Effects of two mindfulness based interventions on the distinct phases of the stress response across different physiological systems

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ABSTRACT

When evaluating the effects of mindfulness-based interventions (MBIs) on the stress response, several aspects should be considered, such as (1) effects on various response systems, (2) temporal dynamics of the stress response, and (3) differences between programs. This study assesses the stress-attenuating effects of a standard mindfulness-based stress reduction (MBSR) and a second-generation MBI: MBSR with elements of other Buddhist practices (MBSR-B). Ninety-nine healthy volunteers were randomly assigned to the MBSR, MBSR-B, or waitlist control groups and their stress response was evaluated with the Trier Social Stress Test. Changes in the activity of the hypothalamic-pituitary-adrenal (HPA) axis, sympathoadrenomedullary system, the autonomic nervous system (ANS), and affect were measured during distinct phases of the task. Compared to waitlist control, the stress-attenuated effects of MBIs were detected across almost all systems and both negative and positive affect. In the parasympathetic branch of the ANS, the effect of MBIs was present in all stress phases (however, in the recovery phase, only MBSR-B has shown a statistically significant effect in comparison with the waitlist control). The stress-attenuating effects of MBIs were observed already in the anticipatory phase for cortisol, ANS, and negative affect (for negative affect, only the modified MBSR-B program has shown statistically significant effect in comparison with the waitlist control).

1. Introduction

Psychological stressors rooted in the social environment have become an important focus in stress research (Slavich, 2020). Social threats, characterized by a loss of acceptance, conflict, rejection, exclusion, or perceived loss of social status, are particularly important in this framework due to substantial empirical evidence of their negative impact on neurohormonal, immune, and psychological functioning (Dickerson et al., 2009; Kemeny, Gruenewald, & Dickerson, 2004). These types of stressors are increasingly prevalent in daily life, placing the attenuation of social threat perception among the top priorities in individual interventions aimed at stress reduction.

In recent years, there has been significant research interest in the stress-buffering effects of mindfulness-based interventions (MBIs)—behavioral approaches based primarily on various types of contemplative training originating in the traditional Buddhist context. The development of mindfulness lies in the center of MBIs and can be broadly defined as a process of attending to the present moment with an open attitude and awareness (Creswell, 2017). Apart from the first and most widely known MBI program designed for clinical purposes (the Mindfulness-Based Stress Reduction, MBSR; Kabat-Zinn, 1990), a number of other evidence-based MBIs differing in lengths and ways of administration are currently used (Creswell, 2017). The focus of most MBIs is the development of the ability to mindfully observe bodily sensations and thoughts during formal practice (breathing exercises, body scans, stretching exercises) and in daily life. The evidence of stress-buffering effects of MBIs is substantial (Chiesa & Serretti, 2009), but most studies employed only self-report–based measures of stress.
Systematic assessment of the effects of contemplative training on the biological changes associated with stress has only recently started. The relationship between meditation practice and the attenuation of the stress response at the physiological level has been found in observational studies comparing long-term meditation practitioners and matched controls (Gamaiunova et al., 2019; Rosenkranz et al., 2016). In addition to observational research designs, several intervention studies have focused on the effects of MBIs on stress-related changes in physiological pathways. A recent report (Morton et al., 2020) systematically reviewed the effects of MBIs on the psychophysiological response to acute stress in a framework of a particular stress-inducing paradigm—the Trier Social Stress Test (TSST; Kirschbaum et al., 1993). The test consists of delivering a speech and doing a mental arithmetic problem in front of a “judging” committee and a camera, which robustly creates a situation of social threat with possible elements of unpredictability, uncontrollability, perceived social status loss, loss of acceptance, or rejection (Dickerson & Kemeny, 2004). This type of stressor is known for its potential to produce considerable psychophysiological activation. The abovementioned review of selected studies allowed for a preliminary evaluation of whether MBIs can reduce physiological reactivity to social threats. The review demonstrated that the stress-buffering effect of MBIs was observed for HPA-axis activity (3 of 12 studies using cortisol measures), for SAM activity (1 of 3 studies using salivary alpha-amylase [sAA]; 2 of 4 studies using blood pressure), and for the Autonomic Nervous System (ANS) (1 of 4 studies using heart rate variability [HRV], a marker of activity of the parasympathetic nervous system [PNS]). Even though the results of a recent study demonstrated an association between dispositional mindfulness and heart rate (HR) response to stress (Beshai et al., 2020), the review did not identify any studies showing the effect of MBIs on HR. Furthermore, none of the selected studies assessed the effects of MBIs on the pre-ejection period (PEP), an index of beta-adrenergic influences on the heart (Berntson et al., 2017; Sherwood et al., 1990). The index is important for stress research, as it permits analysis of cardiac changes driven only by the sympathetic system. Concerning the self-reported evaluation of stress, 70% of studies showed stress attenuation following MBIs. The review demonstrated that most studies largely overlooked the issue of prolonged stress activity, as reflected in anticipatory activation and long recovery (Brosschot et al., 2005). Differences among MBIs (in terms of the content, length, and manner of administration) further confound results. In conclusion, the review showed that the results of the studies investigating the effects of MBIs on the attenuation of the stress response to social-evaluative threat are inconsistent and largely incomplete. To make research in this area more rigorous and address the remaining questions, studies must address (1) effects on various response systems, (2) temporal dynamics of the stress response, and (3) differences between programs.

