R. G. (2002). Distinct and overlapping features of rumination and worry: The relationship of cognitive production to negative affective states.*Cognitive Therapy and Research* , *26* (2), 179–188.

Friedman, B. H. (2007). An autonomic flexibility–neurovisceral integration model of anxiety and cardiac vagal tone. *Biological Psychology* , *74* (2), 185–199.

Gazelle, H., & Druhen, M. J. (2009). Anxious solitude and peer exclusion predict social helplessness, upset affect, and vagal regulation in response to behavioral rejection by a friend.*Developmental Psychology* , *45* (4), 1077.

Gelman, A., Hwang, J., & Vehtari, A. (2014). Understanding predictive information criteria for Bayesian models. *Statistics and Computing* , *24* (6), 997–1016.

Gentzler, A. L., Wheat, A. L., Palmer, C. A., & Burwell, R. A. (2013). Children's responses to cognitive challenge and links to self-reported rumination. *Cognition & Emotion* , *27* (2), 305–317.

Goldberger, J. J., Challapalli, S., Tung, R., Parker, M. A., & Kadish, A. H. (2001). Relationship of heart rate variability to parasympathetic effect. *Circulation* , *103* (15), 1977–1983.

Grol, M., & De Raedt, R. (2020). The link between resting heart rate variability and affective flexibility. *Cognitive, Affective, & Behavioral Neuroscience* , *20* (4), 746–756.

Hamidovic, A., Van Hedger, K., Choi, S. H., Flowers, S., Wardle, M., & Childs, E. (2020). Quantitative meta-analysis of heart rate variability finds reduced parasympathetic cardiac tone in women compared to men during laboratory-based social stress. *Neuroscience & Biobehavioral Reviews* , *114* , 194–200.

Henry, J. D., & Crawford, J. R. (2005). The short-form version of the Depression Anxiety Stress Scales (DASS-21): Construct validity and normative data in a large non-clinical sample. *British Journal of Clinical Psychology* , *44* (2), 227–239.

Johnson, J. A., Key, B. L., Routledge, F. S., Gerin, W., & Campbell, T. S. (2014). High trait rumination is associated with blunted nighttime diastolic blood pressure dipping. *Annals of Behavioral Medicine* ,*48* (3), 384–391.

Kaufmann, T., Sutterlin, S., Schulz, S. M., & Vogele, C. (2011). ARTiiFACT: a tool for heart rate artifact processing and heart rate variability analysis. *Behavior Research Methods* , *43* (4), 1161–1170.

Key, B. L., Campbell, T. S., Bacon, S. L., & Gerin, W. (2008). The influence of trait and state rumination on cardiovascular recovery from a negative emotional stressor. *Journal of Behavioral Medicine* ,*31* (3), 237–248.

Kogan, A., Gruber, J., Shallcross, A. J., Ford, B. Q., & Mauss, I. B. (2013). Too much of a good thing? Cardiac vagal tone's nonlinear relationship with well-being. *Emotion* , *13* (4), 599.

Kubzansky, L. D., Kawachi, I., Spiro III, A., Weiss, S. T., Vokonas, P. S., & Sparrow, D. (1997). Is worrying bad for your heart? A prospective study of worry and coronary heart disease in the Normative Aging Study.*Circulation* , *95* (4), 818–824.

Laborde, S., Mosley, E., & Thayer, J. F. (2017). Heart rate variability and cardiac vagal tone in psychophysiological research–recommendations for experiment planning, data analysis, and data reporting.*Frontiers in Psychology* , *8* , 213.

Larsen, B. A., & Christenfeld, N. J. (2009). Cardiovascular disease and psychiatric comorbidity: The potential role of perseverative cognition.*Cardiovascular Psychiatry and Neurology* , *2009* .

McElreath, R. (2020). *Statistical rethinking: A Bayesian course with examples in R and Stan* . Chapman and Hall/CRC.

McLaughlin, K. A., Borkovec, T. D., & Sibrava, N. J. (2007). The effects of worry and rumination on affect states and cognitive activity.*Behavior Therapy* , *38* (1), 23–38.

McLaughlin, K. A., & Nolen-Hoeksema, S. (2011). Rumination as a transdiagnostic factor in depression and anxiety. *Behaviour Research and Therapy* , *49* (3), 186–193.

