Mindfulness-based cognitive therapy improves heart rate variability amongst individuals with recurrent depression: preliminary findings from a randomized controlled trial.

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ABSTRACT

Persistent ruminative processing has been prospectively linked with poor recovery and new onsets of depression amongst those with recurrent depression. One potential pathophysiological mechanism underlying persistent ruminative processing might be autonomic nervous system dysfunction such as low heart rate variability. Mindfulness practice targets the ability to recognize, decenter and disengage from persistent ruminative processing, by training adaptive attention regulation and present-moment awareness, and, as such, may also impact heart rate variability during rumination. Yet, little is known about whether Mindfulness-Based Cognitive Therapy (MBCT) for recurrent depression effects heart rate variability. Hence, employing a randomized controlled design, we examined the impact of MBCT versus treatment as usual (TAU) on heart rate variability across states of rumination, mindfulness practice and rest. We found increased heart rate variability after MBCT treatment during states of rumination, mindfulness practice and resting state following mindfulness practice, whereas no change was found in the control group. This finding correlates with an increased ability to take a decentred perspective on one's experiences and awareness of the connection between body sensations and emotional states. Heart rate variability may be a physiological mechanism of persistent ruminative processing, and increased heart rate variability following MBCT training may indicate improved mental health, enhanced cognitive flexibility and play a role in the ability to disengage from ruminative mind states.

INTRODUCTION

Major depressive disorder (MDD) is a highly prevalent and debilitating affective disorder and a leading cause of disability worldwide (WHO, 2020). Depression trends to follow an increasingly chronic and recurrent course. After 3 episodes, the risk of relapse or recurrence is up to 80%, and many patients do not fully recover(Fava, 2018) . Consequently, optimizing preventative treatments for recurrence of depression is crucial.

Recurrent depression is characterized by a cognitive vulnerability to relapse, meaning that negative biases and ruminative processes characteristic of previous episodes are easily activated by changes in mood, thus increasing the risk of relapse (Figueroa et al., 2015; Moulds et al., 2008; Segal et al., 2013b; Z. V. Segal et al., 1996). Mindfulness-Based Cognitive Therapy (MBCT) is an effective psychotherapeutic intervention for the prevention of recurrent depressive episodes (Kuyken et al., 2016) which is proposed to target depressive rumination by training adaptive attention, emotion and self regulation skills (van der Velden et al., 2015). Specifically, participants are taught to recognize, decenter and disengage from ruminative negative thoughts, by redirecting attention to the embodied experience of present-moment sensations, and relate to the change and flux of present-moment experience with a non-judgmental, accepting and curious attitude (Segal et al., 2013b). Amidst the growing body of clinical studies documenting the efficacy of MBCT for recurrent MDD, we still do not know precisely how MBCT can reduce vulnerability to depressive recurrence.

A potential cardiophysiological mechanism related to the ability to decenter and disengage from ruminative negative thoughts is heart rate variability. Heart rate variability reflects the extent to which the brain and its central autonomic network can flexibly respond and adapt or react to environmental challenges (J. L. Hamilton & Alloy, 2016). More specifically, heart rate variability is the fluctuation in the length of intervals between consecutive heartbeats, and, as such, reflects the relative ratio of parasympathetic and sympathetic nervous system activity. Higher heart rate variability reflects the body's ability to self-regulate in response to stressful situations, i.e. heart rate would increase in response to actual or perceived stressors, but also decrease as soon as the actual or perceived stressor is gone, resulting in greater heart rate variability. Research on nonclinical populations have shown a close relationship between persistent ruminative processing and low heart rate variability (Stange, Hamilton, Fresco, & Alloy, 2017). Furthermore, individuals with low heart rate variability, persistent ruminative processing, and low decentering have higher prospective risk for symptoms of depression (Stange et al., 2017). Higher heart rate variability has also been related to mental health, resilience and behavioral flexibility (Blons et al., 2019; Perna et al., 2020), executive functioning (Colzato, Jongkees, de Wit, van der Molen, & Steenbergen, 2018; Gillie, Vasey, & Thayer, 2015), emotion regulation (Fiol-Veny, Balle, De la Torre-Luque, & Bornas, 2019; Grol & De Raedt, 2020) and decentering/perspective taking (Grossmann, Sahdra, & Ciarrochi, 2016; Stange et al., 2017); skills that MBCT targets to reduce vulnerability to relapse or recurrence of depression (Segal et al., 2013b; van der Velden et al., 2015).

Two recent reviews have examined the effects of Mindfulness-Based Interventions (MBIs) on resting-state vagally-mediated heart rate variability and heart rate variability reactivity in response to a task/stressor in non-clinical populations. Brown and colleagues (Brown et al., 2020) investigated the effects of MBIs on resting-state vagally-mediated heart rate variability in a random-effects meta-analysis. Across 19 randomized controlled studies, MBIs were not efficacious in increasing vagally-mediated resting-state heart rate variability relative to control conditions, and there was high heterogeneity between studies. In contrast, Christodoulou and colleagues (Christodoulou et al., 2020) found indication that MBIs increase heart rate variability during both practice and stressful tasks across 17 studies, indicating that effects of MBIs on heart rate variability may be broad and responsive in a variety of environmental contexts.

