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

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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 (vmHRV) provides a non-invasive, surrogate measure of vagal modulation of the heart, and higher HRV is considered an indicator of susceptibility, or ability to respond to stress. Past research has suggested a link between trait rumination and vmHRV; however, inconsistent results exist in healthy individuals. In this study, we investigated the association between the tendency to ruminate, brooding, and reflection (using the Ruminative Response Scale) with vmHRV measured at baseline in a healthy population using a large cross-sectional dataset (N = 1189, 88% female; 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 vmHRV and trait rumination (confirmed by Bayesian analysis), 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, vmHRV is not a marker of trait rumination (as measured by the Ruminative Response Scale).

Keywords: Heart rate variability; Rumination; Trait marker; Depression; Electrocardiogram

Introduction

Human consciousness flows continuously and spontaneously from one thought to the next. Sometimes thinking evolves into an endless stream of repetitive, self-referential, and 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, the core neurophysiological mechanisms underlying the 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 nervous systems (SNS, PNS), 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; Malik M, 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). HRV provides a non-invasive, surrogate measure of vagal modulation of the heart, and higher vagally-mediated HRV (vmHRV) reflects better PNS contribution to this stress regulation (Friedman, 2007; Grol & De Raedt, 2020; Nasso et al., 2019, 2020; Pulopulos et al., 2018, Von Borell et al., 2007). Higher vmHRV might also be 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. The Neurovisceral Integration Model of Thayer proposed 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). This model proposes that vmHRV is a read-out of the bi-directional interaction between central and cardiovascular processes, with higher vmHRV denoting more self-regulation and adaptability (Thayer et al., 2009).

Even though the association between rumination and vmHRV 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 vmHRV 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 vmHRV 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, which share a commonality and are highly intercorrelated (Brosschot et al., 2006b; Fresco et al., 2002), was associated with lower vmHRV in healthy volunteers only on state measures (Ottaviani et al., 2016). However, in contrast to the inverse association between stress-induced vmHRV and rumination response, questions remain regarding the association between vmHRV 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 by Ottaviani et al. (2016) reported that there was no association between vmHRV and the trait measure of perseverative cognition; however, the number of correlational studies testing this association is limited. Therefore, the relationship between vmHRV and trait rumination in healthy individuals remains unclear, as many studies focus on clinical populations or the vmHRV in response to induced rumination (i.e., a momentary, reactive state). Even though vmHRV 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 vmHRV and trait rumination based on a large-scale 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 vmHRV (measured during a baseline period) and the habitual tendency to ruminate (measured using the Ruminative Response Scale) in healthy individuals. We hypothesize that vmHRV will be negatively correlated with trait rumination as both high trait rumination and low vmHRV are risk factors for stress-related psychopathology (Key et al., 2008; Larsen & Christenfeld, 2009). In addition, we will investigate whether vmHRV is associated with the tendency to ruminate after controlling for gender, age, and the level of depressive symptoms, which are known to significantly influence vmHRV (Laborde et al., 2017). Moreover, a study has indicated that parasympathetic regulation of the heart through the vagus nerve might not have a strictly linear relationship with emotion (Kogan et al., 2013), so we also explore whether there is a quadratic relationship between vmHRV and emotion in our large cross-sectional dataset.

Method

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 participants took part in 14 experiments in our laboratory (Allaert et al., 2021, 2022; De Smet et al., 2021; De Wandel et al., 2023; Pulopulos et al., 2020; Pulopulos et al., 2020). The specific information about each experiment is presented in the supplementary material (See s*upplementary table 1*). Although there were differences in the inclusion criteria from study to study, all studies excluded participants with cardiovascular disease and psychiatric disorders. Before each participation, the participants were asked not to eat, drink (except water), or smoke at least 1 hour before the study. 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 are .92, .78, and .75 for the RRS total scale, and the brooding and reflection subscales, respectively (Schoofs et al., 2010). RRS was assessed in 1150 participants.

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 ($Depression_{Standardized}$).

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 good 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). The BDI-II was completed by 288 participants.

Mood and Anxiety Symptoms Questionnaire. The MASQ is one of the commonly used 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 ranged from .93 to .95 (Wardenaar et al., 2010). The MASQ was completed by 218 participants.

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). The DASS was completed by 459 participants.

