Degree project

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The Effects of Mindfulness Meditation on Stress Measured by Heart Rate Variability: A Systematic Review

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Abstract

Stress is a global health issue and effective stress management techniques are much needed. Mindfulness meditation in the form of mindfulness-based interventions have been shown to be effective interventions for self-reported stress reduction. However, the effects of mindfulness meditation on the objective physiological markers of stress are less clear. Heart rate variability, the variation in time between each consecutive heartbeat has been shown to be such an objective physiological marker of stress. The aim of this systematic review was to investigate how mindfulness-based interventions affect heart rate variability to better understand the utility of mindfulness meditation as a stress management technique. A literature search was conducted on March 8th, 2022, with the databases Web of Science, Scopus, and MEDLINE EBSCO to identify randomized controlled trials that examined the effects of mindfulness-based interventions on heart rate variability. A total of 10 studies met the inclusion criteria with a total of 970 participants. The results from the systematic review were mixed and indicate inconsistencies across the literature. Thus, there are uncertainties on how mindfulness-based interventions affect heart rate variability. Although the systematic review was limited by a small sample of studies, it highlights that further research on how mindfulness-based interventions affect heart rate variability is needed to better understand the utility of mindfulness meditation as a stress management technique.

Keywords: stress, mindfulness meditation, mindfulness-based interventions, heart rate variability

The Effects of Mindfulness Meditation on Stress Measured by Heart Rate Variability: A Systematic Review

Many people experience stress in their everyday lives. May it be stress from work or stress from taking care of crying children. Lazarus and Folkman (1984) defined stress as the interpretation of potentially threatening stimuli that can exceed the resources of the individual. Chronic stress can lead to consequences such as cardiovascular disease, obesity, stroke, autoimmune disease, depression, and anxiety (Schneiderman et al., 2005; Sharma & Rush, 2014). Stress is a global health issue and stress management techniques including exercise, time management, social skills, and yoga are much needed (Sharma & Rush, 2014). Recently, *mindfulness meditation* has emerged in the Western culture which can potentially combat the consequences of chronic stress (Baer, 2003; Kabat-Zinn, 2003). Researchers' interest in mindfulness meditation has grown and the field of neuroscience is starting to prove that brain changes are associated with such training (Young et al., 2018).

Mindfulness Meditation

Mindfulness originates from the Buddhist philosophy and is linked to meditation practices (Shapiro et al., 2006). Buddhist meditation has been practiced for more than 5000 years for spirituality and healing (Chiesa & Malinowski, 2011). The historical Buddha meditated to contemplate the nature of suffering (Kabat-Zinn, 2003) and from his teachings, the two meditation techniques Samatha or Samadhi and Vipassana emerged. The latter technique might be familiar to people in the Western culture as mindfulness meditation (de Benedittis, 2015). Researchers of Western modern psychology often use the definition of mindfulness provided by Jon Kabat-Zinn (Shapiro et al., 2006). He defined mindfulness as "paying attention in a particular way: on purpose, in the present moment, and non-judgmentally" (Kabat-Zinn, 1994, p.4). People who practice meditation, defined as the intentional self-regulation of attention from moment to moment (Kabat-Zinn, 1982) can reach a state of mindfulness (Chiesa & Malinowski, 2011).

Mindfulness-Based Interventions

In 1979, Jon-Kabat Zinn developed a *mindfulness-based intervention* (MBI), known as *mindfulness-based stress reduction* (MBSR) (Kabat-Zinn, 2003). Kabat-Zinn (1982) used MBSR for patients with chronic pain where they learned to observe thoughts and situations without judging or reacting to them. During the 10-week program, a group of individuals met up for body scanning, meditation, and yoga for two hours each week. Furthermore, they practiced at home for 45 min per day and completed an intensive mindfulness meditation retreat. The results showed a decrease in pain frequency and severity. MBSR is the most popular type of mindfulness practice in clinics and one of the most well-studied MBIs (Khoury et al., 2015; Purser & Milillo, 2015). However, abbreviated forms have been developed because the full format might not be possible for some groups (Carmody & Baer, 2009).

A group of psychologists developed another MBI called *mindfulness-based cognitive therapy* (MBCT) in the early 1990s (Teasdale et al., 1995). MBCT prevents relapse in depression where it integrates aspects of both cognitive-behavioral therapy and MBSR. Individuals who have experienced major depression are prone to negative automatic thinking when exposed to mild dysphoria and are therefore likely to relapse into a major depressive episode (Teasdale et al., 1995). MBCT teaches individuals to pay attention to their negative automatic thoughts and see them as “mental events” instead of identifying with them (Teasdale et al., 2000). Randomized controlled trials have found that MBCT reduces relapse rates of depression in patients with three or more depressive episodes (Keng et al., 2011).

Other MBIs that do not require formal meditation practice are *acceptance and commitment therapy* (ACT) and *dialectical behavior therapy* (DBT) (Keng et al., 2011). ACT teaches individuals to reach higher psychological flexibility by connecting with the present moment, recognizing their values, and then committing to those values. The founders of ACT developed six core processes for the treatment: acceptance, cognitive defusion, being present, self as context, values, and committed action. The first four processes integrate mindfulness aspects (Hayes et al., 2006). DBT was developed as a treatment for patients with borderline personality disorder who displayed self-harmful behaviors (Linehan et al., 1991). DBT focuses on the underlying emotional problems by changing their thoughts, emotions, and behaviors with aspects from both cognitive-behavioral therapy and Zen philosophy (Keng et al., 2011).