Currently, little is known about whether MBCT for recurrent depression effects heart rate variability at rest or during states of mindfulness practice or rumination. Hence, employing a randomized controlled design, we examined the impact of MBCT versus treatment as usual (TAU) on heart rate variability across states of mindfulness practice, rest and rumination.

METHODS

Study design and participants

To speak to whether MBCT for recurrent depression effects heart rate variability either at rest, during state of mindfulness practice or during rumination, we set up a single-blind, randomized controlled trial examining physiological and concurrent psychological processes in MBCT and TAU versus TAU only. The study design was registered at ClinicalTrials.gov (Identifier: NCT03353493).

We recruited participants from general practices and psychiatric units in the Central Denmark Region, Denmark, including Danish speaking adult participants (age 18 or older) with a) a diagnosis of recurrent major depressive disorder with or without a current episode in the mild to moderate range, b) three or more previous major depressive episodes, c) if on antidepressants, a stable dose of SSRI or SNRI medication for a minimum of 8 weeks, and excluding participants with d) psychiatric comorbidity of a history of schizophrenia, schizoaffective disorder, bipolar disorder, current severe substance abuse, organic mental disorder, current/past psychosis, pervasive developmental delay, persistent antisocial behavior, persistent self-injury requiring clinical management/therapy, e) concurrent psychotherapy or previously completion of MBCT or Mindfulness-based stress reduction (MBSR) training and/or extensive meditation experience (i.e. retreats or regular meditation practice), f) anti-psychotic medication and benzodiazepines.

All participants gave written informed consent, and the study protocol was registered at the Danish Data Protection Agency (2016-051-000001), and the original and updated study protocol approved by the the ethics committee in the Central Denmark Region ID: 1-10-72-259-16: 66534.

Randomization

After baseline assessment, participants (N =80) were randomly allocated (in a 5:3 ratio) to receive either an 8-week MBCT class + TAU treatment or adhere to TAU treatment by an independent researcher. This was done using a computer-generated random number sequence stratified according to antidepressant use and participants' symptomatic status using Beck Depression Inventory-II with under 13 = asymptomatic, and greater than or equal to 14 = symptomatic. Research assessors conducting the state manipulation paradigm were blinded to treatment allocation, and questionnaires were administered online. In addition, participants were blinded to treatment allocation at the baseline assessment, but given the nature of psychological treatment, participants, trial coordinator and therapists were made aware of treatment allocation after baseline assessment.

Interventions

MBCT

MBCT is an eight-week manualized group-based program combining psychoeducation elements from cognitive behavioral therapy for depression with a systematic training in mindfulness meditation techniques to teach skills to reduce depressive symptoms, disengage from ruminative mind states and prevent relapse or recurrence in the long term. MBCT was taught by therapists with at least seven years' experience and in accordance with the manual. MBCT consisted of a pre-class interview, weekly classes of two hours during an eight-week period with homework and four booster sessions offered after the program.

Treatment as usual

In Denmark, TAU for recurrent depression typically consists of maintenance antidepressant medication. To enable us to draw conclusions on the effect of MBCT, we restricted TAU to no psychotherapeutic intervention and either a stable dose of antidepressant medication or no medication. We registered any change to TAU.

Measures and procedures

Participants were assessed at baseline (before randomization) and within one month after the end of the eight-week MBCT program.

Before randomization and after treatment, the participants completed cardiac (pulse photo-plethysmography) measures across three states (rest, mindfulness, rumination), as well as questionnaires assessing dispositional mindfulness (the 15-item version of Five Factor Mindfulness Questionnaire (FFMQ) (Gu et al., 2016), dispositional rumination (Rumination Response Scale (RRS), (Kasch, Klein, & Lara, 2001)), decentering (Experiences Questionnaire (EQ), (Fresco, Moore, et al., 2007; Fresco, Segal, et al., 2007)) and interoceptive awareness (Multidimensional Assessment of Interoceptive Awareness (MAIA), (Mehling et al., 2012)).

Paradigm

The paradigm consisted of four states of five minutes duration in the following order: 1) resting state, 2) instructed mindfulness state, 3) resting state, and 4) instructed rumination state. Heart rate was measured continuously throughout the paradigm. The four states consisted of the following instructions:

Resting state instructions: Before the two resting states, participants were told to relax and close their eyes.

Mindfulness meditation instructions: Participants were guided through a well-established mindfulness exercise 'the breathing space', which is used in the MBCT program. During this practice, participants are instructed to become aware of the present moment's thoughts, feelings and bodily sensations, including the sensation of the breath and the awareness to the body as a whole. Throughout the practice, participants are encouraged to embodying an attitude of curiosity and experiential acceptance.

Rumination induction instructions: Participants were asked first to rehearse a sad autobiographical memory and subsequently were instructed to stay with their sad mood and reflect on self-related causes and consequences of their low mood (See Karl et al (2018) (Karl et al., 2018) for detailed description for the paradigm). The use of a negative autobiographical memory to induce sad mood and ruminative thought patterns is well-established method in the field (Karl et al., 2018; Segal et al., 2013b). Out of ethical considerations, it was possible for participants to opt out of the rumination condition, e.g. if they felt it would be too stressful for them.