Physiological assessment of HRV

Data were acquired using two different kinds of devices: 11 out of the 14 studies used BiopacMP150/160 (Biopac Systems Inc., California, USA), and 3 studies used Polar (Polar V800 H7 & H10, Kempele, Finland), at a sampling frequency of 1000 Hz for all devices. For

Biopac, three Ag/AgCL electrodes were used for the configuration of Lead II ECG, in which two electrodes were attached under the left and right clavicle, respectively, and one reference electrode was attached under the abdomen. For Polar, a chest strap was placed just below the participant's chest muscles. 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, also see the table 1 for more information). Data collection was performed in a controlled environment. All data included baseline measurement for 5 or 10 minutes to calculate HRV. For the data that 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

For the data from Biopac, PhysioDataToolbox (Version 0.6.3), a MATLAB-based (MATLAB 2020b Component Runtime (v9.9)) application, was used to pre-process data (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 the 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 successive differences between normal heartbeats (RMSSD) to assess vmHRV in time domains and High-frequency power in frequency domains for the baseline epoch. 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 polar data were used directly from three studies from our lab (Pulopulos et al., 2020a; Pulopulos et al., 2020b; One study not published).

Data analysis

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

Pearson correlation was used to calculate the correlation coefficient between vmHRV, questionnaire scores, and age. 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 analysis were conducted with vmHRV as the dependent variable. In model 1, we included RRS_{total} as the independent variable and age, gender, and $Depression_{standardized}$ as control variables. Given the high correlation between brooding and reflection, these variables were included in independent models. In model 2, we included brooding with the control variables (age, gender, and $Depression_{standardized}$). In model 3, we included reflection with the control variables (age, gender, and $Depression_{standardized}$). To investigate the possibility of a non-linear relationship between vmHRV and rumination, as suggested by prior research, we employed a quadratic term by squaring the questionnaire scores. In the non-linear regression analysis, the first layer incorporated a linear term for each variable, while the second layer included a quadratic term. Additionally, the age, gender, and $Depression_{standardized}$, were added in the third layer to account for potentially confounding variables. One independent variable was included for each estimation. Using one-way ANOVA, we investigated the effect of gender (male vs. female) and baseline (resting vs. vanilla) on vmHRV.

In supplementary material, we reported the results divided by gender. The statistical conclusions were the same when the analysis was performed in males and females separately. Importantly, gender was not a significant moderator in any of the associations investigated (results not shown). In addition, to exclude the influence of additional control variables on the linear regression model, we conducted the hierarchical linear regression model in the supplementary materials, including different control variables as much as possible with their contributions to the model.

Results

Sample characteristics

Table 1 reports descriptive statistics for the vmHRV indices, the subdimensions of the RRS, the three depression questionnaires, and the $Depression_{standardized}$. 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 analysis

As shown in Table 2, RMSSD was not significantly correlated with RRS_{total}, brooding, reflection, BDI-II, $MASQ_{depression}$, or $DASS_{depression}$, nor with $Depression_{standardized}$. No significant correlation between HF and RRS_{total}, brooding, or reflection was found either. 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 statistical conclusions were similar when the analysis was performed for males and females separately (See *supplementary materials*). The analysis with gender as the grouping variable found that the RMSSD was lower in females than in males (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 females than in males, 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). Gender 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 RMSSD between the types of physiological baseline measurement (t (1187) = -2.060, p = .040), showing lower RMSSD during the resting baseline than during the Vanilla baseline. But there was no difference in HF between the types of physiological baseline measurement (t (962) = -2.060, p = .109). The exclusion of data from the polar did not affect the results.

Table 2 places here, please.

Regression analysis

None of the linear predictive models for vmHRV (RMSSD and HF) with RRS_{total}, brooding, and reflection with covariates (age, gender, and $Depression_{standardized}$) were statistically significant (see Table 3, also see supplementary materials for the analysis divided by gender).

Table 3 places here, please.

Based on the frequentists approach showing non-significant regard to vmHRV, rumination, and depression, which thereby failed to reject the null hypothesis, Bayesian factor analysis (using JASP 0.16.3) was 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; van de et al., 2021). The H1 is that vmHRV 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 RMSSD 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. There was no correlation between HF and RRS_{total} (BF_{10} = 0.150), Brooding (BF_{10} = 0.087), and reflection (BF_{10} = 0.083) either.

Table 4 places here, please.

We also investigated the quadratic association between vmHRV and rumination. Results of the analysis controlling for age, gender, and depression are reported in Table 4. None of the associations between vmHRV (RMSSD and HF) and rumination, brooding, or reflection were statistically significant after controlling for covariates (all $p > 0.05$). See supplementary materials for the analysis divided by gender.