Research on Mindfulness Meditation

MBIs have sparked an interest among researchers in the last two decades. It has been found that MBIs improve symptoms of anxiety, depression, and have a small effect on reducing pain intensity (Goldberg et al., 2018; Khoury et al., 2013; Veehof et al., 2016). Eberth and Sedlmeier (2012) investigated the effects of MBIs in non-clinical settings. They found a small to medium effect size on improvements in psychological variables such as anxiety, attention, cognition, emotion regulation, intelligence, self-attributed mindfulness, negative emotions, negative personality traits, neuroticism, well-being, positive emotions, self-concept, self-realization, and stress. Furthermore, MBIs and yoga have positive effects on psychological well-being and behavioral functioning in prisoners (Auty et al., 2015). But these findings should be viewed in the light of some criticism. Researchers of mindfulness meditation fail to agree on a single definition of “mindfulness”. Consequently, there is variation across studies on what type of “mindfulness” has been studied (Van Dam et al., 2018). Additionally, many studies that examined the efficacy of MBIs have lacked active control groups, which makes the evidence unconvincing and may only lead to preliminary implications (Davidson & Kaszniak, 2015; Van Dam et al., 2018).

However, MBIs appear to be an effective intervention for stress reduction. Chiesa and Serretti (2009) conducted the first meta-analysis on the efficacy of MBIs in stress reduction and concluded that MBIs had a positive nonspecific effect on self-reported stress reduction. More recent systematic reviews and metanalyses found moderate effects of MBIs in reducing self-reported stress in non-clinical populations (e.g., Khoury et al., 2015; Sharma & Rush, 2014). Morton et al. (2020) also found that MBIs reduced self-reported stress. However, they found mixed results on the physiological markers of stress and could not conclude that MBIs had positive effects on all aspects of stress reduction. Mindfulness meditation research has focused too much on the self-reported outcomes from MBIs but should move towards the objective physiological markers of stress, as they are less influenced by self-report biases (Brown et al., 2021; Morton et al., 2020).

Physiological Markers of Stress

One objective physiological marker of stress is cortisol. The brain activates the hypothalamic-pituitary-adrenal (HPA) axis in response to stress and releases glucocorticoids (Juster et al., 2010). The adrenal gland produces the naturally occurring glucocorticoid cortisol and these cortisol levels can be measured in blood serum, saliva, urine, and hair (Condon, 2018). Measurements of blood serum and saliva can also detect other markers of stress such as pro-inflammatory cytokines which cause inflammation and anti-inflammatory cytokines which slow down the pro-inflammatory cytokines (Condon, 2018). Chronic stress can also lead to structural changes in the brain (McEwen, 2008). For example, the memory "hub" hippocampus decreases in volume and neural activity during chronic stress (Condon, 2018; Kim & Yoon, 1998; Sapolsky, 2000). These neurological changes can be objectively measured with neuroimaging techniques (Condon, 2018). Furthermore, *heart rate variability* (HRV) is another objective physiological marker of stress (Kim et al., 2018). HRV reflects the variation of successive heartbeats and is affected by autonomic regulation (Billman, 2011). Researchers appreciate HRV measurements because it is non-invasive, relatively affordable, and easy to collect (Laborde et al., 2017). It can be collected via portable electrocardiogram (ECG) devices which allows the subjects to move freely in their everyday environment. This technological development has increased the ecological validity of HRV measurements (Massaro & Pecchia, 2019) and will be used as the outcome measurement of stress in this systematic review.

Heart Rate Variability

A healthy heart does not beat in perfect synchrony like a metronome (Shaffer et al., 2014). Instead, the time between each consecutive beat varies and this is HRV (Shaffer & Ginsberg, 2017). An ECG measures HRV by recording how the heart depolarizes (contracts), represented as the QRS-complex. The highest point of the QRS-complex is the peak of the R-wave and the time between each R-wave peak is called the R-R interval (Reed et al., 2005). HRV is the variability between the R-R intervals (Billman, 2011).

Researchers use HRV to investigate the balance between the divisions of the autonomic nervous system which regulates stress (Berntson et al., 1997). The sympathetic nervous system (SNS) also known as the *"fight or flight response"* prepares the body for stressful situations. The parasympathetic nervous system (PNS) also known as the *"rest and digest response"* activates during restful situations via the vagus nerve to recalibrate the body into a balanced state (i.e., homeostasis) (Massaro & Pecchia, 2019). The two autonomic nervous systems affect the heart rate (HR) by innervating the heart's sinoatrial and atrioventricular nodes. The SNS releases epinephrine and norepinephrine to speed up the action potentials, resulting in a higher HR and lower HRV. By contrast, the PNS releases acetylcholine and slows down the action potential production, resulting in a lower HR and higher HRV (Berntson et al., 1997; Karim et al., 2011). HRV can sometimes be mistaken for respiratory sinus arrythmia (RSA) (Billman, 2011). RSA refers to HRV in synchrony with the respiratory cycle. HR increases during inspiration and slows down during expiration (Yasuma & Hayano, 2004).

HRV Methods

The two most common approaches to quantify HRV are the time-domain and the frequency-domain methods. Both can be determined by measuring the heart rate at any point in time or the normal to normal (NN) interval (time between each QRS complex) (Billman, 2011).

Time-Domain Methods

A simple time-domain method is the standard deviation of all normal NN intervals (SDNN), where normal means all heartbeats except those not generated by sinus node depolarization. SDNN reflects all components responsible for HRV and thus total variability (Shaffer et al., 2014), where a higher SDNN represents an increase in HRV (Kim et al., 2018). A similar method is the standard deviation of the interbeat intervals for all sinus beats (SDRR) which includes abnormal beats (Shaffer & Ginsberg, 2017). Researchers also use the root mean square of successive differences between normal heartbeats (RMSSD) to measure HRV (Laborde et al., 2017). They square each successive time difference between heartbeats in ms and then average that before they obtain the square root of the total. RMSSD measures the beat-to-beat variance and represents PNS activity. Other time-domain methods are SDANN, SDNNI, NN50, and pNN50 (Shaffer & Ginsberg, 2017).

Frequency-Domain Methods

The Task Force of the European Society of Cardiology and the North American Society of Pacing and Electrophysiology (1996) proposed that HRV can be broken down to its underlying component rhythms in different frequency bands. One can use a Fast Fourier Transform or autoregressive modeling to break down HRV into the following frequency bands: ultra-low frequency (ULF), very-low-frequency (VLF), low-frequency (LF), and high-frequency (HF). Shaffer and Ginsberg (2017) suggested that the frequency bands reflect different physiological mechanisms. For example, the HF band (0.15-040 Hz) reflects PNS activity, whereas the LF band (0.04-0-15Hz) reflects both SNS and PNS activity. However, there are still uncertainties regarding the physiological mechanisms behind the ULF band (<0.003Hz) and the VLF band (0.0033-0.04Hz) (Shaffer & Ginsberg, 2017).

