

# Original Communication

## Mindfulness as Self-Regulated Attention

### Associations with Heart Rate Variability

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**Abstract.** Empirical research has demonstrated associations between heart rate variability (HRV) and the regulation of emotion and behavior. Similarly, self-regulation of attention to one's experience of the present moment in an accepting and nonjudgmental manner is an essential characteristic of mindfulness that promotes emotional and behavioral regulation and psychological well-being. The present study investigated the relationship between mindfulness and HRV. A total of 23 undergraduate psychology students completed a recently developed measure of mindfulness, the mindful breathing exercise (MBE), which assesses the ability to mindfully stay in contact with one's breath during breathing meditation. Moreover, indices of HRV were measured during a short version of the MBE. As predicted, positive correlations were found between indices of HRV and mindfulness. The findings demonstrate that the ability to mindfully regulate one's attention is associated with higher HRV, a physiological correlate of physical and psychological health, and therefore support on a physiological level the potential benefit of the implemented mindfulness exercises in mindfulness-based clinical interventions.

**Keywords:** mindfulness, heart rate variability, self-regulation, attention

Heart rate variability (HRV) – the variability in the time intervals between heart beats – is an important indicator of cardiac autonomic activity. Importantly, HRV is associated with physical and mental health. For example, decreased HRV has been established as a proxy for underlying cardiovascular disease processes (Stys & Stys, 1998) and predicts increased mortality following myocardial infarction (Kleiger, Miller, & Moss, 1987). Moreover, reduced HRV was found in patients suffering from depression in comparison to healthy controls (Agelink, Boz, Ullrich, & Andrich, 2002; Nahshoni et al., 2004) and generalized anxiety disorder (Thayer, Friedman, & Borkovec, 1996).

Appelhans and Luecken (2006) highlighted the role of HRV in the regulation of emotional response. Emotions are accompanied by varying degrees of physiological arousal, generated mainly by the autonomic nervous system. High HRV reflects an autonomic nervous system that is flexibly capable of generating the necessary states of physiological arousal associated with emotions (e.g., activating resources in association with anger while being attacked or relaxing the body and saving resources in times of calm). Such a flexible autonomic nervous system is adaptive, as it enables the generation of appropriate emotions and facilitates rapid adjustment to momentary situational demands (Appelhans

& Luecken, 2006). The individual's ability to adjust physiological arousal to situational conditions is critical for functional emotion regulation (Gross, 1998). HRV is an indicator of the flexibility of the autonomic nervous system and therefore an important marker of emotion regulatory ability (Appelhans & Luecken, 2006). Empirical studies support the association between HRV and emotion and behavior regulation (Fabes & Eisenberg, 1997; Segerstrom & Nes, 2007). Segerstrom and Nes (2007) demonstrated that participants displaying higher HRV at baseline also showed higher HRV during an anagram task and, importantly, tried more persistently to solve the anagrams. The authors suggested using HRV as an indicator or index of self-regulatory strength. In sum, there is evidence that higher HRV is associated with more adaptive and healthier functioning and better emotion and behavior regulation.

In the past two decades, the principle of mindfulness has gained importance in promoting healthy functioning and adaptive self-regulation of emotion and behavior. On a fundamental level, self-regulation is an inherent characteristic of mindfulness itself. This is evident in the definition of mindfulness, namely, paying attention in a certain way: on purpose, in the present moment, and nonjudgmentally (Kabat-Zinn, 1990). People practicing mindfulness strive to

stay in contact with the experience of the present moment in an attentive, conscious, and accepting manner. Mindfulness is therefore highly characterized by self-regulatory effort.

Several clinical interventions teach patients to cultivate mindfulness to promote emotion regulation and psychological health (Linehan, 1993; Segal, Williams, & Teasdale, 2002). For example, mindfulness-based cognitive therapy (MBCT; Segal et al., 2002) was developed to prevent relapse in recurrent depressive disorder. Intensive mindfulness training is used to help patients recognize and disengage from self-perpetuating patterns of ruminative and negative thoughts. Such disengagement is believed to prevent the onset of further depressive episodes. A number of empirical studies support the efficacy of MBCT (e.g., Kuyken et al., 2008; Ma & Teasdale, 2004). Emotion regulation enhanced by mindfulness training is also a central aim of dialectical behavioral therapy (DBT; Linehan, 1993) in the treatment of borderline personality disorder. Patients learn to develop mindfulness to increase emotional awareness in order to overcome typical problems, such as interpersonal difficulties and self-injurious or suicidal behaviors. Finally, recent research demonstrates that mindfulness-based interventions effectively treat anxiety disorders such as panic disorder with or without agoraphobia, social phobia, and generalized anxiety disorder (Vollestad, Sivertsen, & Nielsen, 2011). In sum, self-regulation of nonjudgmental attention is an inherent characteristic of mindfulness, which has been shown to promote functional emotion and behavior regulation.

