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The interplay of self-critical rumination and resting heart rate variability on subjective well-being and somatic symptom distress: A prospective study

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ABSTRACT

Objective: The aim of this prospective study was to investigate the association of self-critical rumination, autonomic function (indexed by a time domain metric of resting heart rate variability-RMSSD), subjective well-being and somatic symptom distress.

Method: 84 healthy participants (73 females; mean age = 23.56, SD = 3.35 years) completed the Somatic Symptom Severity Scale of the Patient Health Questionnaire and Mental Health Continuum Short Form at two timepoints (at baseline and six months later). Resting heart rate variability (HRV) was assessed at baseline, along with content specific rumination using the Self-Critical Rumination Scale. Four moderation analyses were performed to test these associations.

Results: The interaction between resting HRV and self-critical rumination significantly explained somatic symptom distress at baseline. For those participants who had high resting HRV, somatic symptom distress was basically independent from the level of self-critical rumination. At the same time, lower resting HRV was associated with higher somatic symptom distress, especially in the presence of more ruminative thoughts. Prospectively, however, the interaction between rumination and resting HRV was not a significant predictor of somatic symptom distress. The association between resting HRV and self-critical rumination did not explain the variance on subjective well-being, but subjective well-being was negatively related to self-critical rumination.

Conclusion: Our findings potentially indicate that self-critical rumination could have a long-term negative impact on psychological functioning, even in a non-clinical sample, and highlight that a lower level of parasympathetic activation, assessed with RMSSD, might be an important factor in the relationship of self-critical rumination and somatic symptom distress.

1. Introduction

Self-criticism, conceptualized as constant negative self-evaluation with belittling, cynical or judging thoughts towards oneself in the context of failures, disappointments or unattended goals [1,2], is a well-known risk factor for several mental health difficulties and for somatic symptom distress [3–8]. A number of studies support the idea that rumination could be one of the processes by which self-critical thoughts are triggered and/or maintained, and the interplay between rumination and self-criticism could also be associated with mental health [9]. For example, ruminative brooding (and perfectionism) mediated the relationship between internalized self-criticism and depressive mood [10] and major depressive episodes across two and a half years [11].

It is worth noting that beyond psychopathologies rumination was also associated with several somatic problems, such as functional dyspepsia [12], fibromyalgia [13,14] or migraine [15]. Moreover, rumination was also associated with subjective health complaints [16,17]. In a longitudinal study rumination significantly predicted self-reported somatic symptoms of young (20–34 years old) adults across one year [18].

Although these results mainly refer to depressive rumination (or simply to the process and frequency of rumination, independently of the content), there are a handful of studies which highlight the relevance and incremental validity of content-specific, self-critical rumination.

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Unlike depressive rumination (where one's attention is directed towards the symptoms of depression [19]), in self-critical rumination the individual is focusing on his/her lack of self-worth, or those aspects of the self of which he/she is ashamed of [2]. Moreira and Canavarro [20] found a significant positive association between self-critical rumination and parenting stress, and a negative association with mindful parenting dimensions [20]. In the study of Kolubinski et al. [9], state self-critical rumination was accompanied by acute distress, and trait self-critical rumination showed negative relationship with self-esteem, and positive association with negative metacognitive beliefs [9]. These findings may support the idea that self-critical rumination has a detrimental effect on mental and somatic health, but more empirical evidence is needed to support this hypothesis, since the opposite direction is equally possible.

Moreover, only little emphasis was placed on the aspects of well-being, despite that positive mental health is not equal to the lack of psychopathology [21]. According to the theoretical framework of Keyes [22], mental health could be conceptualized as subjective well-being, which includes social, emotional, and psychological dimensions as well. While social well-being refers to the individual's perceptions of his or her integration into society, emotional well-being consists of both positive affective components (e.g. happiness) and cognitive aspects (e.g. satisfaction with life). Psychological well-being includes dimensions of psychological functioning such as autonomy, purpose in life, self-acceptance or personal growth [22]. The different facets of well-being are known to be negatively associated with rumination [23] and self-criticism [24], but there is a scarcity of evidence regarding self-critical rumination.

In the past decades, a growing number of studies investigated the potential physiological concomitants of emotion (mis)regulation, with a special focus on the cardiovascular correlates of state and trait rumination [25–27]. Resting heart rate variability (HRV) is one of those concomitants, reflecting the magnitude of oscillation in the time interval between adjacent heartbeats (cardiac interbeat intervals or IBIs), partially mirroring vagal activity [28–30]. HRV was identified as a potential biomarker of health and top-down self-regulation, based on the statements of two prominent theories: the Polyvagal Perspective [31] and the Neurovisceral Integration Model [32]. These perspectives emphasize the importance of the brain-heart connection, highlighting that cardiac activity is influenced by prefrontal cortical substrates of top-down regulation, mainly through the parasympathetic nervous system [33]. Although some researchers did not find significant associations between HRV and self-regulation [34], several studies observed reduced HRV in connection with a wide range of mental and somatic problems and emotion- or self-regulation deficits [35–37]. These studies often differ in the metrics by which they quantify HRV: using indices as respiratory sinus arrhythmia (RSA), high frequency HRV (HF-HRV), or root mean square of successive differences (RMSSD). Since these metrics (especially HF-HRV and RMSSD) are highly correlated, they are almost used interchangeably in psychological research [30].