The ratio of LF to HF power (LF/HF ratio) is thought to quantify the balance between SNS and PNS activity (Shaffer & Ginsberg, 2017). The HF power reflects PNS activity whereas LF power, although more complex, mainly reflects SNS activity. A low LF/HF ratio indicates PNS activity and a high LF/HF ratio indicates SNS activity (McCraty & Shaffer, 2015). However, the LF/HF ratio should be interpreted with caution because the LF power is not only a result of SNS activity but also PNS activity (Billman, 2013).

HRV and Stress

Allostasis is the process where the body adapts to daily stressors and maintains homeostasis through change (McEwen, 2008). But if the stress response (HPA axis and SNS) stays active for too long without the inhibitory PNS, chronic stress occurs known as "allostatic overload" (McEwen, 2008). Thus, measurements of PNS such as HRV can objectively measure stress. For example, a reduced HRV indicates impairments in the homeostatic autonomic nervous system, which weakens the body's ability to handle internal and external stressors (Kim et al., 2018). By contrast, a higher HRV indicates more PNS activity ("rest and digest response") with more efficient autonomic regulation. Here, the body can adapt to stressors and return to homeostasis (McCraty & Shaffer, 2015; Shaffer & Ginsberg, 2017). Moreover, higher HRV is associated with improved regulatory capacity (McCraty & Shaffer, 2015) and with improved performances on tasks that require executive functions (Thayer et al., 2009).

The Present Systematic Review

A previous meta-analysis by Brown et al. (2021) concluded that MBIs do not increase HRV relative to control conditions, whereas Rådmark et al. (2019) reached mixed and inconclusive results. By contrast, a scoping review by Christodoulou et al. (2020) suggested that MBIs increase HRV reactivity (adaptive change in response to a stressor). The present systematic review aims to further investigate how MBIs affect HRV. It will investigate studies that have included a control group (active or non-active) and used HRV as the outcome measure of physiological stress to overcome the limitations of self-report measurements in mindfulness meditation research. This investigation will complement previous studies on mindfulness meditation (e.g., Morton et al., 2020) to better understand its utility as a stress management technique.

Methods

Search Strategy

A literature search was conducted on March 8th, 2022, with the databases Web of Science, Scopus, and MEDLINE EBSCO. Based on previous studies on MBI and HRV, the search terms relating to MBI were the following: (mindful* OR meditat* OR "mindfulness based intervention" OR "mindfulness meditation" OR vipassana OR "mindfulness based stress reduction" OR "mindfulness based cognitive therapy" OR "dialectical behavior therapy" OR "acceptance and commitment therapy"). The search terms relating to "heart rate variability" were the following: ("heart rate variability" OR HRV OR "respiratory sinus arrythmia" OR SDNN OR RMSSD OR "LF band" OR "HF band" OR "LF/HF ratio"). The search terms relating to "MBI" were then combined with the search terms relating to "heart rate variability" by using the Boolean operator "AND". The search strings were adjusted to fit the format of each database. The overall search results were exported to EndNote online by Clarivate Analytics for detection and deletion of duplicates. After that, titles and abstracts were screened and assessed for eligibility. The remaining articles were then assessed based on full-text reading (see figure 1 for a PRISMA flow diagram).

Inclusion/Exclusion criteria

The studies were selected based on the PICO components (Participants, Intervention, Comparison, Outcome). P-Humans over the age of 18 including participants with psychiatric disorders (e.g., PTSD) with little, or no prior meditation experience. I-MBI (e.g., MBSR, MBCT, DBT, or, ACT) of all durations. C-Active control group (e.g., interventions other than MBIs) or non-active control group (e.g., wait-list control group). O-HRV reported in the time-domain (e.g., RMSSD) or in the frequency-domain (e.g., HF-HRV). Published peer-reviewed articles written in English were included and there were no limits on the year of publication. Only randomized controlled trials were included. Any papers that were not original research articles (e.g., review articles, editorials, book chapters, or conference papers), or written in any other language than English were excluded.

Data Extraction

The following data were extracted from the studies: reference, country, population, sample size, gender, age (mean and standard deviation), type of intervention (name and duration), type of comparison, HRV measure, HRV device, and duration of the measurement.