Figure 1: Participant flow

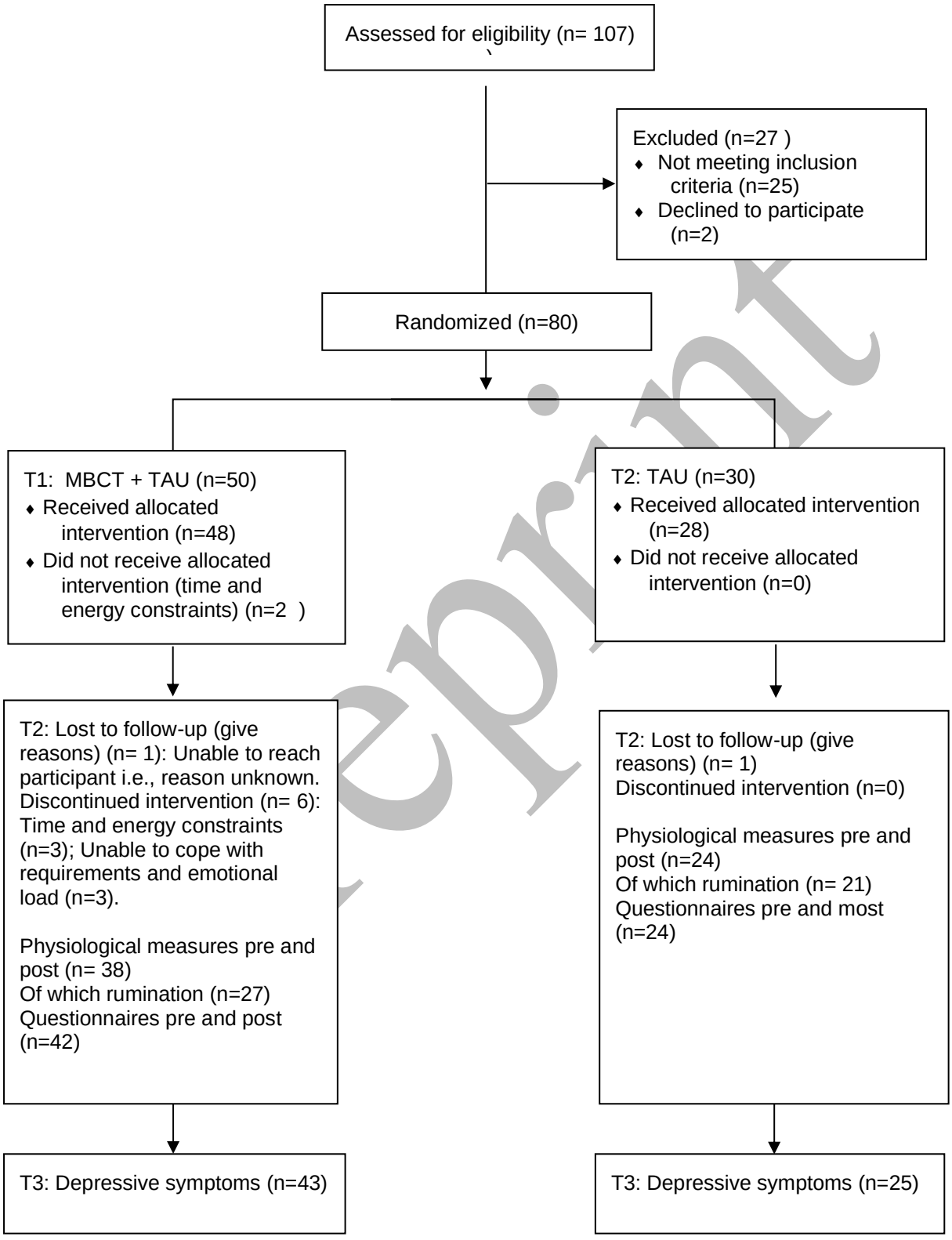

Table 1: Baseline Characteristics

	MBCT+TAU (N=50)	**TAU (N=30)**
Sociodemographic characteristics	N=48	N=28
Age	43.17 (14.22)	45.25 (12.01)
Gender (Female/Male)	35/15 (70%)	23/5 (82%)
Educational level		
Low (<2 years further education)	15 (30%)	3 (11%)
Medium (2-4 years further education)	24 (48%)	21 (75%)
High (>5 years further education)	9 (18%)	4 (14%)
Marital status		
Married/cohabiting	43 (90%)	21 (75%)
Single/not cohabiting	5 (10%)	7 (25%)
Occupational status		
Employed	24 (50%)	14 (50%)
Unemployed/benefits	10 (10%)	4 (14%)
Student	3 (6%)	1 (4%)
Retired	7 (15%)	4 (14%)
Other	9 (19%)	5 (18%)
Clinical Characteristics	N=50	N=28
Symptomatic (QIDS>5)	43 (83%)	25 (76%)
Antidepressant usage	43/7 (86%)	21/7 (75%)
Childhood Trauma	58.79 (6.22) N=42	58.96 (6.33) N=26
Previous episodes of depression	3.90 (1.44) N=41	3.80 (1.36) N=23

RESULTS

Between February 2017 and February 2018, we assessed 107 participants were assessed for eligibility and recruited 80. Of these, 50 participants were randomly allocated to receive MBCT in addition to treatment as usual (TAU) and 30 participants to TAU. Participant flow over the study period with attrition and reasons are shown in figure 1. Baseline characteristics were balanced between the two groups (Table 1).