Although HRV is often considered a state phenomenon which it is not temporally stable, there are previous results which suggest a longitudinal association between rumination and HRV. Stange et al. [38] found that parasympathetic inflexibility (lack of reduction in respiratory sinus arrhythmia during a sad film clip) predicted significantly higher depressive symptoms among individuals with greater levels of rumination/worry, but not among individuals with lower level of rumination/worry, across a 12-week time span [38]. In addition, Carnevali et al. [25] found that resting HRV measured at follow up, was an important mediator of the association of trait rumination (measured at baseline) and depressive symptoms in a non-clinical setting over almost three years [25].

Regardless of the exact metric, reduced HRV was often found in experiments, when rumination or worry were artificially induced [39–41], and resting HRV was negatively associated with trait rumination [42,43] and trait worry as well [44]. In addition, the naturally occurring, momentarily assessed intrusive, ruminative or worrying thoughts were accompanied by low resting HRV [45] and HRV reductions [46]. However, it is worth noting that results of HRV and rumination/worry or emotion regulation are equivocal. In some studies, lower tonic HRV (e.g. HF-HRV) was not detected among individuals with more emotion regulation difficulties at baseline [47]; trait rumination was not associated with changes in RSA levels [48], and worriers did not differ from non-worriers in terms of autonomic rigidity [49,50].

Overall, HRV seems to be an integrative measure of mental and somatic health-related information. For instance, reduced resting HRV was related to metabolic syndrome [51], cardiovascular disease risk and mortality [52], functional somatic symptoms among children and adolescents [53], and self-reported subjective health. Indeed, Jarczok et al. [54] found that vagally-mediated HRV was more strongly associated with self-reported health than any other tested biomarker (i.e.: blood pressure, glycemic status, inflammation etc.) [54].

To sum up, previous studies found that lower resting HRV was associated with higher levels of stress, certain somatic diseases, and trait rumination, while higher resting HRV was linked to long-term well-being [27,55], and higher HRV reactivity was connected to successful emotion regulation [56]. In addition, the results of Fantini-Hauwel et al. [57] indicated a potential buffering effect of HRV on depressive symptoms. They found that resting HRV (measured by lnRMSSD) moderated the relationship between emotion regulation (ER) difficulties and depressive symptoms. When the level of HRV was high, emotion regulation difficulties were not related to depressive symptom scores, but at a low HRV level, emotion regulation difficulties were associated with more depression symptoms [57]. These findings and those studies that found longitudinal associations between HRV/rumination and somatic symptoms [18,54] provides the rationale for our research.

To investigate these associations, we conducted a prospective study. We expected that higher resting HRV, which could be defined as a surrogate parameter of the interaction between the brain and cardiovascular system [58], was associated with more ruminative cognitions [45], lower subjective well-being and higher somatic symptom distress. We hypothesized: 1.) a negative (cross-sectional) association between the interplay of trait self-critical rumination and cardiovascular activity (indexed by time domain metrics of HRV) and subjective well-being, conceptualized as emotional, psychological and social well-being, 2.) that self-critical rumination and resting HRV explains somatic symptom distress among healthy adults cross-sectionally, 3.) that self-critical rumination and resting HRV had long-term negative effect on subjective well-being and 4.) that the interaction of resting HRV and self-critical rumination showed a negative prospective association between resting HRV and somatic symptom distress.

2. Method

2.1. Sample and participants

Undergraduate university students were enrolled to this prospective study. Participants were compensated with extra course credits for taking part in the study. Out of the 103 volunteers 10 did not complete the follow-up questionnaires, and 9 participants were excluded from the further analysis due to poor data quality on resting HRV measures (due to excessive movement), physical exercise, smoking or caffeine consumption 6 h prior to resting HRV registration. In addition, general exclusion criteria were psychotropic or cardiovascular drug use (i.e. beta blockers) and chronic conditions (e.g. hypertension). Excluded participants did not differ from those who were included in the analysis in terms of age, body mass index (BMI), subjective well-being or self-critical rumination. The final sample comprised 84 participants (73 females [87%], mean age = 23.56, SD = 3.35). The study was ethically approved by the Institution Review Board of ELTE Eötvös Loránd University (Budapest, Hungary), and the work was conducted in full compliance with the principles of the Declaration of Helsinki.

2.2. Procedure

The study consisted of two stages: a laboratory session at baseline and a follow-up stage six months later. The procedure of the laboratory session (including HRV measurement) was similar to our previous research reported elsewhere [45].

At baseline upon arrival at the laboratory, participants read and signed an informed consent form, and were asked to fill out a short questionnaire regarding basic demographic information (e.g. age, sex) and physical status (e.g. whether they were taking any medication, weight, height, physical fitness, tiredness etc.). Every participant was previously asked by e-mail to refrain from smoking, consuming alcohol and caffeine, and strenuous training 6 h prior to the appointment.

After that, participants were placed in a quiet experimental room in small groups (2–4 persons), where plastic chest belts were attached to them. All participants completed a 7-min baseline resting period in a supine position, with closed eyes and spontaneous breathing. They were explicitly asked to try to relax and not move or fall asleep.

Following the registration of cardiac activity, participants were asked to fill out a few trait and state questionnaires including measurements for self-critical rumination and physical/mental health. The duration of the session was 60 min.

Six months later, participants were asked to come back to the laboratory and to complete self-reported questionnaires regarding their subjective and somatic well-being. In order to maximize compliance, we did not gather HRV data again. After participants gave their consent, they filled out the questionnaires on-line in the computer lab which took approximately 20 min.