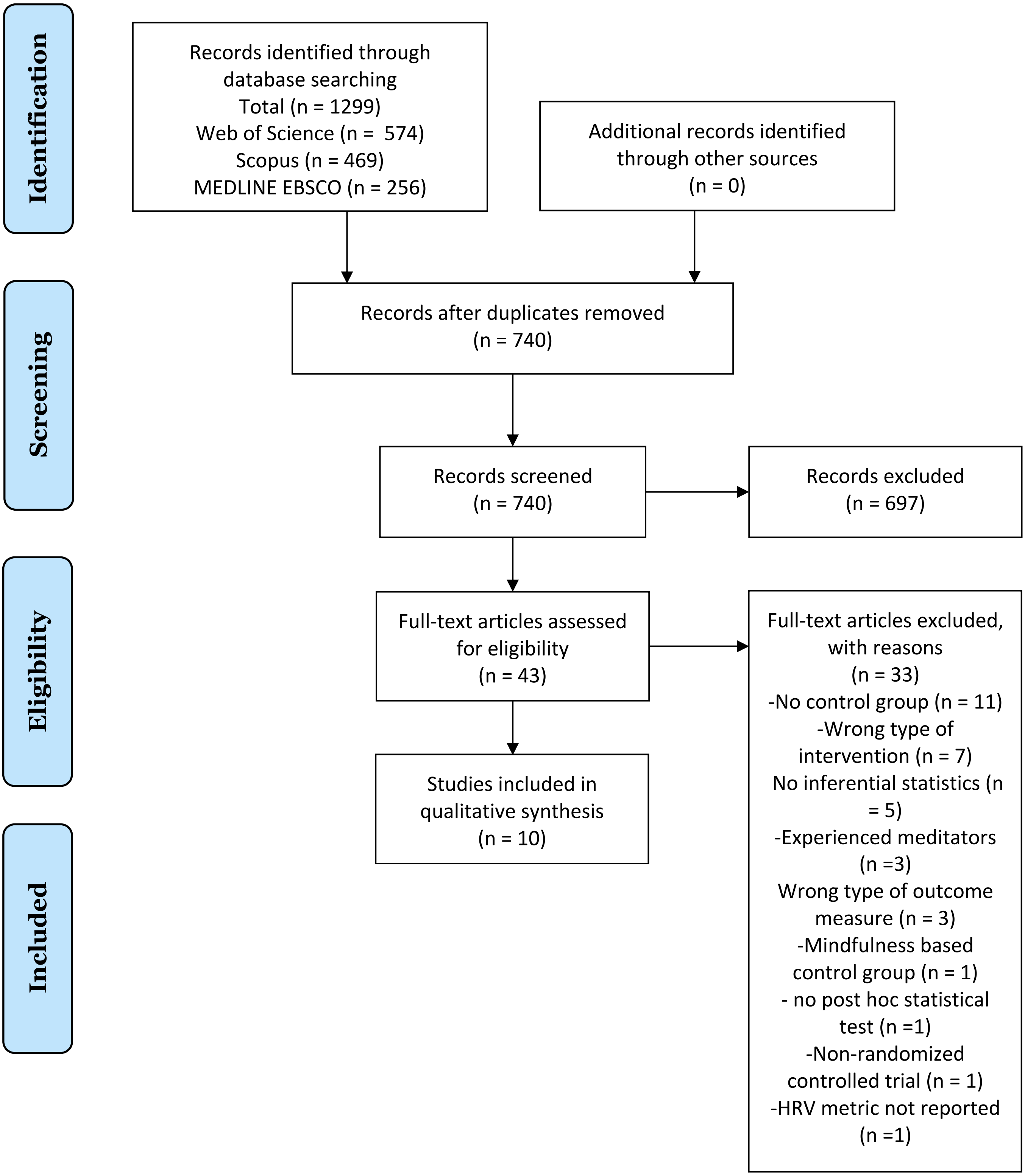
Results

Search Results

The database search yielded a total of 1299 records. After the removal of duplicates, a total of 740 records remained. After the first sitting (title/abstract reading), 697 records were excluded and 43 records were included. After the second sitting (full-text reading), 33 records were excluded with reasons and 10 records were included for the qualitative synthesis. Reasons for exclusion: no control group (n = 11), wrong type of intervention (n = 7), no inferential statistics (n = 5), experienced meditators (n = 3), wrong type of outcome measure (n = 3), mindfulness-based control group (n = 1), no post hoc statistical tests (n = 1), non-randomized controlled trial (n = 1), and HRV metric not reported (see figure 1 for a PRISMA flow diagram).

Figure 1

PRISMA 2009 Flow Diagram



Note. Standard flow diagram used to document the literature search process (Moher et al., 2009).

Study Characteristics

Most of the included studies were conducted in the USA (n = 6). The rest of the studies were conducted in a variety of countries: Spain (n = 1), Ireland (n = 1), Denmark (n = 1), and Germany (n = 1). Six studies were conducted on a healthy population, one on a population with substance use disorder (Carroll & Lustyk, 2018), one on breast cancer survivors (Crosswell et al., 2017), one on university students high in worry (Delgado-Pastor et al., 2015), and one on mildly stressed adults (Oken et al., 2017). A total of 970 participants (allocated to intervention or control group) were included from all studies. While most studies included both genders, two studies only included females (Crosswell et al., 2017; Delgado-Pastor et al., 2015), and one study did not report the gender (Dunne et al., 2019). Participants' mean age ranged from 19.3 years (Hunt et al., 2018) to 59.8 years (Oken et al., 2017). Five studies used an active control group, whereas five studies used a non-active control group. Six studies reported HRV in the time-domain, two studies reported HRV in the frequency-domain, whereas two studies reported HRV in both domains (see table 1 for study characteristics).

Table 1
Study Characteristics of Included Studies

Reference (country)	Population, sample size (no. of males), (randomized or after dropouts)	Mean age years (*M*), standard deviation (*SD*), approx. [a]	Intervention (duration)	Comparison	HRV measure	HRV device	Duration of measurement
Brinkmann et al. (2020) (USA)	Healthy adults, 52 (15), (after dropouts)	*M* = approx. 43.3, *SD* = approx. 10.4	Mixture of MBSR, ACT, and MBCT (30 min each day for six weeks)	Heart rate variability-biofeedback and wait-list control group	SDNN and RMSSD	ECG via two electrodes and an ear clip	Deep breathing test (not reported), RSA measurement (1 min), and short-term (5 min)
Carroll and Lustyk (2018) (USA)	Substance use disorder, 34 (25), (both)	*M* = 43.4, *SD* = 9.7	MBRP, (eight weeks)	RP and TAU	HF-HRV	ECG via PowerLab 8/35 high performance data acquisition system	Baseline (7 min), stress test (7 min), and recovery period (2 x 7 min)
Crosswell et al. (2017) (USA)	Breast cancer survivors, 71 (0), (both)	*M* = 47, *SD* = not reported	MAPs (six weekly 2 hr group sessions)	Wait-list control group	RMSSD	ECG and ICG via Biopac Systems	Baseline (10 min), task (5 min), post task (not reported), and rest (12 min)
Delgado-Pastor et al. (2015) (Spain)	University students high in worry, 45 (0), (randomized)	*M* = 21.5, *SD* = 3.9	Mindfulness interoceptive and mindfulness cognitive training (2 hr each week for three weeks)	Non-intervention control group	RMSSD	ECG via Biopac-instrument (model MEC-110C)	Baseline (5 min), worry period (5 min), and mindfulness period (5 min)
Dunne et al. (2019) (Ireland)	Emergency department personnel, 42 (not reported), (after dropouts)	Not reported	ABT program (four 4 hr sessions + home practice 40 min each day for seven weeks)	Non-intervention control group	HF-HRV	Wearable charge 2 device by Fitbit	24 hr
Hunt et al. (2018) (USA)	College students, 119 (31), (randomized)	*M* = 19.3, *SD* = not reported	MM and MM with yoga (weekly sessions for 4 weeks)	Dog therapy, yoga, and non-intervention control group	SDNN	emWave Pro by HeartMath	Baseline (5 min) and during stress task (not reported)