Mezulis, A., Crystal, S., & Ahles, J. (2014). Resting RSA predicts stress-reactive rumination following induced stress among young adolescents. *Psychophysiology* , *51* , S53–S53.

Nashiro, K., Sakaki, M., & Mather, M. (2012). Age differences in brain activity during emotion processing: Reflections of age-related decline or increased emotion regulation. *Gerontology* , *58* (2), 156–163.

Nasso, S., Vanderhasselt, M.-A., & De Raedt, R. (2020). Testing the neurocognitive framework for regulation expectation: The relationship between actual/ideal self-esteem and proactive/reactive autonomic stress regulation. *Journal of Behavior Therapy and Experimental Psychiatry* , *69* , 101598.

Nasso, S., Vanderhasselt, M.-A., Demeyer, I., & De Raedt, R. (2019). Autonomic regulation in response to stress: The influence of anticipatory emotion regulation strategies and trait rumination.*Emotion* , *19* (3), 443.

Nolen-Hoeksema, S. (1991). Responses to depression and their effects on the duration of depressive episodes. *Journal of Abnormal Psychology* , *100* (4), 569.

Nolen-Hoeksema, S., McBride, A., & Larson, J. (1997). Rumination and psychological distress among bereaved partners. *Journal of Personality and Social Psychology* , *72* (4), 855.

Nolen-Hoeksema, S., & Morrow, J. (1991). A prospective study of depression and posttraumatic stress symptoms after a natural disaster: The 1989 Loma Prieta Earthquake. *Journal of Personality and Social Psychology* , *61* (1), 115.

Nolen-Hoeksema, S., & Morrow, J. (1993). Effects of rumination and distraction on naturally occurring depressed mood. *Cognition & Emotion* , *7* (6), 561–570.

Nolen-Hoeksema, S., Wisco, B. E., & Lyubomirsky, S. (2008). Rethinking rumination. *Perspectives on Psychological Science* , *3* (5), 400–424.

Ottaviani, C., & Shapiro, D. (2011). Do we need a stressor to be stressed? Insights from cardiac regulation 1. *Japanese Psychological Research* , *53* (2), 155–162.

Ottaviani, C., Thayer, J. F., Verkuil, B., Lonigro, A., Medea, B., Couyoumdjian, A., & Brosschot, J. F. (2016). Physiological concomitants of perseverative cognition: A systematic review and meta-analysis.*Psychological Bulletin* , *142* (3), 231.

Ottaviani, C., Watson, D. R., Meeten, F., Makovac, E., Garfinkel, S. N., & Critchley, H. D. (2016). Neurobiological substrates of cognitive rigidity and autonomic inflexibility in generalized anxiety disorder.*Biological Psychology* , *119* , 31–41.

Penttila, J., Helminen, A., Jartti, T., Kuusela, T., Huikuri, H. V., Tulppo, M. P., Coffeng, R., & Scheinin, H. (2001). Time domain, geometrical and frequency domain analysis of cardiac vagal outflow: Effects of various respiratory patterns. *Clinical Physiology* ,*21* (3), 365–376.

Perna, G., Riva, A., Defillo, A., Sangiorgio, E., Nobile, M., & Caldirola, D. (2020). Heart rate variability: Can it serve as a marker of mental health resilience?: Special Section on "Translational and Neuroscience Studies in Affective Disorders" Section Editor, Maria Nobile MD, PhD. *Journal of Affective Disorders* , *263* , 754–761.

Porges, S. W. (2001). The polyvagal theory: Phylogenetic substrates of a social nervous system. *International Journal of Psychophysiology* ,*42* (2), 123–146.

Porges, S. W. (2007). The polyvagal perspective. *Biological Psychology* , *74* (2), 116–143.

Pulopulos, M. M., Baeken, C., & De Raedt, R. (2020). Cortisol response to stress: The role of expectancy and anticipatory stress regulation.*Hormones and Behavior* , *117* , 104587.

Pulopulos, M. M., Schmausser, M., De Smet, S., Vanderhasselt, M.-A., Baliyan, S., Venero, C., Baeken, C., & De Raedt, R. (2020). The effect of HF-rTMS over the left DLPFC on stress regulation as measured by cortisol and heart rate variability. *Hormones and Behavior* ,*124* , 104803.