Participation in the whole study was voluntary and anonymous. To connect data at baseline to six months later as well as self-reported and HRV data, participants were instructed to use an individually chosen code.

2.3. Measurements

2.3.1. Cardiac measures

Heart rate (HR) data was recorded at a 1024 Hz sampling rate via a mobile heart rate monitoring device, the FirstBeat TeamBelt (from the FirstBeat Sports Team Pack, FirstBeat Technologies Ltd., Jyvaskyla, Finland). These chest belts (with two built in electrodes) were placed on the ribcage of participants, below the musculus pectoralis major, and resting HR was assessed during a 7-min baseline period (with spontaneous breathing and supine resting position). The reliability of this device [59], similarly to other mobile tools (such as Suunto and Polar) was supported by previous studies [60–62]. Raw data was recorded, and inter-beat-intervals (IBIs) were identified by FirstBeat Sports software using the last 5-min of the recordings. The first two minutes of the 7-min measuring were considered as adaptation period therefore it were not analyzed. HRV indices (derived from IBIs) were calculated by Kubios 2.0 software. Automatic outlier correction was carried out by the FirstBeat software using linear interpolation (but no artifacts were deleted or cut from the recordings during the correction) (for details see [63,64]).

HRV was measured by computing the root mean square of successive beat-to-beat interval differences (RMSSD in ms). This metric is considered as a reliable time domain measurement of HRV [28,65], especially during resting conditions, showing high trait specificity [66]. Since in the present study, the frequency domain measurement, the high-frequency band power (in ms^2) and RMSSD showed high correlation ($r = 0.94$), we only used the latter in the analyses. RMSSD values were natural (ln) log transformed in order to approximate normal distribution. In addition, mean heart rate (HR in bpm) and mean IBI (in ms) were calculated.

2.3.2. Questionnaires

Self-Critical Rumination Scale (SCRS) [2]. To assess a content specific form of rumination, the SCRS was used at baseline. This one-factor, self-reported questionnaire, which consists of 10 items, was designed to measure those thoughts that constantly criticize the self for failures, mistakes or bad habits in a repetitive manner. Participants were asked to rate the statements (i.e. *"Sometimes, it is hard for me to shut off critical thoughts about myself."; "I spend a lot of time thinking about how ashamed I am of some of my personal habits."*) on a 4-point Likert scale from 1 (*not at all*) to 4 (*very much*), where higher scores indicate more self-critical ruminative thoughts. The sum of the scores were calculated and used in the analysis. With the permission of the authors (Laura M. Smart) the questionnaire was translated from English to Hungarian by two independent translators and the back-translated version was approved by Smart. Both the original (Cronbach $\alpha = 0.92$) and the Hungarian version (Cronbach $\alpha = 0.90$) [67] showed high internal consistency. In the present sample, Cronbach α was also 0.90.

Patient Health Questionnaire Somatic Symptom Severity Scale (PHQ-15) [68]. The PHQ-15 (derived from the full PHQ) was used to measure self-reported somatic symptom distress, both at baseline and six months later. This one-factor, 15-item instrument assesses several somatic complaints, such as headache, joint or limb pain, fatigue or back pain which are also prevalent in DSM somatization disorders (however, this instrument cannot differentiate between medically explained and unexplained symptoms, therefore it is not considered as a diagnostic tool of somatic symptom disorders). Although it was developed to measure somatization among clinical populations, it is a widely used screening questionnaire among college students as well [69–72]. Participants were asked to rate how often they were bothered by any of the symptoms over the last four weeks from 0 (*not bothered at all*) to 2 (*bothered a lot*). The sum of the scores were calculated and used in the analysis, where higher scores indicated more distress about the symptoms. In line with previous studies [68,73] using PHQ-15, missing data for males (i.e. the menstrual pain item) were imputed with the mean of the remaining items. The internal consistency of the original questionnaire (Cronbach $\alpha = 0.90$) and the Hungarian adaptation [74,75] was good. In the present sample, Cronbach α's were ranging from 0.93 to 0.68 in Study 1 and 2, respectively. We will use the abbreviation PHQ-15 to indicate somatic symptom distress scores at baseline, and PHQ_2–15 to refer to the somatic symptom distress scores measured six months later.

Mental Health Continuum Short Form (MHC-SF) [22]. The 14-item MHC-SF was used to measure the emotional (3 items), psychological (6 items), and social (5 items) aspects of well-being at baseline and six months later. Respondents had to rate the frequency of each feeling (e.g. *"in the last month, how often did you feel happy?"*) in the last month on a 6-point Likert scale from 0 (*never*) to 5(*every day*). The total scores and the sum of the scores belonging to each subscale were calculated and used in the analyses. The reliability of the original scale and the Hungarian adaptation ($\omega = 0.91$) [76] proved to be good. In the present work, we will use the abbreviation MHC-SF to indicate subjective well-being of baseline and MHC_2-SF when referring to well-being of six months after baseline. Both at baseline (Cronbach $\alpha = 0.89$) and six months later (Cronbach $\alpha = 0.92$) the internal consistency of the scale was good.

Besides these dispositional questionnaires we gathered data about the participants' age and gender. Since body mass index (BMI) was associated with autonomous nervous system activity, measured by HRV in non-obese, healthy individuals (especially in short term (5-min) recordings) [77], we also registered self-reported weight and height data, from what BMI was calculated. In addition, we measured self-reported physical fitness, where participants had to rate their fitness status on a 5-point Likert scale from 1(*poor*) to 5(*excellent*).