Reference (country)	Population, sample size (no. of males), (randomized or after dropouts)	Mean age years (*M*), standard deviation (*SD*), approx. [a]	Intervention (duration)	Comparison	HRV measure	HRV device	Duration of measurement
Kirk and Axelsen (2020) (Denmark)	College students, 90 (27), (after dropouts)	*M* = approx. 36.6, *SD* = approx. 10.5	MM (20-30 min each day for 10 days)	Music-listening and non-intervention control group	RMSSD, HF-HRV, and LF/HF ratio	ECG via Firstbeat Bodyguard II HRV monitor	Pre-and post-intervention 48 hr and during training 20-30 min
Krick and Felfe (2020) (Germany)	Police officers, 267 (210), (both)	*M* = 26, *SD* = 5.6	Mixture of MBSR and other MBIs (six weeks of 2 hr weekly sessions)	Non-intervention control group	RMSSD	Polar V800	Before and after the first and the last session (5 min)
Oken et al. (2017) (USA)	Mildly stressed adults, 134 (27), (randomized)	*M* = approx. 59.8, *SD* = approx. 6.8	Mixture of MBSR and MBCT (60-90 min sessions once a week for six weeks + 30-45 min home practice each day)	Wait-list control group	SDRR and LF/HF ratio	ECG	Pre-and post-intervention (5 min)
Shearer et al. (2016) (USA)	College students, 74 (32), (randomized)	Not reported	MBI based on MBSR (1 hr session once a week for four weeks)	Dog therapy and non-intervention control group	SDNN	ECG via Vernier LabQuest Mini	During stress test (not reported)

Note. ABT = Attention-based training; ACT = Acceptance and commitment therapy; ECG = Electrocardiogram; ICG = Impedance cardiography; HF-HRV = High frequency heart rate variability; LF-HRV = Low frequency heart rate variability; LF/HF ratio = Ratio of LF to HP power; MAPs = Mindfulness awareness practices; MBCT = Mindfulness-based cognitive therapy; MBI = Mindfulness based intervention; MBRP = Mindfulness-based relapse prevention; MBSR = Mindfulness-based stress reduction; MM = Mindfulness meditation; RP = Relapse prevention; RMSSD = Root mean square of successive differences; SDNN = Standard deviations of all normal NN intervals; SDRR = Standard deviation of the interbeat intervals for all sinus beats; TAU = Treatment as usual.

[a] Combined means and standard deviations of several groups. Calculations based on the formula given in table 7.7.a in the Cochrane handbook (Higgins et al., 2022).

Studies With an Active Control Group Reporting HRV in the Time-Domain

Brinkmann et al. (2020) examined the effectiveness of MBI on stress reduction in 69 healthy adults. The researchers randomly assigned participants to MBI, heart rate variability-biofeedback (HRV-Bfb), or a wait-list control (WLC) group. The MBI included formal guided meditations and informal exercises based on a mixture of MBSR, ACT, and MBCT. The HRV-Bfb group used a mobile HRV device to breathe at an optimal frequency to increase HRV. Both training groups practiced for 30 min each day for six weeks. The researchers assessed the participants' HRV at pre-intervention, post-intervention, and after twelve weeks. Each assessment consisted of a deep breathing test, a 1 min RSA measurement during which participants breathed six breaths/min, and a short-term HRV-test for 5 min during which participants breathed at their own pace. The researchers measured ECG with two electrodes and an ear clip. They reported HRV in RMSSD and SDNN. They analyzed data from 52 participants (due to dropouts) and conducted a 3 x 3 repeated-measures analysis of variance (ANOVA) to assess the effect of time and differences between groups. There were no significant interaction effects on neither RMSSD ($p = .88$) nor SDNN ($p = .566$) during the RSA measurement. Additionally, there were no significant between-group effects at any point of measurement on the HRV parameters (*p*-value not reported).

Hunt et al. (2018) investigated the active stress-reducing component of MBSR. They randomized 119 college students into five groups: mindfulness meditation, yoga, multicomponent (mindfulness meditation and yoga), active control group (interactions with a therapy dog and snacks), or a non-intervention control group. The participants in the active groups attended weekly sessions for four weeks. One hundred ten participants attended the post-intervention assessment and conducted four subtests of a stressor task, the Wechsler Adult Intelligence-IV IQ test. The researchers collected ECG data during a 5 min baseline period and during the stressor task with an emWave pro device by HeartMath. They reported HRV in SDNN. The ANOVA revealed significant group differences in baseline HRV ($p = .01$). The multicomponent and yoga groups exhibited the highest HRV, followed by the active control and mindfulness groups. The non-intervention control group had the lowest HRV. The results also showed significant group differences during the stressor task ($p < .05$). The pairwise comparisons showed that the non-intervention control group had the lowest HRV, whereas all the other active groups were not significantly different from each other. The mindfulness group was the only group to show no significant decrease in HRV regarding the change from baseline to the cognitive stressor ($p = .46$). The multicomponent and yoga groups decreased significantly in HRV ($p = .001$) and ($p < .001$) respectively. The active control decreased significantly ($p < .05$) and the non-intervention control group decreased but non-significantly (ns).