Self-reported trait findings

Self-reported trait results have been reported in full elsewhere (van der Velden et al., in prep, 2021). In summary, MBCT treatment compared with treatment as usual. increased mindfulness skills (FFMQ_15, p<.001, g=0.68, 95% CI [1.49 to 9.57]), decentering (EQ, p<.001, g=0.98, 95% CI [3.76 to 11.01]), an increased ability to notice bodily sensations (MAIA -noticing subscale (p<.001, g= 0.95, CI [1.60-4.76]), awareness of the manifestation of emotions in the body (MAIA -emotional awareness subscale (p<.001, g= 1.10, CI [2.82, 7.12]); active listening to the body for insight (MAIA -body listening subscale (p<.001, g= 1.19, CI [1.63-3.85]) and the ability to sustain and control attention to body sensations (MAIA: attention regulation (p<.001, g= 1.00, CI [2.56-7.44]).

Heart rate, respiration rate and heart rate variability

Heart rate was measured with pulse photo-plethysmography (PPG) by applying a pulse oximeter. Respiration rate measures were obtained from the respiratory chest motion with a chest belt. The pulse and respiration measures were digitized at a sampling rate of 400 Hz. After recording, PPG signals were filtered with a passband filter between 2-10 Hz, the respiration signals with a passband filter between 1-5 Hz. Subsequently, all PPG and respiration signals were visually inspected for artifacts. PPG signals were converted to NN intervals with the RRest Toolbox v. 3.0 for Matlab (Charlton et al., 2017).We computed heart rate variability using the standard deviation of NN intervals (SDNN) in milliseconds. Respiration rate was extracted from the respiration signal with the BreathMetrics Toolbox v. 2.0 for Matlab (Noto et al., 2018).

Heart rate variability

As shown in Figure 2, we observed a pattern of higher heart rate variability across states after MBCT treatment compared to baseline. Running a 3-way ANOVA (session x state x group, F(2.25,87.88)=0.82, p=.455, η^2=.02), we did not find an effect, suggesting that the observed effect was not specific to a particular state. Although we expected a group x time interaction effect based on the figure 2, the 2-way ANOVA (group x time) was not significant, F(1,39)=1.41, p=.243, η^2=.04, and may not have been powered due to rather large variations. However, one-tailed paired samples t-tests supported the observed trends by showing that heart rate variability was significantly higher in the MBCT treatment group in the follow-up session compared to first session during rumination t(24)=2.01, M_{diff}=+11.4, 95% CI [2.0, 20.7], p=.028, d_z=0.40, during the mindfulness practice, t(24)=1.75, M_{diff}=+6.5, 95% CI [0.4, 12.6], p=.044, d_z=0.29 and during the resting state following the mindfulness practice, t(24)=1.91, M_{diff}=+13.4, 95% CI [1.8, 25.0], p=.032, d_z=0.31, whereas no significant treatment effect was seen in the TAU group. Also, there was a non-significant trend of higher heart rate variability after treatment during resting state 1 in the MBCT group, t(35)=0.52, M_{diff}=2.3, 95% CI [-4.8, 9.4], p=.303, d_z=0.09.