2.4. Statistical analysis

All statistical tests and data visualization were conducted using SPSS software (version 25). Descriptive analyses were carried out (bivariate correlation and Wilcoxon signed ranks test) in SPSS and moderation analyses (and figures) were performed using the PROCESS macro of Hayes (Model 1, version 3.5.2) [78].

First, we investigated the associations between variables using Kendall's tau correlation due to the violation of normality for a number of variables. Furthermore, using Wilcoxon signed ranks test, we examined whether any differences exist in self-reported somatic symptom distress and subjective well-being, measured at baseline and six months later.

Second, we ran four moderation analyses. In Model I, we aimed to investigate the cross-sectional (baseline) association between self-critical rumination (SCRS) and subjective well-being (MHC-SF) (controlling for the effects of age, gender, and BMI), and we tested the interaction effect of SCRS and lnRMSSD on MHC-SF. In other words, SCRS, the interaction term of SCRS x lnRMSSD and the demographic variables were entered as predictors, and MHC-SF was the criterion variable. In Model II, we tested whether SCRS, lnRMSSD, and their interaction could have any long-term impact (six months after baseline) on subjective well-being (as indexed by MHC_2-SF) after controlling for MHC-SF at baseline, age, gender and BMI.

In Model III and Model IV, the same predictors and interactions were tested on PHQ-15 and PHQ_2–15, respectively. In both prospective models (Model II and IV), we controlled for the effect of somatic symptom distress (PHQ-15) and subjective well-being (MHC-SF), measured at baseline as well.

In every moderation model, continuous variables were mean centered. All analyses were two-tailed, the level of significance was set to $p < 0.05$ and the confidence interval was 95%.

3. Results

Descriptive analyses were performed, and gender and time course differences were tested (see Table 1). The mean heart rate was in the normal range (~74/min), as well as the mean RMSSD (45.2) and BMI (21.6). Comparing scores we found that participants had more somatic symptoms at baseline than six months later ($Z = 3.40$; $p < 0.001$), but their subjective well-being scores did not differ between timepoints ($Z = 0.13$; $p = 0.89$).

As expected, self-critical rumination showed significant positive association with somatic symptom distress and negative association with MHC-SF scores (and every subscale) both at baseline and six months later, but these variables did not correlate with resting HR or lnRMSSD (Table 2).

We hypothesized that the relationship or interaction between SCRS and lnRMSSD would significantly explain the variance of MHC-SF and MHC_2-SF. These interactions were tested in two models using the PROCESS macro.

Despite our expectations, the interaction between SCRS and lnRMSSD was not a significant predictor of MHC-SF, neither at baseline nor six months later (see Table 3 for details). Apart from the non-significant interplay between the variables, SCRS still was a significant predictor of subjective well-being, but only cross-sectionally. It is not surprising that in Model II, MHC-SF (at baseline) explained most of the variance, since the correlation between these variables was high ($r = 0.79$). When we removed MHC-SF from Model II, SCRS was a significant predictor ($p < 0.001$).

At the same time, the results of Model III (Table 4) supported our hypothesis, since SCRS x lnRMSSD was a significant predictor of PHQ-15, even after controlling for the effects of age, gender, and BMI (the explained variance was 16%). Fig. 1 also illustrates that this interaction could have the biggest effect on somatic symptom distress when the level of self-critical rumination is high and the lnRMSSD is low. The slopes of lnRMSSD significantly differed from 0 ($p < 0.05$).

The findings of the fourth model showed that although SCRS had a significant relationship with somatic symptom distress six months later (adjusting for the effects of age, gender, BMI and PHQ-15 at baseline), the interaction of SCRS and lnRMSSD did not remain significant (see Table 4 for details). These results indicate that lnRMSSD did not have long-term effect on somatic symptom distress, but we could assume a prospective positive association between SCRS and PHQ_2–15 (Fig. 2).

We should note here that there is a debate in the literature about the relationship of HRV and HR. Sacha [79] indicated that under resting conditions, heart rate is also strongly determined by vagal activity and it is often difficult to conclude what is the heart rate contribution to the prognostic power of HRV [79]. To control for its effect, we made a post-hoc moderation analysis. However, we followed the recommendations of de Geus et al. [28] and we included the mean IBI (or heart period in ms) instead of HR in the statistical model, to avoid mixing units of measurements (since RMSSD is expressed in ms, while heart rate is expressed in minutes). As Geus et al. pointed out, once we use intervals (in ms) versus rates (in bpm) the negative nonlinear relationship between HRV and HR predictably turns into a positive, more linear one. During the post-hoc analysis, we found that the interaction of lnRMSSD and trait self-critical rumination (SCRS) was a significant predictor of PHQ-15 scores ($B = -0.466$; $t = 2.08$; $p = 0.04$) after controlling for the effects of age, sex and mean IBI. We also controlled for the effect of heart period in Model I and II, but the interaction between SCRS and lnRMSSD was not a significant predictor of MHC-SF, neither at baseline ($B = 0.39$; $t = 1.22$; $p = 0.23$) nor six months later ($B = -0.02$; $t = 0.07$; $p = 0.95$).