Shearer et al. (2016) explored how an MBI affected HRV compared to dog therapy and a non-intervention control group. They randomly assigned 74 college students into three groups. The MBI was based on MBSR which included breathing exercises, yoga, meditation, and education about stress. The active control group was given snacks and interacted with a therapy dog. Both groups attended four 1 hr long weekly group sessions. Sixty-nine participants completed the post-intervention assessment and conducted subtests of a stressor task, the Wechsler Adult Intelligence Scale-IV. The researchers collected ECG data with a Vernier LabQuest Mini during the stressor task and reported HRV in SDNN. The ANOVA showed that the mindfulness group had significantly higher mean HRV during the stressor task compared to the control groups ($p < .05$). The effects sizes (measured by Cohen's *d)* were large, mindfulness versus dog group ($d = 1.15$), and mindfulness versus non-intervention control group ($d = 0.85$).

Studies With an Active Control Group Reporting HRV in the Frequency Domain

Carroll and Lustyk (2018) examined how eight weeks of mindfulness-based relapse prevention (MBRP), relapse prevention (RP), or treatment as usual (TAU) affected HRV. They recruited 34 participants with substance use disorder from a phase III clinical trial. Participants in the clinical trial were randomized to complete eight weeks of MBRP, RP, or TAU. RP is the gold standard for substance use treatment and integrates cognitive-behavioral strategies. MBRP is a therapy program based on RP and MBSR. TAU is a 12-step program delivered in a group format. The researchers scheduled each participant to perform a stressor task, the Paced Auditory Serial Addition Task which involved adding a number they just heard with the one immediately preceding it. They collected ECG data with a PowerLab 8/35 high-performance data acquisition system during a 7 min baseline period, 7 min stressor task, and 7 min recovery phase. They used a repeated-measures analysis of covariance (ANCOVA) to assess group differences at different time points, whilst controlling for age, gender, severity of substance use intake, Vo_2 max, and trait anxiety. They reported HRV in HF-HRV. There was a significant two-way interaction of time by condition that involved differences at baseline HF-HRV and in response to the stressor ($p < .01$). The MBRP group had significantly greater baseline HF-HRV than RP ($p < .01$). There was also a significant effect of treatment regarding the change from baseline to stressor HF-HRV ($p < .001$). Pairwise comparisons showed that the MBRP group had a significantly higher HF-HRV than the control groups, MBRP versus RP ($p = .011$), and MBRP versus TAU ($p < .001$).

Studies With an Active Control Group Reporting HRV in Both Domains

Kirk and Axelsen (2020) investigated the effects of mindfulness meditation on acute and chronic HRV responses in 99 university students. The researchers randomly assigned participants to mindfulness meditation, music-intervention, or a non-intervention control group. The mindfulness meditation consisted of guided sessions delivered via the Headspace app, whereas the music-intervention group listened to instrumental music via an app. Both interventions lasted for 10 days. The first five days required 20 min of training and the last five days required 30 min. The researchers used a wearable Firstbeat bodyguard II HRV monitor to measure HRV in RMSSD, HF-HRV, and LF/HF ratios. Ninety participants completed 48 hr continuous HRV measurements pre-and post-intervention to assess the chronic effects on HRV. Additionally, the researchers measured HRV in the intervention groups during each of their 10 training sessions to assess the acute effects on HRV. They used a mixed 2 x 3 ANOVA to examine differences pre-and post-intervention on the groups' mean RMSSD, HF-HRV, and LF/HF ratios. Significant interaction effects from the ANOVA were followed up with paired *t*-tests. For the three groups' mean daytime RMSSD, there was a significant interaction of time and group condition ($p = .003$). The mindfulness group had a significantly higher mean daytime RMSSD from pre-to post-intervention ($p < .001$). The music-intervention group showed no significant difference ($p = .45$) and the non-intervention control group showed a significantly lower mean daytime RMSSD from pre-to post-intervention ($p = .007$). However, there were no significant differences between group and time regarding HF-HRV ($p = .37$) or LF/HF ratio ($p = .24$). The researchers used a mixed 10 x 2 ANOVA for the acute effects to assess if the two interventions influenced the groups' RMSSD, HF-HRV, and LF/HF ratio. They computed a delta variable from the participants' 10 sessions and subtracted it from the pre-intervention daytime mean RMSSD value. A mixed ANOVA revealed no significant effect on the participants' acute RMSSD between the two interventions (*p*-value not reported). Furthermore, a mixed ANOVA revealed no significant differences during the acute phase for the two groups regarding HF-HRV ($p = .24$) or LF/HF ratio ($p = .17$).

Studies With a Non-Active Control Group Reporting HRV in the Time Domain

Crosswell et al. (2017) investigated if mindfulness training improved cardiovascular recovery after induced negative affect. The data came from another study that randomized 71 female breast cancer survivors to mindfulness training or a WLC-group. The intervention group participated in six weekly 2 hr group sessions of Mindfulness Awareness Practices (MAPs) program. It included theory and research on mindfulness and relaxation, mindfulness practice, and a psycho-educational component for cancer survivors. All participants completed a post-intervention assessment that entailed telling an anxiety-inducing story of their breast cancer experience for 5 min. The researchers collected HRV data (RMSSD) with ECG and impedance cardiography during a 10 min baseline period, during the 5 min task, immediately post-task, and during a 12 min resting period. The researchers analyzed the data with multilevel modeling. The control group had a significantly higher RMSSD during the task compared to the intervention group ($p = .047$). The recovery slope from task to post-task differed by group ($p = .006$), with the control group showing a steeper decline of RMSSD compared to the intervention group.

Delgado-Pastor et al. (2015) examined two aspects of mindfulness in the treatment of chronic worry. They randomly assigned 45 female university students who scored high on the Penn State Worry Questionnaire to mindfulness cognitive training, mindfulness interoceptive training, or a WLC-group. The intervention groups attended two 1 hr sessions per week for three weeks. The guided meditations for the interventions focused on different aspects. The cognitive training involved recognizing and labeling their mental state, whereas the interoceptive training focused on recognizing and labeling their bodily states. Forty-one participants completed pre-and post-intervention assessments. The assessments consisted of a 5 min baseline resting period, a 5 min self-induced worry period, and a 5 min mindfulness period (cognitive, interoceptive, or control). The researchers collected ECG data with a Biopac instrument during the three 5 min periods and reported HRV in RMSSD. They analyzed the data with a 3 x 3 ANOVA with a between-group factor with 3 conditions (cognitive, interoceptive, and control) and a repeated-measures factor with 3 conditions (baseline, worry, and mindfulness). Post-hoc comparisons were conducted with student's *t*-test. There was a significant group effect ($p < .03$). The mindfulness interoceptive group showed a significant increase in RMSSD (post minus pre score) across the three periods compared to the control group ($p < .009$). The mindfulness cognitive group showed a decrease in RMSSD, but the comparison with the mindfulness interoceptive group was non-significant ($p < .07$).