Figure 2: Heart rate variability across time and treatment

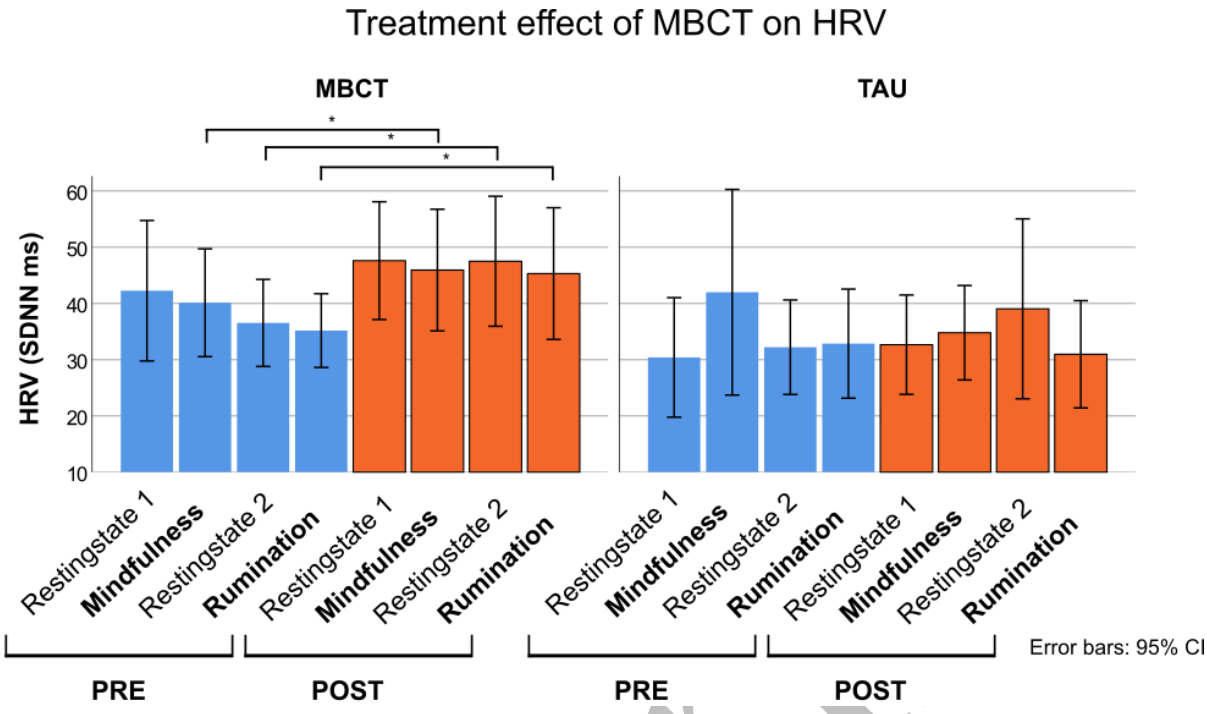

Figure 2 Caption: State effects (resting state 1, mindfulness, resting state 2, rumination) divided into treatment group (MBCT vs TAU), or session pretreatment (pre) or post treatment (post). Error bars show 95% confidence intervals. *p<0.05.

Within the MBCT group heart rate variability changes across states was positively correlated with change in EQ assessing the ability to take a decentred or an observer's stance on one's experiences r=-0.48, p=0.001, (see supplements for covariance table). Given the exploratory nature of the study, we did not correct for multiple corrections.

For ethical reasons, participants could opt out of the rumination condition. The only difference between participants who choose to opt out of the rumination condition (N=20) and those who completed it, was higher depressive symptoms at baseline for the former. Otherwise, there was less than one standard deviation difference between those opting for the rumination condition and does who did not (see supplements).

DISCUSSION

This is, to our knowledge, the first study to explore the impact of MBCT for recurrent depression on heart rate variability across different mind states. We found preliminary evidence for increased heart rate variability after MBCT during states of rumination, mindfulness practice and during the resting state that followed mindfulness practice,- with the resting state before mindfulness practice showing a non-significant increasing trend. As such, our findings replicate and extend findings from previous research on non-clinical populations indicating that effects of MIBs on heart rate variability may be broad and responsive in a variety of tasks, such as mindfulness practice, and during stressful situations, but may be less pronounced during resting states (Brown et al., 2020; Christodoulou et al., 2020; Wheeler et al., 2014)).

Heart rate variability has received growing attention in the depression field (Kircanski, Williams, & Gotlib, 2019; Koch et al., 2019; Yaroslavsky, Bylsma, Rottenberg, & Kovacs, 2013). Research has consistently shown a relationship between low heart rate variability and negative depression outcomes (Koch et al., 2019). Furthermore, low heart variability has been proposed as a physiological marker of persistent ruminative processing (Ottaviani et al., 2018). Hence, it is possible that heart rate variability during rumination might be related to the ability to disengage from ruminative mind states. In contrast, higher heart rate variability has been related to mental health, resilience and cognitive flexibility (Blons et al., 2019; Perna et al., 2020)), and a number of studies have demonstrated a link between heart variability and executive functioning (Colzato et al., 2018; Gillie et al., 2015), emotion regulation (Fiol-Veny et al., 2019; Grol & De Raedt, 2020; Howells, Laurie Rauch, Ives-Deliperi, Horn, & Stein, 2014) and decentering or perspective taking (Grossmann et al., 2016); skills that MBCT is proposed to target to reduce vulnerability to relapse or recurrence of depression (Segal et al., 2013b; van der Velden et al., 2015). Indeed, the change in heart rate variability after MBCT treatment was significantly correlated with questionnaires assessing the ability to take a decentered or an observer's stance on one's experiences. Research on a nonclinical population have shown that individuals with both parasympathetic inflexibility, persistent ruminative processing and low decentering have higher prospective risk for symptoms of depression (Stange et al., 2017). Hence, it is possible that the increase in both heart rate variability and decentering work to protect against relapse risk or deterioration of depressive symptoms. However, we were only able to detect the observed differences in heart rate variability with individual t-tests and not with ANOVA's, as there was rather large variation in the data. Hence, these findings should be treated as preliminary and needs to be replicated in a bigger sample.

This research has several methodological limitations. Given the novelty of the design, it was difficult to make precise statistical power estimations, and, hence, we cannot interpret the meaning of null findings. Furthermore, as we did not have an active control group, we cannot know whether the treatment effects are specific to MBCT treatment or whether other effective depression treatments or active control treatments may yield similar effects. Finally, the results on the rumination state are only generalizable to the participants who here willing to participate in the rumination induction. Those who did not participate in the rumination condition had higher depression symptoms at baseline, and as such the finding on the rumination state may mainly be applicable to those with no residual symptoms to mild symptoms.

CONCLUSION

We found evidence for increased heart rate variability after MBCT treatment during states of rumination, mindfulness practice and resting state following mindfulness practice. Increased heart rate variability correlated with an increased ability to take a decentred or an observer's stance on one's experiences. Heart rate variability may reflect the physiological underpinnings of persistent

ruminative processing and, as such, may play a role in the ability to disengage from ruminative mind states.

Data sharing statement and trial registration

Deidentified individual participant data that underlie the results reported in this article is available upon request to researchers with a methodological sound proposal. Proposals should be directed to the corresponding author. Group data, study protocol and analytical code will be made available for download on Github. The study was registered at ClinicalTrials.gov (NCT03353493).