4. Discussion

In our exploratory study, we investigated the complex association between self-critical rumination, resting HRV, subjective well-being and somatic symptom distress in a non-clinical sample, both cross-sectionally and prospectively. Our results show that the interaction between resting HRV (indexed by lnRMSSD) and self-critical rumination significantly explained somatic symptom distress at baseline. These novel results might indicate that a higher parasympathetic activation (indexed by higher HRV) [80] is associated with less somatic symptom distress, especially for those participants who reported an elevated tendency of rumination about self-critical content. Prospectively, the interaction between rumination and resting HRV (lnRMSSD) was not a significant predictor of somatic symptoms, but a positive association was still detected between self-critical rumination and somatic symptom distress. Contrary to our hypotheses, the association between resting HRV and self-critical rumination did not explain the variance on subjective well-being, neither at baseline nor six months later, but again, subjective well-being was negatively related to self-critical rumination.

The associations between rumination and somatic symptoms, that are well-documented in the literature across clinical and non-clinical (medically healthy) samples as well, could be manifested by two pathways [13,81–83].

The first identified pathway states that state and trait rumination (or

Table 1
Mean, median and standard deviations of demographic and psychophysiological factors.

	Mean	SD	Median
Age	23.6	3.35	23.0
BMI	21.6	4.24	21.0
physical fitness	2.8	0.89	3.0
RMSSD(ms)	45.2	25.16	39.8
Mean IBI(ms)	822.9	100.02	816.6
Mean HR(bpm)	74.3	8.99	73.6
SCRS	22.2	7.22	20.5
PHQ-15 total	11.3	7.77	8.0
PHQ_2–15 total	7.1	3.64	7.0
MHC-SF	42.8	11.01	44.0
MHC_2-SF	43.1	11.61	45.0

Note. $N = 84$ (11 males, 73 females); BMI = body mass index; RMSSD = root mean square of successive differences; IBI = inter-beat-interval; ms = milliseconds; HR = heart rate; bpm = beats per minute; SCRS=Self-Critical Rumination Scale; PHQ-15 = Patient Health Questionnaire; MHC-SF = Mental Health Continuum Short Form; 2 in subscript indicates six months after baseline; $^*p < 0.05$.

Table 2
Correlation matrix between cardiac measures, demographic variables, self-critical rumination, well-being and somatic symptom distress at baseline and six months later.

	1	2	3	4	5	6	7	8	9	10
1.Age										
2.BMI	0.06									
3.fitness	−0.15	−0.05								
4.lnRMSSD	−0.07	0.07	0.07							
5.Mean IBI	−0.01	0.19*	0.13	0.49**						
6.Mean HR	−0.02	−0.19*	−0.13	−0.48**	−0.99**					
7.SCRS (α = 0.90)	−0.05	0.06	−0.16	−0.06	−0.03	0.02				
8.PHQ-15 (α = 0.93)	−0.21**	0.01	−0.07	0.03	0.04	−0.04	0.17*			
9.PHQ_2–15 (α = 0.68)	0.09	0.05	−0.14	0.08	0.19*	−0.20*	0.29**	0.18*		
10.MHC-SF (α = 0.89)	0.03	0.03	0.20*	0.12	0.09	−0.09	−0.23**	−0.18*	−0.20*	
11.MHC_2-SF (α = 0.92)	0.02	0.05	0.09	0.13	0.09	−0.08	−0.26**	−0.09	−0.20*	0.63**

Note. $N = 84$ (11 males, 73 females); BMI = body mass index; lnRMSSD = natural based logarithm of root mean square of successive differences; HR = heart rate; IBI = inter-beat-interval; SCRS=Self-Critical Rumination Scale; PHQ-15 = Patient Health Questionnaire; MHC-SF = Mental Health Continuum Short Form; 2 in subscript indicates six months after baseline; *$p < 0.05$; **$p < 0.001$.

Table 3
Moderator role of heart rate variability in the relationship of self-critical rumination and subjective well-being at baseline (Model I) and six months later (Model II).

Model I							
MHC-SF	B	SE	t	p	LLCI	ULCI	R^2 (p)
constant	47.85	12.74	3.76	<0.001	22.47	73.24	0.17(0.03)
SCRS	−0.50	0.16	−3.04	<0.01	−0.82	−0.17	
lnRMSSD	2.42	2.28	1.06	0.29	−2.13	6.96	
SCRSxlnRMSSD	0.41	0.32	1.28	0.20	−0.23	1.04	
gender	−1.05	3.50	−0.30	0.77	−8.03	5.93	
age	−0.40	0.46	−0.88	0.38	−1.32	0.51	
BMI	0.29	0.30	0.98	0.33	−0.30	0.88	
Model II MHC_2–15							
constant	3.56	9.63	0.37	0.71	−15.64	22.76	0.65(<0.001)
SCRS	−0.20	0.12	−1.69	0.10	−0.44	0.04	
lnRMSSD	0.17	1.59	0.11	0.91	−3.00	3.35	
SCRSxlnRMSSD	−0.02	0.22	−0.08	0.94	−0.46	0.43	
gender	1.31	2.43	0.54	0.59	−3.53	6.15	
age	−0.08	0.32	−0.25	0.80	−0.72	0.56	
BMI	0.25	0.21	1.20	0.23	−0.16	0.66	
MHC-SF(baseline)	0.78	0.08	9.69	<0.001	0.62	0.94	

Note. lnRMSSD = natural based logarithm of root mean square of successive differences; SCRS=Self-Critical Rumination Scale; MHC-SF = Mental Health Continuum Short Form; 2 in subscript indicates six months after baseline.

Table 4
Moderation analysis of self-critical rumination and resting HRV on somatic symptom distress at baseline (PHQ-15) and six months later (PHQ_2–15).