Krick and Felfe (2020) examined the effects of MBI on physiological outcomes in 267 police officers. They randomly assigned participants to MBI or a control group. The MBI group attended six 2 hr sessions over six weeks. The MBI was a mixture of MBSR and other MBIs that included mindfulness practice, mindful body movements, stretching, education about stress, and group discussions. The control group received regular education courses while the intervention group attended their sessions. The researchers collected 5 min of HRV from both groups before and after the first session, but also before and after the last session with a Polar V800 system. They investigated two short-term effects: a) change from pre-to post-session 1 and b) change from pre-to post-session 6. They also investigated three long-term effects: c) change between pre-session 1 and post-session 6, d) change between pre-session 1 and pre-session 6, and e) change between post-session 1 and post-session 6. They analyzed the data with a 2 x 2 mixed-design ANOVA and paired samples *t*-tests to compare pre-and-post RMSSD-values for each group. The ANOVA revealed a significant interaction effect on HRV for the short-term effects a) within session 1 ($p <.001$) and b) within session 6 ($p < .001$). Furthermore, the ANOVA revealed a significant interaction effect for the long-term effects c) change between pre-session 1 and post-session 6 ($p < .001$), d) change between pre-session 1 and pre-session 6 *(p* < .001), and e) change between post-session 1 and post-session 6 ($p < .001$). Paired samples *t*-tests revealed significant increases in HRV for the intervention group in a) change from pre-to post-session 1 ($p < .05$) and a significant decrease for the control group ($p < .01$). Additionally, significant increases for the intervention group in c) change between pre-session 1 and post-session 6 ($p < .001$), whereas the control group showed a significant decrease ($p < .001$).

Studies With a Non-Active Control Group Reporting HRV in the Frequency-Domain

Dunne et al. (2019) investigated the effects of attention-based training (ABT) on reducing symptoms of burnout. They randomly assigned 58 emergency department personnel to ABT or a non-intervention control group. The ABT participants attended four 4 hr group sessions over seven weeks. They discussed the importance of attention and practiced ABT which involved focusing on a non-English phrase. The weekly target was to practice ABT for 20 min, twice daily, during a seven-week period. The participants wore a Charge 2 device by Fitbit throughout the study time to measure HF-HRV. The researchers analyzed data from 42 participants with paired and unpaired *t*-tests to examine within-and between-group differences. There was a significant increase in HF-HRV slope values for the ABT group over time ($p = .01$), whereas the control group showed no significant increase ($p = .05$). Additionally, the researchers reported HRV in non-linear SD2. There was a significant increase in total mean time SD2 for the adherent ABT group (10% over the weekly target) compared with the non-intervention control group over time ($p = .06$), with a large effect size measured by Cohen's *d* ($d = 0.86$).

Studies With a Non-Active Control Group Reporting HRV in Both Domains

Oken et al. (2017) tested if mindfulness meditation improved 134 mildly stressed older adults' physiology. The researchers randomly assigned participants to mindfulness meditation or a WLC-group. The intervention group attended one-on-one 60-90 min sessions once a week for six weeks. The mindfulness meditation integrated aspects of MBCT and MBSR. It included body scanning, sitting meditation, sitting with difficulty, and a 4 min breathing space. Furthermore, the goal was to practice at home for 30-40 min each day. The researchers collected ECG data during pre-and post-intervention assessments. They analyzed the data from the post-intervention assessment with an ANCOVA using the data from the pre-intervention assessment as a covariate. They reported HRV in LF/HF ratio and SDRR. The ANCOVA revealed no significant group effects on neither SDRR ($p = .99$) nor LF/HF ratio ($p = .29$).

Discussion

The aim of this systematic review was to further investigate how MBIs affect HRV to better understand the utility of mindfulness meditation as a stress management technique.

Randomized controlled trials using an MBI of any duration that assessed HRV as the outcome measure were included in this systematic review to investigate how mindfulness meditation affects an objective physiological marker of stress. Ten studies were included in the qualitative synthesis. Six studies showed that MBIs increased HRV (Delgado-Pastor et al., 2015; Dunne et al., 2019; Hunt et al., 2018; Krick & Felfe, 2020; Shearer et al., 2016). Two studies showed no significant increase in HRV compared to the control condition (Brinkmann et al., 2020; Oken et al., 2017). One study showed a significant increase in HRV for the control group compared to the intervention group (Crosswell et al., 2017), whereas one study showed that an MBI led to increases in HRV but also found no significant group differences (depending on which HRV metric to assess) (Kirk & Axelsen, 2020). The mixed results highlight that further research on how MBIs affect HRV is needed to conclude whether mindfulness meditation is an effective stress management technique.

These results are in line with a meta-analysis by Rådmark et al. (2019) who reached mixed and inconclusive results, probably due to a small number of high-quality studies with active control groups and long-term follow-ups. The results from the present systematic review differ from the most recent meta-analysis by Brown et al. (2021) who indicated that MBIs were not significantly related to higher resting-state vagally mediated HRV compared to a control condition. These different results may be explained by the present systematic review only included studies with inferential statistics, which led to a small sample of studies. Whereas Brown et al. (2021) calculated effects sizes from studies that provided means and standard deviations, which allowed them to include a larger sample of studies. They also included RSA as a measurement of vagal tone and studies that did not state their HRV metric. Contrary to a scoping review (Christodoulou et al., 2020) the present systematic review does not support that MBIs increase HRV reactivity. Scoping reviews hold the potential for bias as they do not include a process of quality assessment (Grant & Booth, 2009). Christodoulou et al. (2020) included lower quality studies without control groups which may explain the different results.