Pulopulos, M. M., Vanderhasselt, M.-A., & De Raedt, R. (2018). Association between changes in heart rate variability during the anticipation of a stressful situation and the stress-induced cortisol response. *Psychoneuroendocrinology* , *94* , 63–71.

Quintana, D. S., & Williams, D. R. (2018). Bayesian alternatives for common null-hypothesis significance tests in psychiatry: A non-technical guide using JASP. *BMC Psychiatry* , *18* (1), 1–8.

Radstaak, M., Geurts, S. A., Brosschot, J. F., Cillessen, A. H., & Kompier, M. A. (2011). The role of affect and rumination in cardiovascular recovery from stress. *International Journal of Psychophysiology* , *81* (3), 237–244.

Raes, F., Hermans, D., Williams, J. M. G., & Eelen, P. (2007). A sentence completion procedure as an alternative to the Autobiographical Memory Test for assessing overgeneral memory in non-clinical populations. *Memory* , *15* (5), 495–507.

Rankin, C., Bernardi, A., Upchurch, B., Cash, C., Koenig, J., Williams, D. P., & Thayer, J. F. (2014). The relationship between heart rate variability and perceptions of emotional control. *Psychophysiology* , *51* , S57.

Reynard, A., Gevirtz, R., Berlow, R., Brown, M., & Boutelle, K. (2011). Heart rate variability as a marker of self-regulation. *Applied Psychophysiology and Biofeedback* , *36* (3), 209–215.

Saul, J. P., Rea, R. F., Eckberg, D. L., Berger, R. D., & Cohen, R. J. (1990). Heart rate and muscle sympathetic nerve variability during reflex changes of autonomic activity. *American Journal of Physiology-Heart and Circulatory Physiology* , *258* (3), H713–H721.

Schoofs, H., Hermans, D., & Raes, F. (2010). Brooding and reflection as subtypes of rumination: Evidence from confirmatory factor analysis in nonclinical samples using the Dutch Ruminative Response Scale. *Journal of Psychopathology and Behavioral Assessment* ,*32* (4), 609–617.

Schwartz, A. R., Gerin, W., Davidson, K. W., Pickering, T. G., Brosschot, J. F., Thayer, J. F., Christenfeld, N., & Linden, W. (2003). Toward a causal model of cardiovascular responses to stress and the development of cardiovascular disease. *Psychosomatic Medicine* ,*65* (1), 22–35.

Silvia, P. J., Jackson, B. A., & Sopko, R. S. (2014). Does baseline heart rate variability reflect stable positive emotionality? *Personality and Individual Differences* , *70* , 183–187.

Sjak-Shie, E. E. (2022). *PhysioData Toolbox (Version 0.6.3) [Computer software]* . Retrieved from https://PhysioDataToolbox.leidenuniv.nl.

Song, X., Long, J., Wang, C., Zhang, R., & Lee, T. M. (2022). The inter-relationships of the neural basis of rumination and inhibitory control: Neuroimaging-based meta-analyses. *Psychoradiology* ,*2* (1), 11–22.

Spasojević, J., & Alloy, L. B. (2001). Rumination as a common mechanism relating depressive risk factors to depression. *Emotion* ,*1* (1), 25.

Tak, L. M., Riese, H., de Bock, G. H., Manoharan, A., Kok, I. C., & Rosmalen, J. G. (2009). As good as it gets? A meta-analysis and systematic review of methodological quality of heart rate variability studies in functional somatic disorders. *Biological Psychology* ,*82* (2), 101–110.

Tarvainen, M. P., Niskanen, J.-P., Lipponen, J. A., Ranta-Aho, P. O., & Karjalainen, P. A. (2014). Kubios HRV–heart rate variability analysis software. *Computer Methods and Programs in Biomedicine* ,*113* (1), 210–220.

Tarvainen, M. P., Ranta-Aho, P. O., & Karjalainen, P. A. (2002). An advanced detrending method with application to HRV analysis. *IEEE Transactions on Biomedical Engineering* , *49* (2), 172–175.

Task Force of the European Society of Cardiology the North American Society of Pacing. (1996). Heart rate variability: Standards of measurement, physiological interpretation, and clinical use. *Circulation* , *93* (5), 1043–1065.