Model III							
PHQ-15	B	SE	t	p	LLCI	ULCI	R^2 (p)
constant	23.32	9.10	2.56	0.01	5.19	41.45	0.16(0.04)
SCRS	0.20	0.12	1.73	0.09	−0.03	0.43	
lnRMSSD	0.43	1.61	0.27	0.79	−2.78	3.64	
SCRSxlnRMSSD	−0.46	0.22	−2.06	0.04	−0.90	−0.02	
gender	−0.19	2.50	−0.08	0.94	−4.79	5.18	
age	−0.69	0.33	−2.01	0.04	−1.34	−0.04	
BMI	0.17	0.21	0.80	0.43	−0.25	0.59	
Model IV PHQ_2–15							
constant	−9.48	4.14	−2.29	0.03	−17.74	−1.23	0.29(<0.001)
SCRS	0.16	0.05	3.02	<0.01	0.05	0.26	
lnRMSSD	0.60	0.70	0.86	0.40	−0.80	2.01	
SCRSxlnRMSSD	−0.07	0.10	−0.66	0.51	−0.26	0.13	
gender	2.21	1.09	2.03	0.05	−0.36	4.39	
age	0.43	0.15	2.92	0.01	0.14	0.73	
BMI	0.08	0.09	0.81	0.42	−0.11	0.26	
PHQ-15(baseline)	0.06	0.05	1.23	0.22	−0.04	0.16	

Note. lnRMSSD = natural based logarithm of root mean square of successive differences; SCRS=Self-Critical Rumination Scale; PHQ-15 = Patient Health Questionnaire.; 2 in subscript indicates six months after baseline.

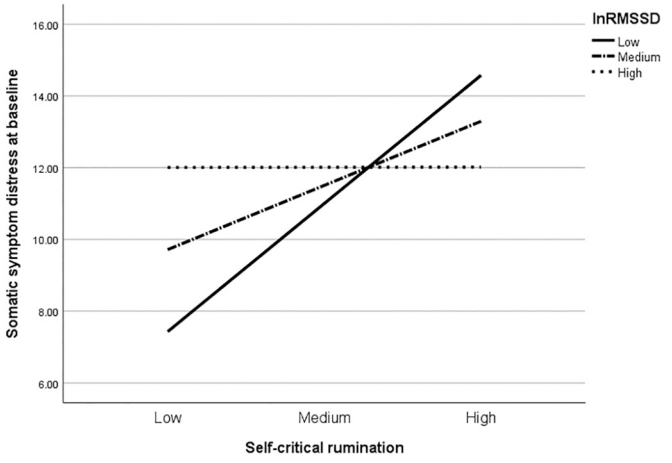

Fig. 1. Resting heart rate variability as a moderator in the relationship between self-critical rumination (SCRS) and somatic symptom distress (PHQ-15).
Note. HRV (RMSSD) categories are expressed as the mean and +/− 1 standard deviation.

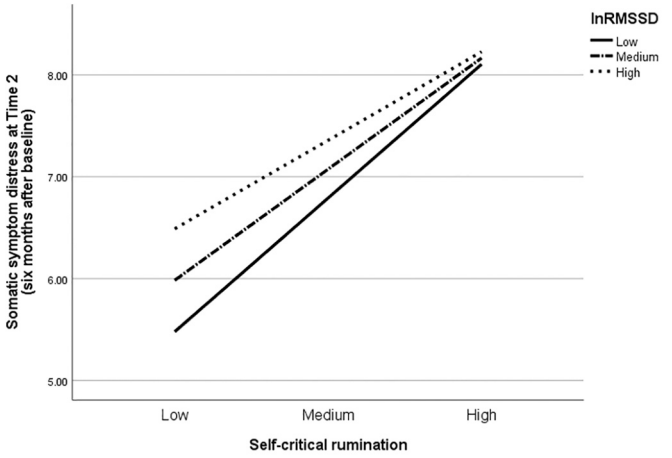

Fig. 2. The effect of self-critical rumination (SCRS) on somatic symptom distress (PHQ-15) six months later, in relation to resting HRV.
Note. HRV(RMSSD) categories are expressed as the mean and +/− 1 standard deviation.

more broadly perseverative cognition) could evoke genuine somatic distress through various physiological pathways. The rumination mediated prolonged biological stress response could have detrimental effects on ambulatory and resting blood pressure or cortisol level as well [84,85], potentially leading to high levels of somatic symptom distress or functional syndromes [86].

The second possible pathway by which rumination can exert its effect on somatic symptoms says that rumination might intensify the perception of (often harmless) bodily sensations, and magnify the influence of perceived symptoms on general health. This is a crucial factor in hypochondriasis [87] and medically unexplained symptoms [88], since this prolonged perseveration about one's illness and symptoms might cause activation and/or reactivation of specific illness-related cognitive networks [89,90]. Due to the misattribution of harmless or ambiguous signals, more and stronger illness-related memories will be consolidated, therefore symptom reporting and perceived symptom distress will be enhanced [90,91]. Also, somatic symptoms can be perceived in the very absence of bottom-up interoceptive signals, i.e., in a completely top-down fashion [92–94]. In this case, rumination might enhance patients' conscious and non-conscious expectations (aka priors), which in turn lead to the perception of symptoms.