The use of HRV as an index of self-regulatory strength, on the one hand, and the self-regulatory characteristic of mindfulness, on the other hand, suggest that HRV is an important physiological correlate of mindfulness. Do mindful people, who are able to regulate and to focus their attention nonjudgmentally on the present moment, have higher HRV? To date, this question has not been examined in detail. Several studies showed that HRV increases during meditation and with the training of meditation (Ditto, Eclache, & Goldman, 2006; Lehrer, Sasaki, & Saito, 1999; Takahashi et al., 2005). For example, Ditto et al. (2006) demonstrated an increase in HRV in participants practicing the body scan exercise of the Mindfulness-Based Stress Reduction Program (MBSR; Kabat-Zinn, 1990). However, since the level of self-regulated attention was not measured in previous studies, a specific association between HRV and the ability to self-regulate attention to the experience of the present moment has not been demonstrated yet. The reported observations could also be explained alternatively. For example, regardless of the focus of attention, the practice of mindfulness may create deeper states of relaxation, which would be expected to be associated with a higher HRV (reflecting mainly the respiratory sinus arrhythmia) because of a higher parasympathetic influence (vagal tone). Therefore, it is possible that a relaxed but sleepy (unmindful) mind during a mindfulness exercise is associated with higher HRV. The solution to this problem is to directly as-

sess people's ability to mindfully self-regulate their attention as the present study sought to do.

The present study aimed to test whether HRV is a physiological correlate of mindfulness; a single convenience sample was employed for an initial exploration of this hypothesis. To assess mindfulness, we employed the mindful breathing exercise (MBE), a recently introduced measure of mindfulness (Burg & Michalak, 2011). The MBE assesses the participant's ability to mindfully stay in contact with the bodily sense of the breath during an exercise aligned with breathing meditation, a central mindfulness practice in Buddhism as well as in modern mindfulness-based clinical interventions. We expected to find positive correlations between indices of HRV and mindfulness as assessed by the MBE. Support for our predictions would suggest HRV as a possible important physiological correlate of the mindful state of mind.

## Method

### Participants

A total of 23 (20 females, 3 males) undergraduate psychology students of the Ruhr University Bochum, Germany, participated in the study. Their mean age was 23.8 years ( $SD = 4.7$ , range: 19 to 35 years). This nonclinical sample's mean ( $M = 11.8$ ) and standard deviation ( $SD = 6.7$ ) on the Allgemeine Depressions-Skala (ADS; Hautzinger & Bailer, 1993; German version of the Center of Epidemiological Studies Depression Scale) were lower than the values reported by Hautzinger & Bailer (1993) based on a sample of the general population ( $M = 14.3$ ;  $SD = 9.7$ ). Most of the participants had no meditation experience; only two participants indicated that they had meditated regularly for more than 1 year. All participants gave informed consent and received class credit for participation.

### Measures

#### Mindful Breathing Exercise (MBE)

The mindful breathing exercise (MBE; Burg & Michalak, 2011) measures participants' ability to mindfully stay in contact with their breath during breathing meditation. Participants sit in front of a computer screen wearing earphones and holding a computer mouse on their lap. They start by reading a short introduction on the meaning of mindfulness and meditation (e.g., being mindful in the present to worship life, returning to one's breath in an accepting and patient manner). Next, participants are instructed to mindfully observe and sense their breath while seated in a semireclined position looking at an arbitrary point in the lower visual field. They are asked to return to their breath nonjudgmentally when their mind wanders and to give a response each time they hear a tone: To press the left button

whenever they sense their breath at the moment of the tone (mindful) and to press the right button whenever they do not sense their breath (mindless). In addition, they are asked to press the right button each time they notice on their own, independently of a signal, that they are not in contact with their breathing. The entire MBE period comprises 22 phases, each consisting of a period of silence and a signal tone at the end. The first phase always lasts 20 s. The remaining 21 phases are randomized (20, 30, 40, 50, 60, 70, 80 s, three times each). Consequently, the MBE lasts just under 18 min (without instruction). The score of the task is calculated as the sum of all phases during which the participant's mind never wandered (no click within the period and a left click at the end upon the signal). Thus, the maximum possible score for the MBE is 22. Moderate positive correlations with self-reports of mindfulness (Kentucky Inventory of Mindfulness Skills and Mindful Attention and Awareness Scale) as well as negative correlations with measures of rumination and depression in a sample of 42 students support the validity of this assessment method of mindfulness (Burg & Michalak, 2011). Moreover, the MBE can claim high ecological validity because of its alignment with one of the most central mindfulness exercises, namely, breathing meditation.