1.1. Stress response systems

The stress response is a complex and multidimensional process evoked through cognitive-affective integration and neurological triggering of the activation of several interrelated physiological pathways, such as the neural axis, the sympathoadrenomedullary (SAM) system, and the HPA axis (Everly & Lating, 2013) (See Supplementary Materials, Additional details: Stress response systems). As a result, psychosocial stressors are associated with several physiological changes, such as an initial increase in sympathetic and a decrease in parasympathetic cardiac control (Bernston & Cacioppo, 2004), further increase of adrenergic somatic activity via secretion of catecholamines (Everly & Lating, 2013), and the activation of the HPA axis leading to the release of glucocorticoids (Hellhammer et al., 2009). Often, physiological changes associated with stress have several etiologies. For example, stress-induced changes in HR might result from increased beta-adrenergic sympathetic drive or from diminished parasympathetic vagal effects on the heart, and those responses are not necessarily coupled (Bernston et al., 1991). Thus, it is preferable to measure changes in the ANS activity using separate indices of both branches (PNS and SNS). Similarly, differential responses to the TSST have been observed across other physiological response systems (Nater et al., 2005; Schommer et al., 2003). Considering that we still have a poor understanding of what systems are most affected by MBIs, studies that include measures of different physiological response systems and the use of indices that allow disentangling different response systems are most informative.

Measures of the affective concomitants of the stress response should also be expanded: most studies to date have drawn on measures of affective states with negative valence, as the TSST is expected to provoke negative affect. However, a recent qualitative study exploring the experience of long-term meditation practitioners undergoing the TSST demonstrated that participants in the meditation group reported experiences of positive affect (Gamaiunova et al., 2021). It has been proposed that two separate motivational substrates and different brain mechanisms underlie negative and positive processes (Cacioppo et al., 1997). Self-report evaluations of stress-induced affective changes in MBI research would benefit from independent unipolar measures of both negative and positive affect.

1.2. Temporal dynamics of the stress response

Another crucial issue acknowledged in the stress research, but not largely explored in relation to MBIs, is the temporal dynamics of the stress response, in particular prolonged physiological activation. The “reactivity hypothesis,” which has dominated research for many years, assumes that the pathogenic effects of stress are primarily linked to strong and frequent bursts of physiological activation in response to distress. This model has been expanded by incorporating stress-induced physiological activation preceding stress or anticipatory reactivity and prolonged recovery once the stress is over (Brosschot et al., 2005). Both the anticipation of stress and inability to shut off the stress response are risk factors for allostatic load by driving the output of physiological mediators (McEwen, 1998). The necessity to differentiate phases of the stress response has been emphasized in relation to both the HPA axis (Engert et al., 2013) and the ANS (Linden et al., 1997). Very few studies investigating the effects of MBIs on the stress response to social threat have addressed this question, especially using physiological measures but the results suggest that MBIs represent an important area for future investigations. The effects of MBIs on stress attenuation during anticipation or recovery were observed for emotional reactivity (Britton et al., 2012), cortisol (Hoge et al., 2018), negative affect (Mayor & Gamaiunova, 2015), and cardiovascular measures (Koerten et al., 2020).

1.3. Differences between programs

The comparison of effects of different MBIs has high priority in this research area due to the increasing evidence of the differential effects of various contemplative programs (e.g., Engert et al., 2017). The expansion of research on MBIs led to the development of different programs that incorporate, in addition to mindfulness, other aspects of Buddhist practice. So-called second-generation MBIs (SG-MBIs) are mindfulness-based programs that more explicitly integrate elements of a larger Buddhist framework, such as philosophy, the cultivation of adaptive mental states, and/or ethical inquiry (Van Gordon & Shonin, 2020). Enhancing standard MBIs with additional elements of Buddhist practice has the potential to increase the stress-buffering effects of MBIs (See Supplementary Materials, Additional details: Differences between programs). Those additional elements are represented by (1) training in wisdom, allowing experiential understanding of Buddhist doctrinal tenets, (2) cultivation of Four Immeasurables (i.e., brahma-viharas), referring to a set of four affective states encompassing all living beings as objects (Wallace, 2010), and (3) reinforcing ethical discipline, which consists in refraining from nonvirtuous actions and engaging in virtuous actions. Wisdom training can reduce stress response via the creation of
an alternative cognitive schema with a potential to alter the cognitive processing of a stressor and to reduce fixation on the self-image, which is the key factor in the initiation of psychological stress in this context. The cultivation of Four Immeasurables helps to develop an ability to generate feelings of self-reassurance or self-soothing, increasing the feeling of social safety that counteracts the sense of threat and reduces self-conscious cognition and emotion (Gilbert & Proctor, 2006). Further, it increases feelings of social connection and fosters positivity toward novel individuals on both explicit and implicit levels (Hutcherson et al., 2008). Taking into consideration that the most profound stress response is evoked by situations in which one could be negatively judged by others (Dickerson & Kemeny, 2004), positivity towards novel individuals can play an important role in the attenuation of stress response. Reinforcing the ethical conduct can reduce the occurrence of negative mental states induced by unskillful action and potentially attenuate perseverative cognition, directly related to prolonged stress activation (Brosschot et al., 2005).