Due to multifinality, the association between self-critical rumination and somatic symptom distress might be explained by both pathways. Although we did not measure cortisol level or blood pressure changes to directly support the perseveration cognition hypothesis, our results seemed to converge with this theory. Nevertheless, the second pathway it is plausible as well, mainly in light of previous studies on health anxiety and somatosensory amplification which highlighted the role of perception and higher interoceptive sensitivity in somatic symptom distress [72].

Although a growing number of studies investigated somatic symptoms in terms of depressive rumination (or just the process of rumination independently of the content) [95,96], only a few results indicated that *content-specific* ruminative thoughts, especially anger rumination, could have significant association with somatic, particularly cardiovascular symptoms [97]. Self-critical rumination has not been tested in the context of somatic symptoms, despite the role of self-criticism in somatic symptom severity [4]. Our results draw attention to this undertested construct, emphasizing its relationship with resting HRV.

As we have noted above, low HRV (indexed by a wide range of metrics such as RSA, HF power or RMSSD) was related to trait rumination [43,98], naturally occurring or experimentally induced state rumination [39,99], and both physical and psychological symptoms [100,101]. The association of HRV and rumination (or more broadly cognitive emotion regulation), was mainly discussed in the framework of Polyvagal Theory of Porges [31] and Neurovisceral Integration Model of Thayer and Lane [32], emphasizing the importance of the brain-heart connection. Previous studies showed that emotion regulation and HRV was associated via common brain regions [102]. For instance, higher HRV (indexed by RMSSD) was associated with higher amygdala and medial prefrontal cortex functional connectivity [103,104], and HRV was associated with cerebral blood flow in anterior midcingulate cortex and amygdala [30]. These regions (limbic regions, mPFC, vlPFC etc.) have cardinal roles in emotion regulation, and, more narrowly, in rumination [43,105].

Previous results also raised the possibility that low HRV was more strongly related to somatic than psychological symptoms. Indeed, in a study involving medically healthy, dysphoric participants, low resting HRV (indexed by the standard deviation of R-R (NN) intervals (SDNN)) was significantly associated with somatic but not cognitive-affective symptoms of depression [106].

These results provide indirect evidence that the interaction of trait rumination and resting HRV could be related to self-reported somatic symptoms as well, but until now, no study has tested it directly, particularly in the context of self-criticism. We found that for those participants who had high resting HRV, somatic symptom distress was basically independent from the level of self-critical rumination. At the same time, those individuals who had low resting HRV reported heightened somatic symptom distress, especially in the presence of more self-critical ruminative thoughts. Our findings potentially indicate that higher resting HRV, indexing a sympathovagal balance [80], might be an important factor in the relationship of self-critical rumination and somatic symptoms. Considering that high resting HRV could be an indicator of successful top-down regulation [32,33], we could assume that the presence of self-critical ruminative thoughts on its own is not equal to poor regulation, and is not necessarily connected to worse self-reported somatic health. Consequently, it is paramount to explore psychophysiological moderators. Our results might indicate that HRV could be one of these factors, so further studies need to extend their focus to measure other indices of well-functioning self−/emotion regulation along with content-specific trait rumination and HRV. For instance, the interplay or ratio of adaptive/maladaptive emotion regulation strategies (e.g. cognitive reappraisal/rumination), might be a more accurate predictor of mental and somatic well-being than trait rumination alone [107].

In our study, the association between HRV and somatic symptom distress was only detected cross-sectionally. In the absence of

prospective studies, we could not compare this result to the literature, but it is worth mentioning that six months later, significantly less somatic symptom distress was registered than at baseline, and we did not measure resting HRV at follow-up. For this reason, we could not analyse the HRV changes between timepoints. The correlational analyses, however, support the long-term effect of self-critical rumination on somatic symptom distress, somewhat in agreement with previous results [18,95].

Contrary to our expectations, the *interaction* between self-critical rumination and resting HRV was not a significant predictor of subjective well-being, neither at baseline nor six months later. We believe that this non-significant result is interesting and valuable for several reasons. Firstly, this was an exploratory study, since no one tested these associations, therefore it is an important contribution to the field of content-specific rumination. Secondly, we measured the connection of subjective well-being and *trait* self-critical rumination, in contrast to those studies which investigated the association of well-being and HRV reactivity or HRV recovery after a stressful induction [108,109]. In addition, the link of well-being and HRV was mostly investigated in intervention studies, for example before and after of Vipassana meditation [110] or HRV-biofeedback training [111]. Thirdly, subjective well-being is a multidimensional construct, which can be defined by many ways [21]. In this study, we conceptualized it as subjective well-being, comprising emotional, psychological and social well-being, contrary to those rumination and/or HRV studies where subjective well-being was measured solely by the cognitive component of well-being, life satisfaction [112] or optimism [113].

Besides HRV, it is worth mentioning that in our study, self-critical rumination was a predictor of lower subjective well-being at both timepoints. Despite the relative lack of evidence about the relationship of content-specific rumination and mental health, our results concord previous studies' findings, where (depressive) rumination was linked to lower psychological, social and emotional well-being [23].

The present study is not without limitations. Due to the relatively small sample size and convenience sampling, the generalizability of our results to other populations is limited. We included young, undergraduate students to our study, who declared themselves to be completely healthy. They were free from any medical, neurological, and psychiatric disorders. We excluded those participants from the study who did not meet these criteria. One person was excluded because of hypertonia, three volunteers were excluded due to psychotropic or cardiovascular drug use and we excluded one individual due to neurological/psychiatric disorder. It is worth mentioning that this information was based on self-report, not on medical records, so it might be biased. In addition, the race and ethnic composition of our samples were homogenous; all participants were Hungarians.