Thayer, J. F., Åhs, F., Fredrikson, M., Sollers III, J. J., & Wager, T. D. (2012). A meta-analysis of heart rate variability and neuroimaging studies: Implications for heart rate variability as a marker of stress and health. *Neuroscience & Biobehavioral Reviews* , *36* (2), 747–756.

Thayer, J. F., Hansen, A. L., Saus-Rose, E., & Johnsen, B. H. (2009). Heart rate variability, prefrontal neural function, and cognitive performance: The neurovisceral integration perspective on self-regulation, adaptation, and health. *Annals of Behavioral Medicine* , *37* (2), 141–153.

Thayer, J. F., & Lane, R. D. (2000). A model of neurovisceral integration in emotion regulation and dysregulation. *Journal of Affective Disorders* , *61* (3), 201–216.

Thayer, J. F., & Lane, R. D. (2009). Claude Bernard and the heart–brain connection: Further elaboration of a model of neurovisceral integration. *Neuroscience & Biobehavioral Reviews* , *33* (2), 81–88.

Treynor, W., Gonzalez, R., & Nolen-Hoeksema, S. (2003). Rumination reconsidered: A psychometric analysis. *Cognitive Therapy and Research* , *27* (3), 247–259.

Tseng, J., & Poppenk, J. (2020). Brain meta-state transitions demarcate thoughts across task contexts exposing the mental noise of trait neuroticism. *Nature Communications* , *11* (1), 1–12.

Van der Does, A. J. W. (2002). Manual of the Dutch version of the Beck Depression Inventory (BDI-II-NL). *Amsterdam, NL: Harcourt* .

Vanderhasselt, M.-A., & Ottaviani, C. (2021). Combining top-down and bottom-up interventions targeting the vagus nerve to increase resilience. *Neuroscience & Biobehavioral Reviews* .

Wardenaar, K. J., van Veen, T., Giltay, E. J., de Beurs, E., Penninx, B. W., & Zitman, F. G. (2010). Development and validation of a 30-item short adaptation of the Mood and Anxiety Symptoms Questionnaire (MASQ).*Psychiatry Research* , *179* (1), 101–106.

Watson, D., Weber, K., Assenheimer, J. S., Clark, L. A., Strauss, M. E., & McCormick, R. A. (1995). Testing a tripartite model: I. Evaluating the convergent and discriminant validity of anxiety and depression symptom scales. *Journal of Abnormal Psychology* , *104* (1), 3.

Wesarg, C., Van den Akker, A. L., Oei, N. Y., Wiers, R. W., Staaks, J., Thayer, J. F., Williams, D. P., & Hoeve, M. (2022). Childhood adversity and vagal regulation: A systematic review and meta-analysis.*Neuroscience & Biobehavioral Reviews* , 104920.

Wilkinson, P. O., Croudace, T. J., & Goodyer, I. M. (2013). Rumination, anxiety, depressive symptoms and subsequent depression in adolescents at risk for psychopathology: A longitudinal cohort study. *BMC Psychiatry* , *13* (1), 1–9.

Woody, M. L., McGeary, J. E., & Gibb, B. E. (2014). Brooding rumination and heart rate variability in women at high and low risk for depression: Group differences and moderation by COMT genotype. *Journal of Abnormal Psychology* , *123* (1), 61.

	N	**Min**	**Max**	**Mean**	**SD**
Sample (age)					
Men	197	18	44	22.19	3.71
Women	1048	17	48	21.43	2.89
HRV					
RMSSD	1189	4.22	165.72	40.85	24.03
Man	184	6.89	150.79	45.23	27.55
Women	1005	4.22	165.72	40.05	23.26
Baseline					
Rest	883	4.22	150.79	40.01	23.27
Vanilla	306	5.50	165.72	43.29	26.00
Questionnaires					
RRS_{total}	1150	22	83	41.66	12.60
Man	197	22	76	38.81	12.04

	N	Min	Max	Mean	SD
Women	953	22	83	42.25	12.63
Brooding	1150	5	20	9.84	3.4
Man	197	5	20	9.07	3.24
Women	953	5	20	10.00	3.45
Reflection	1150	5	20	9.17	3.28
Man	197	5	18	8.59	3.08
Women	953	5	20	9.29	3.31
BDI-II	344	0	26	5.38	5.24
Man	67	0	25	4.81	5.00
Women	277	0	26	5.52	5.30
$MASQ_{depression}$	218	11	49	27.63	8.38
Man	0				
Women	218	11	49	27.63	8.38
$DASS_{depression}$	479	0	19	4.08	3.80
Man	64	0	17	4.27	3.96
Women	395	0	19	4.05	3.77
$Depression_{standardized}$	1021	-1.99	3.94	0	1

Table 1. Descriptive Statistics for the demographic information, physiological variables, and questionnaire scores.