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Contributors

AMV, AR and WK were responsible for the original proposal and AMV secured funding for the trial. AMV developed the design and protocol, and AR and WK advised on the design. AMV was responsible for the general management of the study, and LOF oversaw the clinical management of the study. AMV, EE and LOF collected the data. AMV, NTH, AR and WK created the analysis strategy. NTH analyzed the data. AMV, NTH, AR and WK interpreted the data. AMV wrote the initial draft. All authors contributed to, and approved, the final manuscript.

Conflicts of interest

The author(s) declares the following potential conflicts of interest. WK is the director of the Oxford Mindfulness Centre. He receives payments for training workshops and presentations related to MBCT and donates all such payments to the Oxford Mindfulness Foundation, a charitable trust that supports the work of the Oxford Mindfulness Centre. WK was until 2015 an unpaid Director of the Mindfulness Network Community Interest Company and gave evidence to the UK Mindfulness All Party Parliamentary Group. He received royalties for several books on mindfulness published by Guilford Press. LOF is director of the Danish Centre for Mindfulness. She receives payments for presentations, workshops and teacher training related to MBSR and MBCT and donates payments to the Danish Centre for Mindfulness

REFERENCES

1. WHO. *World Health Organization: fact sheet depression*. 2020.
2. Fava, G.A., *Time to rethink the approach to recurrent depression.* Lancet Psychiatry, 2018. **5**(5): p. 380-381.
3. Segal, M. Williams, and J.D. Teasdale, *Mindfulness-Based Cognitive Therapy for Depression*. 2nd ed. 2013, New York: The Guilford Press.
4. Moulds, M.L., et al., *An investigation of the relationship between cognitive reactivity and rumination.* Behav Ther, 2008. **39**(1): p. 65-71.
5. Segal, Z.V., et al., *A cognitive science perspective on kindling and episode sensitization in recurrent affective disorder.* Psychol Med, 1996. **26**(2): p. 371-80.
6. Figueroa, C.A., et al., *Cognitive reactivity versus dysfunctional cognitions and the prediction of relapse in recurrent major depressive disorder.* J Clin Psychiatry, 2015. **76**(10): p. e1306-12.
7. Kuyken, W., et al., *Efficacy of Mindfulness-Based Cognitive Therapy in Prevention of Depressive Relapse: An Individual Patient Data Meta-analysis From Randomized Trials.* JAMA Psychiatry, 2016. **73**(6): p. 565-74.
8. van der Velden, A.M., et al., *A systematic review of mechanisms of change in mindfulness-based cognitive therapy in the treatment of recurrent major depressive disorder.* Clin Psychol Rev, 2015. **37**: p. 26-39.
9. Hamilton, J.L. and L.B. Alloy, *Atypical reactivity of heart rate variability to stress and depression across development: Systematic review of the literature and directions for future research.* Clinical psychology review, 2016. **50**: p. 67-79.
10. Stange, J.P., et al., *Perseverate or decenter? Differential effects of metacognition on the relationship between parasympathetic inflexibility and symptoms of depression in a multi-wave study.* Behav Res Ther, 2017. **97**: p. 123-133.
11. Blons, E., et al., *Alterations in heart-brain interactions under mild stress during a cognitive task are reflected in entropy of heart rate dynamics.* Sci Rep, 2019. **9**(1): p. 18190.
12. Perna, G., et al., *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.* J Affect Disord, 2020. **263**: p. 754-761.
13. Colzato, L.S., et al., *Variable heart rate and a flexible mind: Higher resting-state heart rate variability predicts better task-switching.* Cogn Affect Behav Neurosci, 2018. **18**(4): p. 730-738.
14. Gillie, B.L., M.W. Vasey, and J.F. Thayer, *Individual differences in resting heart rate variability moderate thought suppression success.* Psychophysiology, 2015. **52**(9): p. 1149-60.
15. Fiol-Veny, A., et al., *Negative cognitive emotion regulation as a predictor of adolescent heart rate variability and entropy under social stress.* Anxiety Stress Coping, 2019. **32**(6): p. 641-653.
16. Grol, M. and R. De Raedt, *The link between resting heart rate variability and affective flexibility.* Cogn Affect Behav Neurosci, 2020. **20**(4): p. 746-756.
17. Grossmann, I., B.K. Sahdra, and J. Ciarrochi, *A Heart and A Mind: Self-distancing Facilitates the Association Between Heart Rate Variability, and Wise Reasoning.* Frontiers in behavioral neuroscience, 2016. **10**: p. 68-68.
18. Brown, L., et al., *The Effects of Mindfulness and Meditation on Vagally-Mediated Heart Rate Variability: A Meta-Analysis.* Psychosomatic Medicine, 2020. **Publish Ahead of Print**.
19. Christodoulou, G., N. Salami, and D.S. Black, *The Utility of Heart Rate Variability in Mindfulness Research.* Mindfulness, 2020. **11**(3): p. 554-570.
20. Gu, J., et al., *Examining the factor structure of the 39-item and 15-item versions of the Five Facet Mindfulness Questionnaire before and after mindfulness-based cognitive therapy for people with recurrent depression.* Psychol Assess, 2016. **28**(7): p. 791-802.