Discussion

In this study, we aimed to explore whether vmHRV at baseline (measured via RMSSD and HF) 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 vmHRV at baseline and trait rumination.

Reduced vmHRV 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 vmHRV 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 females (55 recovered from depression and 56 healthy controls) found a significant relation between brooding, a maladaptive form of rumination, and vmHRV, such that females reporting higher levels of brooding exhibited lower levels of vmHRV (Woody et al., 2014). Another study monitored vmHRV 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 vmHRV (Brosschot et al., 2007). In line with these results, the seminal Neurovisceral Integration Model proposed 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 vmHRV; Thayer & Lane, 2009). As a result, these neural and autonomic regulations result in less viscous cycles of ruminative thoughts and, in turn, higher vmHRV (Song et al., 2022). However, in the current study, this association between the tendency to ruminate and vmHRV measured at rest cannot be observed in healthy individuals, even after controlling for gender, age, and the level of depressive symptoms. Moreover, Bayesian analysis showed a higher likelihood of no association. Finally, our results excluded a non-linear relationship between vmHRV with trait 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 vmHRV on positive emotion and depression (Silvia et al., 2014).

A meta-analysis investigating the relationship between physiological concomitants with perseverative cognition found that maladaptive thought processes (including rumination and worry) were associated with decreased vmHRV in seven 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 vmHRV 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 vmHRV and emotion regulation, as measured by the difficulties in emotion regulation scale, in 198 undergraduate students (Williams et al., 2015). Only the two studies described in the previous paragraph specifically focused on trait rumination, worry, and vmHRV and reported significant negative associations (Brosschot et al., 2007; Woody et al., 2014). The remaining two studies were all related to instantaneous changes in vmHRV or state rumination and worry showing significant results (Gazelle & Druhen, 2009; Fox et al., 2018). Thus, the current evidence is mixed, and the number of existing studies to test this association is limited. In addition, although there is an overlap between rumination and worry, there is still distinguishing characteristic between them (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 vmHRV in healthy individuals.

Some characteristics of our study can, at least in part, explain the null association between vmHRV 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 vmHRV 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 (Wesarg et al., 2022) recently showed, childhood adversity had no significant overall association with vmHRV; however, vmHRV was associated with childhood adversity in samples in which part of the participants was diagnosed with a psychiatric disorder. Along this line, since RRS assesses depression-related repetitive negative thinking, it is possible that its association with vmHRV is stronger in patients with depressive disorder. These might provide an explanation for the no significant association between trait rumination and vmHRV in the current large sample of healthy individuals. Also, vmHRV 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 vmHRV under experimental induction paradigms rather than in a resting phase (Ottaviani et al., 2016). In sum, based on our findings, vmHRV at baseline 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 vmHRV and rumination, associations between other variables are in line with the literature. The results of our large-scale cross-sectional dataset show that the vmHRV of males was slightly higher than that of females

(Hamidovic et al., 2020). Furthermore, gender 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 colouring). Importantly, our results show that different baseline types influenced vmHRV, denoting that the vmHRV 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 gender ratio in this study is not balanced and that gender itself affects vmHRV, which may impede the broad applicability of our results. Numerous internal and external factors can significantly impact vmHRV, including body mass index, caffeine and alcohol consumption, smoking, sleep patterns, exercise habits, and so on. Unfortunately, we did not assess all the variables in all the studies included in this dataset, and we could only ask participants not to eat, drink (except water), or smoke for one hour before the experiment. Although the analysis including some potential confounders (BMI, regular menstrual cycle, use of hormonal contraceptives, smoking, alcohol, and caffeine consumption, physical exercise, self-perception of mental and physical health, and sleep quality) with subsamples of our dataset suggests that

they do not affect the null association between vmHRV and rumination (Analysis reported in Supplementary material), future research is needed to investigate the influence of these variables in the vmHRV-rumination link. In addition, the measurement of trait rumination and vmHRV was inconsistent in time and space. The trait rumination questionnaire was generally completed online (before the experiment), while vmHRV 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 who 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 vmHRV at baseline and trait rumination in healthy individuals. The results indicate that there is no association between vmHRV 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, vmHRV at baseline could not be regarded as a marker of trait rumination in healthy individuals.

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Data availability statement

To acquire access to the data from Open Science Framework (OSF), see https://osf.io/423fv/.

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