### Heart Rate Variability (HRV)

HRV was measured by a Polar WearLink® W.I.N.D. transmitter, which participants wore around their chest, and a Polar RS800 heart rate monitor watch, which they wore on their wrist. The watch recorded the signals from the transmitter. We chose a sampling frequency of 1000 Hz, which provided a temporal resolution of 1 ms for each RR interval (i.e., the interval between two consecutive R waves on the electrocardiogram). We did not measure HRV during the actual MBE to avoid possible effects of the belt (e.g., belt tension) on the participants' ability to mindfully stay in contact with the bodily sense of the breath. To collect the HRV data, we asked participants to put the belt on after the actual MBE and to repeat a short version of the MBE (another program which terminated after about 7 min) with identical instructions, while the Polar RS 800 assessed the HRV. A time frame of 5 min of the short MBE was used for HRV assessment, starting at 1:30 min and ending at 6:30 min. The only purpose of the short MBE was to measure the HRV during the mindfulness task. The scores (mindful phases) were not analyzed. The HRV data were analyzed with Polar specific software (Polar ProTrainer 5™). The software contains an automatic RR interval filtering and interpolation algorithm, which was used to correct for aberrant beats and errors. The default setting of a minimum beat protection zone of 6 beats\*min<sup>-1</sup> was chosen. Heart rate and time-domain measures of HRV were calculated: The standard deviation of the NN ("normal-to-normal," representing R waves based on depolarization of the sinus node) intervals (SDNN), the square root of the

mean squared differences of successive NN intervals (RMSSD), and the number of interval differences of successive NN intervals greater than 50 ms divided by the total number of NN intervals (pNN50) (Task Force of the European Society of Cardiology and the North American Society of Pacing and Electrophysiology, 1996). Previous studies have demonstrated the reliability and validity of the Polar S810 (Gamelin, Berthoin, & Bosquet, 2006; Nunan et al., 2008), an older model of the heart rate monitor used in the present study.

### Procedure

Data collection took place in a comfortable windowless laboratory. Each participant was assessed twice, 1 week apart. We held two sessions to attain better estimates of the variables, particularly of the HRV measures, as especially physiological variables often reveal a certain susceptibility to unintended factors (events just before the study session, study distress, etc.). Accordingly, retest reliabilities for the physiological measures were not very high (SDNN:  $r = .40$ ; RMSSD:  $r = .50$ ; p50NN:  $r = .53$ ), as compared to the retest reliability of the MBE ( $r = .70$ ). In order to avoid potential bias due to circadian rhythm, all sessions were held between 2 p.m. and 6 p.m. Participants were told not to drink coffee or to smoke after 12 a.m. After providing informed consent, participants were left alone in the laboratory to complete the MBE. Next, during the short version of the MBE, HRV was assessed with Polar RS800. The same procedure was repeated about 1 week later.

### Statistical Analyses

The data of the two study sessions were aggregated for each variable by computing the arithmetic average of the two time points. All analyses are based on the aggregated variables, which were checked for normality and influential outliers. As the inspection revealed clear deviances from normality concerning the variables MBE, RMSSD, and pNN50 and as no conventional transformation could improve the situation sufficiently, we decided to carry out all correlations as nonparametric correlations (Spearman's rank correlation). Statistical tests were calculated one-tailed based on the predictions outlined in the introduction.