1.4. The present study

This study was designed to test the stress-attenuating effects of MBIs by addressing (1) effects on various response systems, (2) temporal dynamics of the stress response, and (3) differences between programs. We aimed to investigate the effects of two MBIs on the psychophysiological stress response over distinct temporal stages of the TSST across multiple response systems: HPA axis, SAM system, both branches of the ANS (SNS/PNS), and negative and positive affect. To account for the temporal dynamics of the stress response, we chose to distinguish three phases of the test: anticipation, task, and recovery. Cortisol was used as an index of the HPA axis activity (Hellhammer et al., 2009), and sAA as an indicator for SAM system changes (Nater et al., 2005). To differentiate between the effects on the sympathetic and parasympathetic branches of the ANS, we assessed pre-ejection period (PEP) and the RMSSD. PEP is a sympathetic measure of the ANS influence on the heart. It is quantified as the interval from the depolarization of the heart to the ejection of blood through the aortic valve. The RMSSD is a time-domain based measure of the heart period variability. To assess affective changes, we chose unipolar measures of negative and positive affect. MBIs examined were a standard MBSR and a second-generation MBI, represented by an MBSR with an additional module including elements of other Buddhist practices (MBSR-B).

We hypothesized that (a) compared to a control group, stress-attenuating effects of MBIs would be found across different stress systems, resulting in reduced cortisol and sAA output, a lower magnitude of sympathetic activation and parasympathetic withdrawal, a lesser increase in negative affect, and a lesser decrease in positive affect; (b) the MBIs stress-attenuating effect would manifest beyond task reactivity resulting in attenuation of stress response across different systems during anticipation and recovery. Furthermore, we aimed to explore whether the stress-attenuating effects of MBSR-B would be larger than those of MBSR.

2. Method

2.1. Participants

Recruitment of participants for a stress-reduction course was done in the communities of the Lausanne region and the university campus via flyers, online advertisements in a local newspaper, and a promotional website. Interested individuals (N = 182) filled out an online screening survey. The sample size calculation was based on a fixed effect one-way analysis of variance (ANOVA) to detect any group difference in each outcome variable. The optimal total sample size of N = 72 (effect value of $f = 0.4$, with a significance level set at $\alpha = .05$, power $1 - \beta = .85$) was calculated prior to the recruitment using G-Power (Faul et al., 2009). The following inclusion criteria were set as follows: Age 18–40 years, no prior regular practice of meditation (more than 3 h/week), good command of French language, ability and desire to participate in the group sessions, comply with home assignments, and participation in a one-day retreat. Exclusion criteria consisted of prior participation in the TSST (volunteers were asked whether they participated in psychological experiments and asked to specify which ones), chronic or acute mental or physical disease, addiction to substances, use of medications that interfere with HPA axis or ANS functioning, severe obesity (BMI > 30), smoking more than five cigarettes per day, pregnancy or lactation, and inability to give consent. Out of 182 interested individuals, 52 did not meet the inclusion criteria, and 31 declined to participate. The resulting sample of 99 participants was randomized into the three experimental groups. Due to attrition, a sample of 65 participants was included in the survey analysis, and a sample of 62 participants was included in the analyses of physiological and self-report data related to the TSST (see Fig. 1 for CONSORT flow chart). As more than 80% of the attrition happened prior to the actual beginning of measurements or interventions for reasons unrelated to the study, and the remaining attrition did not show any systematic trends we do not expect any attrition bias. The individual characteristics of 65 participants are presented in Table 1.

2.2. Procedure

Interested volunteers filled out an online screening survey to determine eligibility. Eligible participants were invited for an in-person visit, where they received additional details on their participation in the study, signed the informed consent, and received a participant ID (assigned sequentially). In order to balance the influence of sex, we performed a stratified randomization (Suresh, 2011): Participants were assigned to two blocks (male or female), and then simple randomization was performed within each block to assign each participant into one of the three conditions. The randomization plan was created by the first author with the help of an online software (http://www.randomization.com). Enrolled participants were blind to their study condition.