The following section will assess the scientific quality and the methodological differences between the included studies. A critique against research on mindfulness meditation concerns the lack of high-quality studies with active control groups (Davidson & Kaszniak, 2015) which includes the expectation of a benefit but excludes the "active ingredient" (Chiesa & Malinowski, 2011). This systematic review included five studies of lower quality with non-active control groups. Future studies should include active control groups to ensure that the effects of MBIs were not caused by nonspecific effects (e.g., expectancy effects) (Chiesa & Serretti, 2009). The included studies varied in terms of which HRV metric they assessed. Two studies included LF/HF ratio in their assessment (Kirk & Axelsen, 2020; Oken et al., 2017) which is not recommended as it may not accurately reflect the balance between SNS and PNS activity (Billman, 2013). Additionally, three studies did not include a metric that reflects PNS activity (Hunt et al., 2018; Oken et al., 2017; Shearer et al., 2016). As suggested by Laborde et al. (2017), future research would benefit from reporting HRV in RMSSD or HF-HRV as it gives a reflection of PNS activity and because it would ease the comparability across studies.

Most of the included studies used validated devices for HRV assessment. Kirk and Axelsen (2020) used Firstbeat Bodyguard II monitor which has been validated with standard physiological systems (Parak & Korhonen, 2013). Six studies used ECG to measure HRV which allows the researchers to see the QRS-complex, leading to precise artifact corrections (Laborde et al., 2017). However, three studies used consumer devices, chest belts, and earlobe sensors (Dunne et al., 2019; Hunt et al., 2018; Krick & Felfe, 2020) which all have their limitations. Chest belts create artifacts due to friction against the skin, earlobe sensors are not appropriate for measuring HRV during stress, and consumer devices have not been validated against ECG measurements (Laborde et al., 2017; Quintana et al., 2016). The three studies that used these devices showed that MBIs increased HRV but should be treated with caution due to the limitations of the devices. Concerning the recording duration, most of the studies followed the recommendations from the Task Force of the European Society of Cardiology and the North American Society of Pacing and Electrophysiology (1996) of a short-term recording of at least 5 min and a long-term recording of at least 18 hr to ensure comparability across studies. However, two studies failed to report the duration of recording during the stressor task (Hunt et al., 2018; Shearer et al., 2016). There are different assessment types of HRV. Tonic HRV represents baseline HRV and is measured at one-time point. Phasic HRV represents reactivity or recovery from an event and is measured by taking the change from baseline to event or change from event to post-event (Laborde et al., 2018). Only two studies assessed both types according to the definition of tonic and phasic HRV by Laborde et al. (2017). One of them indicated that MBIs led to significant increases in phasic HRV (Carroll & Lustyk, 2018), giving support to Christodoulou et al. (2020) who concluded that MBIs increased HRV reactivity. However, one study is not enough to make any conclusions. Furthermore, the included studies varied in the intervention duration. It varied from four 1 hr sessions (Shearer et al., 2016) to more rigorous programs with 60-90 min sessions once a week for six weeks with 30-45 min home practice each day (Oken et al., 2017). This variability along with two studies not reporting the duration of each session (Carroll & Lustyk, 2018; Hunt et al., 2018) makes it challenging to assess which practice dose leads to changes in HRV. Future studies on MBIs and HRV would benefit from using standardized MBI-programs such as MBSR to ease the comparability across studies. Finally, four studies were conducted on college students, one study on breast cancer survivors, and one study on addicts, limiting the generalization of the results to other populations (e.g., populations with lower education or a healthy population).

Limitations

This systematic review has some limitations. One limitation is the small number of studies included in the final synthesis which limited the conclusions that can be made from this systematic review. It could have been more comprehensive if it included studies that did not provide inferential statistics, which might have helped reach more conclusive results. Another limitation concerns the inclusion criteria. The initial plan was to only include studies with rigorous active control groups. But due to the limited number of high-quality studies, the inclusion criteria had to be adjusted to include studies with non-active control groups. This inclusion affected the rigorousness of this systematic review as non-active control groups cannot control for non-specific effects. The other limitation regarding the inclusion criteria was that MBIs of any duration were included. This inclusion makes it more difficult to assess which practice dose is needed for affecting HRV. Another limitation is that only studies written in English were included, which means that there might be more studies on MBIs and HRV but in other languages. Furthermore, due to a lack of time and resources, only one person (the author) screened the articles and assessed them for eligibility instead of two independent reviewers. This assessment means that selection bias could not be controlled for and there is a risk that relevant studies were excluded (Gartlehner et al., 2020; Page et al., 2021).

Societal and Ethical Aspects

Most of the included studies reported that informed consent was given and that the studies were approved by ethical committees or review boards. Three studies failed to report that informed consent was given and three studies did not state that the research was approved by ethical committees or review boards. This ambiguity raises concerns as it violates the ethical principles of the Helsinki declaration (World Medical Association, 2013). Stress is a global health issue in modern society and can lead to numerous negative consequences (Sharma & Rush, 2014). Thus, more knowledge about alternative stress management techniques is warranted for health care professionals, patients, and society. Studies examining the effectiveness of mindfulness meditation on the objective physiological markers of stress can complement the positive effects found on self-reported stress reduction (Chiesa & Serretti, 2009). This complementary work will help develop evidence-based recommendations for stress reduction and will lead to more certainty for clinicians to recommend mindfulness meditation to their patients (Khoury et al., 2015). However, the results from the present systematic review are mixed. Consequently, there is inconclusive evidence on whether mindfulness meditation can be recommended to reduce physiological stress.

Conclusion

This systematic review investigated how MBIs affect HRV to better understand the utility of mindfulness meditation as a stress management technique. The results from the systematic review were mixed and indicate inconsistencies across the literature. Thus, there are uncertainties on how MBIs affect HRV. Further research on how MBIs affect HRV is needed to complement the positive effects of mindfulness meditation in self-reported stress reduction. This further research will help the understanding of mindfulness meditation as a stress management technique.

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