### Results

The study results are displayed in Table 1. No association between the MBE ( $M = 14.0$ ;  $SD = 4.2$ ; range 8–21) and heart rate was expected or found. However, two out of three predicted correlations between the MBE and measures of HRV reached statistical significance. The analysis revealed a significant and moderate positive association between the

**Table 1**  
*Descriptive statistics and Spearman's rank correlations between the MBE and heart rate as well as measures of heart-rate variability*

Variable	<i>M</i>	<i>SD</i>	<i>r</i>
HR	72.9	13.9	.12
SDNN	78.0	25.1	.36*
RMSSD	60.6	26.9	.36*
pNN50	16.3	9.1	.25

*Notes.* *N* = 23. HR = heart rate; SDNN = standard deviation of normal-to-normal RR intervals; RMSSD = square root of the mean of the sum of the squares of differences between adjacent NN intervals; pNN50 = number of interval differences of successive NN intervals greater than 50 ms divided by the total number of NN intervals. \**p* < .05.

MBE and the SDNN as well as between the MBE and the RMSSD. Participants who were more able to mindfully stay in contact with their breath during the MBE displayed higher HRV as indicated by the SDNN and the RMSSD. The correlation with the pNN50 was in the expected direction, but not statistically significant.

Because there were only three male participants in the sample, we conducted a supplementary analysis based only on the 20 female participants. The results were identical regarding statistical significance.

## Discussion

Previous research considers HRV an indicator of the ability to regulate one's emotions and behavior. Similarly, self-regulation is an essential characteristic of mindfulness. We hypothesized that HRV is a physiological correlate of mindfully self-regulated attention. Overall, the results support this assumption. Participants better able to self-regulate their attention to breathing during the MBE displayed significantly higher values on two of three indices of HRV. These findings extend current knowledge of the association between mindfulness and physiology. Previous studies showed an increase in HRV during mindfulness practice and with advanced training in mindfulness (Ditto et al., 2006; Lehrer et al., 1999). However, the relevance of the self-regulatory characteristic of mindfulness to these physiological observations remained unclear. Keeping in mind the definitions of mindfulness that describe it as self-regulated nonjudgmental attention to the present moment (Bishop et al., 2004; Kabat-Zinn, 1990), it is important to assess this self-regulatory ability in the research on physiological correlates of mindfulness. The present findings and the previous research on the role of HRV in self-regulation support the view that higher HRV during mindfulness practice might be at least in part an indication of enhanced self-regulated attention to the experience of the present moment. Thus, the results suggest that HRV is a physiological cor-

relate of a mindful state. Similarly, the findings provide evidence that the increasing HRV observed over time among people practicing mindfulness might indeed indicate a higher level of self-regulated attention to the experience of the present moment. Therefore, the correlations reported in the present study support the intensive application of mindfulness exercises that teach people how to focus their attention on their breathing (breathing meditation) or their bodily sensations (body scan exercise), within mindfulness-based interventions such as MBSR and MBCT because the regulatory ability cultivated in these mindfulness exercises is associated with an important physiological parameter indicating better health and more functional adaptation.

However, some limitations of the study must be acknowledged. First, the sample size was relatively small and the participants were predominantly female. This convenience sample served to reveal the existence of an association between mindfulness and HRV, but is not sufficient to establish that these findings can be generalized to other populations; future research is needed for that. Second, so far only one study has supported the validity of the recently developed MBE for the assessment of mindfulness. This might be a limitation of the study. Interestingly, Bishop et al. (2004) distinguished two components of mindfulness: Self-regulation of attention and orientation to experience. The MBE particularly focuses on self-regulation of the attention component of mindfulness. Although the MBE can claim high ecological validity because of the alignment with one of the most central mindfulness exercises (breathing meditation), it is also true that mindfulness is more than regulation of attention to one's breathing, but also includes an attitude of acceptance, appreciation, and curiosity toward one's experiences (orientation to experience). Therefore, it is important to keep in mind that the reported correlations between mindfulness and HRV are based particularly on self-regulation of the attention component of mindfulness. Addressing the issue of validity, future research might examine a group of experienced meditators and a group of inexperienced controls to test whether MBE scores and HRV indices are affected by meditation experience. Finally, no causal inferences can be drawn based on the correlational data of the present study. Instead, the results suggest that HRV may be an important physiological correlate of self-regulated attention during mindfulness practice. However, it would be interesting to further investigate whether, for example, increasing HRV by means of HRV feedback training improves mindful self-regulation of attention during the MBE.

In summary, the present study suggests that HRV, as a well-known physiological indicator of self-regulation, may be an important correlate of the self-regulatory characteristic of mindfulness. Bearing in mind that higher HRV predicts physical and psychological health and adaptation (Appelhans & Luecken, 2006; Thayer, Hansen, Saus-Rose, & Johnsen, 2009), the results indicate that a mindful state of mind is associated with beneficial physiological processes promoting well-being.

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