Despite the non-clinical sample of our study, we found a relatively high somatic symptom distress level at both timepoints. These are disturbing results, which could be (at least partially) due to the high female proportion of the sample. We found a significant gender difference in the mean scores of PHQ_2–15 (at six months follow-up) (Mann-Whitney $U = 331.5$; $p = 0.03$), but we did not find significant differences at baseline (Mann-Whitney $U = 331.5$; $p = 0.35$). These results are interesting especially in the light of the research of Huang et al. [114], who found that the association between HRV indices and psychological factors may vary between men and women. Although in their study PHQ-15 was not a significant predictor of LF-HRV and HF-HRV in the whole sample, among SSD (somatic symptom disorder) patients, the association between HRV and depressive symptoms was significant only in men [114]. These results shed light on the importance of gender/sex differences in the relation of HRV and psychosomatic symptoms and might indicate that it is worthwhile to measure cue-specific HRV as well beyond resting- state HRV [115]. Our findings seem to converge with these interesting findings, but due to the moderate sample size, non-clinical sample and very unbalanced male-female ratio (only 13% of the sample was male) of our study, one should be cautious when interpreting or comparing these results.

Furthermore, previous results also indicated that some specific factors such as academic stress [116], or sleep problems [117] could be associated with somatic syndromes and complaints among undergraduate students. The measurement of these specific constructs was outside of our scope, but it is possible that they could contribute to the higher PHQ-15 scores (e.g., perhaps participants had an extraordinarily stressful semester). Similar results were found in previous studies [69], where the PHQ-15 scores of undergraduate students were above the cutoff, and the mean PHQ-15 scores did not differ from the scores of a patient group [70].

In addition, as we have mentioned before, we did not measure HRV data six months later. Although it would have been useful to compare resting HRV at both timepoints, we wanted to maximize participants' adherence in this prospective study, therefore we decided to register only self-reported data at follow-up. One could argue that the six months gap between measurements was quite arbitrary. Although HRV is often considered a state phenomenon, there are previous results which suggest a longitudinal association between rumination and HRV. Previous studies showed that resting HRV measured at follow-up, was an important mediator of the association of trait rumination (measured at baseline) and depressive symptoms in a non-clinical setting over almost three years [25]. Furthermore, baseline resting HRV level and HRV response to stress were significant predictors of the same variable 1.5 years later as well [118]. Considering that we aimed to test putative associations at long-term, and we involved university students in our study, the six months gap allowed us to measure the university students in two semesters as well.

In addition, we should mention that in this research rumination was conceptualized (and measured) as a trait-like characteristic. Although negative mood, aversive events and stressful situations could trigger ruminative thoughts [119,120], and rumination could have diurnal fluctuation [121], previous results suggest that the person who responds to triggering events with rumination will likely continue to do so, unless rumination itself is directly targeted in treatment [122]. The significant relationship consistently found between neuroticism and rumination [123], could further support the trait-like characteristic of rumination. Overall, rumination is considered a stable trait-like characteristic, but in stability we do not mean the duration of the ruminative process, but rather the tendency to react with rumination in response to a stressful event.

Furthermore, we did not control for the effect of breathing in the HRV analysis, but it is a factor that could have a major influence on HRV metrics [124,125]. We need to mention here, that during the registration of cardiac activity, our participants were lying in their black with closed eyes, while their breathing was even and calm, and we only used the last 5-min period of the recordings. Moreover, we did control for chronic conditions, but not to acute illnesses, which could have had an impact on our results. However, we would like to note that we measured the distress or perceived burden of somatic symptoms, and not just the number of somatic symptoms which is strongly associated with psychological distress [68,72,126].

Despite these limitations, our study has many strengths as well. To the best of our knowledge, we firstly measured *self-critical rumination* in the relation to subjective well-being and somatic symptom distress, emphasizing that ruminative self-critical thoughts could have long-term health consequences, even in a non-clinical sample. In addition, we assessed the interaction of self-critical rumination and resting HRV in a cross-sectional and prospective design, indicating a significant association of resting HRV, content-specific rumination and somatic symptom distress.

We also believe that our results might have practical implications. Based on previous findings and our own results, psychophysiological pathways such as HRV might be important intervention targets. Increasing levels of physical activity, for instance, was prospectively related to more favourable indices (i.e. higher SDNN values) of HRV

among older people [127], and HRV-biofeedback significantly improved emotional and physical health and overall functioning [128]. Our present work also raises the possibility that an HRV-targeted intervention might be beneficial in the relation of self-ruminative thoughts and somatic symptom distress.

5. Conclusion

Our findings potentially indicate that higher resting HRV, might be an important factor in the relationship of self-critical rumination and somatic symptoms. At the same time, the effect of resting HRV on the association between self-critical rumination and subjective well-being might be unimportant. Some of these results are preliminary and need replication in studies with bigger clinical populations (with a more balanced male/female ratio) and with more measurements of HRV and emotion regulation.

Ethics approval

The study was approved by the Institutional Review Board of ELTE Eötvös Loránd University (Budapest, Hungary). All participants provided written informed consent before entering the study and the work was carried out in accordance with the Declaration of Helsinki.

Availability of data and materials

The datasets generated during and/or analyzed during the current study are available from the corresponding author on reasonable request.

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Declaration of Competing Interest

The authors report no conflict of interest.

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