21. Kasch, K.L., D.N. Klein, and M.E. Lara, *A construct validation study of the Response Styles Questionnaire Rumination Scale in participants with a recent-onset major depressive episode.* Psychol Assess, 2001. **13**(3): p. 375-83.
22. Fresco, D.M., et al., *Initial psychometric properties of the experiences questionnaire: validation of a self-report measure of decentering.* Behav Ther, 2007. **38**(3): p. 234-46.
23. Fresco, D.M., et al., *Relationship of posttreatment decentering and cognitive reactivity to relapse in major depression.* J Consult Clin Psychol, 2007. **75**(3): p. 447-55.
24. Mehling, W.E., et al., *The Multidimensional Assessment of Interoceptive Awareness (MAIA).* PLoS One, 2012. **7**(11): p. e48230.
25. Karl, A., et al., *Dispositional self-compassion and responses to mood challenge in people at risk for depressive relapse/recurrence.* Clin Psychol Psychother, 2018. **25**(5): p. 621-633.
26. Charlton, P.H., et al., *Extraction of respiratory signals from the electrocardiogram and photoplethysmogram: technical and physiological determinants.* Physiol Meas, 2017. **38**(5): p. 669-690.
27. Noto, T., et al., *Automated analysis of breathing waveforms using BreathMetrics: a respiratory signal processing toolbox.* Chem Senses, 2018. **43**(8): p. 583-597.
28. Wheeler, A., et al., *Investigating the Effect of Mindfulness Training on Heart Rate Variability in Mental Health Outpatients: A Pilot Study.* Behaviour Change, 2014. **31**(3): p. 175-188.
29. Yaroslavsky, I., et al., *Combinations of resting RSA and RSA reactivity impact maladaptive mood repair and depression symptoms.* Biological psychology, 2013. **94**(2): p. 272-281.
30. Kircanski, K., L.M. Williams, and I.H. Gotlib, *Heart rate variability as a biomarker of anxious depression response to antidepressant medication.* Depress Anxiety, 2019. **36**(1): p. 63-71.
31. Koch, C., et al., *A meta-analysis of heart rate variability in major depression.* Psychol Med, 2019. **49**(12): p. 1948-1957.
32. Ottaviani, C., et al., *Heart rate variability as a mediator of the longitudinal association between rumination and depressive symptoms.* International Journal of Psychophysiology, 2018. **131**: p. S44.
33. Howells, F.M., et al., *Mindfulness based cognitive therapy may improve emotional processing in bipolar disorder: pilot ERP and HRV study.* Metab Brain Dis, 2014. **29**(2): p. 367-75.

S1: Sample characteristics of those not participating in the rumination condition

One way ANOVA based on rumination state participation

		Sum of Squares	df	Mean Square	F	Sig.
FFMQ_change	Between Groups	74.145	1	74.145	1.060	.307
	Within Groups	4478.173	64	69.971		
	Total	4552.318	65			
EQ_change	Between Groups	10.237	1	10.237	.155	.695
	Within Groups	4233.650	64	66.151		
	Total	4243.887	65			
RRS_change	Between Groups	119.667	1	119.667	1.020	.316
	Within Groups	7506.469	64	117.289		
	Total	7626.137	65			
MAIA.NO_change	Between Groups	1.898	1	1.898	.151	.699
	Within Groups	803.633	64	12.557		
	Total	805.530	65			
MAIA.ND_change	Between Groups	.346	1	.346	.040	.842
	Within Groups	555.472	64	8.679		
	Total	555.818	65			
MAIA.EA_change	Between Groups	10.691	1	10.691	.434	.512
	Within Groups	1575.441	64	24.616		
	Total	1586.132	65			
MAIA_AR_change	Between Groups	3.270	1	3.270	.110	.741
	Within Groups	1899.215	64	29.675		
	Total	1902.485	65			
MAIA_BL_change	Between Groups	7.151	1	7.151	1.086	.301
	Within Groups	421.349	64	6.584		
	Total	428.500	65			
QIDS_change*	Between Groups	186.708	1	186.708	7.522	.008
	Within Groups	1712.616	69	24.821		
	Total	1899.324	70			

Table S1. Comparing those who participated in the rumination condition (n=68) versus those who did not (n=20) on mechanism measures and depressive symptoms. Differences between QIDS were driven by higher depressive symptoms at baseline amongst those opting out of ruination, whereas post treatment results on depressive symptoms were similar. QIDS: Quick Inventory of Depressive Symptomology (Rush et al., 2003); EQ: Experience Questionnaire(Fresco, Moore, et al., 2007); FFMQ: Five Factor Mindfulness Questionnaire(R. A. Baer et al., 2008); RRS: Rumination Response Scale(Roelofs et al., 2006); MAIA (Multidimensional Assessment of Interoceptive Awareness(Mehling et al., 2012).