Note. Abbreviation: RMSSD = root mean square of successive differences; RRS_{total} = total score of Ruminative Response Scale; BDI = Beck Depression Inventory; $MASQ_{depression}$ = Anhedonic Depression score of the Mood and Anxiety Symptoms Questionnaire; $DASS_{depression}$ = depression subscale score of the Depression, Anxiety, and Stress Scale; $Depression_{standardized}$ = Z-scores from BDI-II, MASQ, and DASS.

Table 2. Correlation matrix between rumination and the level of depressive symptoms

	RMSSD	RMSSD	N	Power	RRS_{total}	N	Power	Brooding
RMSSD	**RMSSD**	1						
RRS_{total}	**RRS_{total}**	-.038	1094	.242	1			
Brooding	**Brooding**	-.016	1094	.083	.841**	1150	1	1
Reflection	**Reflection**	-.003	1094	.051	.771**	1150	1	.521**
BDI-II	**BDI-II**	-.004	335	.051	.341**	342	.999	.296**
$MASQ_{depression}$	**$MASQ_{depression}$**	.133	215	.993	.363**	218	.999	.256**
$DASS_{depression}$	**$DASS_{depression}$**	.022	440	.075	.591**	365	1	.548**
$Depression_{standardized}$	**$Depression_{standardized}$**	.034	990	.019	.436**	925	1	.380**

Note. The correlation coefficients between HRV with the dimension of RRS, three depression questionnaires, and $Depression_{standardized}$ are reported above. N is the sample size for the analyses for that outcome. Power = 1 - β. *p < 0.05; **p < 0.001.

HRV	B	SE	t	p	95%CI	95%CI	R^2
Model 1							
RRS_{total}	-.022	.068	-.317	.751	[-.155, .112]	[-.155, .112]	.008
Age	-.142	.281	-.503	.615	[-.693, .410]	[-.693, .410]	
Gender	-5.585	2.261	-2.470	.014	[-10.022, -1.147]	[-10.022, -1.147]	
$Depression_{standardized}$	.866	.869	.997	.319	[-.839, 2.571]	[-.839, 2.571]	

HRV	B	SE	t	p	95%CI	95%CI	R^2
Model 2							
Brooding	-.244	.278	-.880	.379	[-.789, .301]	[-.789, .301]	.011
Reflection	.400	.271	1.477	.140	[-.132, .932]	[-.132, .932]	
Age	-.152	.281	-.542	.588	[-.704, .400]	[-.704, .400]	
Gender	-5.737	2.260	-.085	.011	[-10.171, -1.302]	[-10.171, -1.302]	
$\text{Depression}_{\text{standardized}}$	.758	.849	.893	.372	[-.909, 2.424]	[-.909, 2.424]	

Table 3. Linear regressions with HRV as the dependent variable.

Table 4. Curve estimation of quadratic effect for the HRV and rumination, depression.

	Linear term	Linear term	Linear term	Linear term	Quadratic term	Quadrati
HRV	B	SE	t	p	B	SE
$\text{RRS}_{\text{total}}$	-.643	.349	-1.842	.066	.006	.004
Brooding	-1.331	1.209	-1.101	.271	.056	.054
Reflection	-2.621	1.171	-2.239	.025	.125	.055
BDI-II	-.060	.610	-.098	.922	.002	.032
$\text{MASQ}_{\text{depression}}$	-1.244	1.028	-1.210	.228	.027	.017
$\text{DASS}_{\text{depression}}$	.182	.849	.214	.830	-.003	.061
$\text{Depression}_{\text{standardized}}$	.692	.941	.735	.462	.097	.536

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`Table.docx` available at https://authorea.com/users/568090/articles/614100-resting-hrv-as-a-trait-marker-of-rumination-in-healthy-individuals-a-large-cross-sectional-analysis