ANOVA based on treatment allocation

		Sum of Squares	df	Mean Square	F	Sig.
FFMQ_change*	Between Groups	526.080	1	526.080	8.362	.005
	Within Groups	4026.238	64	62.910		
	Total	4552.318	65			
EQ_change*	Between Groups	881.048	1	881.048	16.768	.000
	Within Groups	3362.839	64	52.544		
	Total	4243.887	65			
RRS_change	Between Groups	150.717	1	150.717	1.290	.260
	Within Groups	7475.420	64	116.803		
	Total	7626.137	65			
MAIA_NO_change*	Between Groups	150.286	1	150.286	14.679	.000
	Within Groups	655.244	64	10.238		
	Total	805.530	65			
MAIA_ND_change	Between Groups	12.175	1	12.175	1.433	.236
	Within Groups	543.643	64	8.494		
	Total	555.818	65			
MAIA_EA_change*	Between Groups	388.285	1	388.285	20.746	.000
	Within Groups	1197.847	64	18.716		
	Total	1586.132	65			
MAIA_AR_change*	Between Groups	415.247	1	415.247	17.869	.000
	Within Groups	1487.238	64	23.238		
	Total	1902.485	65			
MAIA_BL_change*	Between Groups	115.500	1	115.500	23.617	.000
	Within Groups	313.000	64	4.891		
	Total	428.500	65			
QIDS_change*	Between Groups	273.547	1	273.547	11.610	.001
	Within Groups	1625.777	69	23.562		
	Total	1899.324	70			

S2: Group x time effects QIDS: Quick Inventory of Depressive Symptomology (Rush et al., 2003); EQ: Experience Questionnaire(Fresco, Moore, et al., 2007); FFMQ: Five Factor Mindfulness Questionnaire(R. A. Baer et al., 2008); RRS: Rumination Response Scale(Roelofs et al., 2006); MAIA (Multidimensional Assessment of Interoceptive Awareness(Mehling et al., 2012), and the subscales of AR: Attention Regulation; BL: Body listening; NO: Noticing; TR: Trusting; ND: Non distracting; EA: Emotional awareness.

S3: Correlations between change in heart rate variability and change in questionnaires

Correlations

		Mean_HRV	FFMQ	EQ_2	MAIA_NO	MAIA_ND	MAIA_EA	MAIA_AR	MAIA_BL	QIDS2	Broo2Cha
Mean_HRV	Pearson Correlation	1	.198	.340**	.160	-.112	.340**	.089	.217	-.253*	-.186
	Sig. (2-tailed)		.137	.009	.232	.402	.009	.508	.102	.049	.161
	N	62	58	58	58	58	58	58	58	61	58
FFMQ	Pearson Correlation	.198	1	.744**	.379**	-.375**	.472**	.684**	.429**	-.406**	-.515**
	Sig. (2-tailed)	.137		.000	.002	.002	.000	.000	.000	.001	.000
	N	58	66	66	66	66	66	66	66	65	66
EQ	Pearson Correlation	.340**	.744**	1	.380**	-.335**	.492**	.669**	.665**	-.485**	-.502**
	Sig. (2-tailed)	.009	.000		.002	.006	.000	.000	.000	.000	.000
	N	58	66	66	66	66	66	66	66	65	66
MAIA_NO	Pearson Correlation	.160	.379**	.380**	1	-.440**	.576**	.509**	.423**	-.226	-.302*
	Sig. (2-tailed)	.232	.002	.002		.000	.000	.000	.000	.071	.014
	N	58	66	66	66	66	66	66	66	65	66
MAIA_ND	Pearson Correlation	-.112	-.375**	-.335**	-.440**	1	-.267*	-.280*	-.244*	.147	.441**
	Sig. (2-tailed)	.402	.002	.006	.000		.030	.023	.048	.244	.000
	N	58	66	66	66	66	66	66	66	65	66
MAIA_EA	Pearson Correlation	.340**	.472**	.492**	.576**	-.267*	1	.494**	.594**	-.290*	-.302*
	Sig. (2-tailed)	.009	.000	.000	.000	.030		.000	.000	.019	.014
	N	58	66	66	66	66	66	66	66	65	66
MAIA_AR	Pearson Correlation	.089	.684**	.669**	.509**	-.280*	.494**	1	.625**	-.402**	-.488**
	Sig. (2-tailed)	.508	.000	.000	.000	.023	.000		.000	.001	.000
	N	58	66	66	66	66	66	66	66	65	66
MAIA_BL	Pearson Correlation	.217	.429**	.665**	.423**	-.244*	.594**	.625**	1	-.289*	-.313*
	Sig. (2-tailed)	.102	.000	.000	.000	.048	.000	.000		.019	.010
	N	58	66	66	66	66	66	66	66	65	66
QIDS	Pearson Correlation	-.253*	-.406**	-.485**	-.226	.147	-.290*	-.402**	-.289*	1	.366**
	Sig. (2-tailed)	.049	.001	.000	.071	.244	.019	.001	.019		.003
	N	61	65	65	65	65	65	65	65	71	65
RRS	Pearson Correlation	-.186	-.515**	-.502**	-.302*	.441**	-.302*	-.488**	-.313*	.366**	1
	Sig. (2-tailed)	.161	.000	.000	.014	.000	.014	.000	.010	.003	
	N	58	66	66	66	66	66	66	66	65	66

**. Correlation is significant at the 0.01 level (2-tailed).

*. Correlation is significant at the 0.05 level (2-tailed).

Abbreviations: HRV= Heart Rate Variability across states; QIDS: Quick Inventory of Depressive Symptomology (Rush et al., 2003); EQ: Experience Questionnaire(Fresco, Moore, et al., 2007); FFMQ: Five Factor Mindfulness Questionnaire(R. A. Baer et al., 2008); RRS: Rumination Response Scale(Roelofs et al., 2006); MAIA (Multidimensional Assessment of Interoceptive Awareness(Mehling et al., 2012), and the subscales of AR: Attention Regulation; BL: Body listening; NO: Noticing; TR: Trusting; ND: Non distracting; EA: Emotional awareness.