The MBI groups received a link to an online pre-intervention questionnaire two weeks prior to the intervention and were instructed to fill out a printed version of the participant’s log daily. After the intervention, participants received a link to an online post-intervention questionnaire and were scheduled for two experimental sessions, the TSST and an emotion regulation task (not presented here). The wait-list control group received the questionnaire link in a similar timeframe.

To account for diurnal variation of cortisol (Labuschagne et al., 2019), the TSST sessions were scheduled between 12 and 16 o’clock; participants were instructed to refrain from caffeine, alcohol, food, and strenuous exercise 2 h preceding the session. Female participants were instructed to schedule their sessions during the luteal phase of the menstrual cycle; (Kudielka & Kirschbaum, 2005). On arrival, participants answered questions on their current mood, previous night’s sleep, and medication (see Materials). Next, the participant was accompanied to the experimental room and connected to the physiological recording devices (see Materials). The experimenter instructed the participant to sit quietly and relax, and then left the experimental room for 10 min.

To manipulate social-evaluative stress, we used a modified TSST: the anticipation period was increased to 15 min in order to assess the pre-performance cortisol stress reactivity (Engert et al., 2015). Two research assistants dressed in white coats and with clipboards entered the room, and the experimenter presented the task. After that, the participant was instructed to fill out questionnaires and was given 15 min to prepare for the task. Next, the participant delivered a five-minute speech and performed a five-minute arithmetic task in front of the evaluators and a camera. The evaluators were instructed to maintain a critical attitude and to urge the participant to continue if they felt uncomfortable. After the task, the participant was asked to fill out questionnaires and remained connected to the physiological recording devices for 30 more minutes. Taking into consideration that...
cardiovascular metrics are very sensitive to postural changes (Houtveen et al., 2005), we made a change in the protocol and instructed the participants to remain seated throughout the experiment. Data was collected as followed: continuously for the ANS measures (time stamps were introduced by the experimenter during the procedure), and six saliva samples were taken after the 10-min rest period, after the anticipatory period, in the middle of the task, and 10, 20, and 30 min after the task. Self-reported rating of the affective stress was collected after rest, anticipation, during the task, after the task, and then 10, 20 and 30 min after the task (Fig. 2).

Upon completion of data collection, the experimenter disconnected the participant from the device, took a short interview (not presented here), and completed a full debriefing. The participant was explained the nature of the TSST, presented with the goals of the study, and compensated for their participation.

2.3. Materials

2.3.1. Intervention

Participants were randomly assigned to one of three conditions: MBSR, MBSR-B, and wait-list control (WAITLIST). MBSR was administered by an officially trained MBSR instructor who had more than 10 years of experience. It was composed of a standard program: eight weekly group sessions (2h30 each), a retreat day during week seven, and guided home practice of 55 min per day (Kabat-Zinn, 1990).

The MBSR-B program was a modified version of the MBSR and designed in collaboration with the MBSR instructor and advanced meditation practitioners in Buddhist traditions. Each week from week one to week six included an additional module targeting a particular concept from broader Buddhist practice: Impermanence (anicca), ethics (sila), loving kindness (metta), compassion (karuna), not-self or dis-identification (anatta), and craving (tanna). The introduction of each concept included a short discourse administered during a group session, which was then put into practice during the week through, both informal “daily life practices” and a specific meditation practice (except for week one’s theme, impermanence, when only the informal practices were used). For example, during week five, not-self was introduced during the group session, and then practiced during the week through 10 min of daily, guided formal meditation, as well as informal practices (for instance, being aware of moments of “selfing”). The theme-specific guided meditation and daily life practices were both presented through audio recordings, which could be scheduled by participants. A description of themes in the MBSR-B is available in Supplementary Materials, Table S1.

2.4. Measures

2.4.1. HPA axis (cortisol) and SAM system (sAA) stress response

Six saliva samples were collected using Salivate® tubes (Sarstedt Inc.) throughout the experiment. The samples were taken after the rest
period at approximately 25 min after arrival (pre-TSST), at the end of the 15-min anticipation period (anticipation), in the middle of the task (task), 10, 20, and 30 min after the task (post-task, post-task 2, and post-task 3 respectively) (Fig. 2). Participants were instructed to place a tube in the mouth, keep it in for a period of two minutes, and return it to the tube without touching it. After the experiment, the tubes were stored in a freezer and shipped in three batches to Dresden, Germany for cortisol and alpha-amylase analyses.

2.4.2. ANS (SNS/PNS) stress response

Electrocardiography and impedance cardiography data were collected continuously throughout the task using a Bioxex data acquisition unit from MindWare Technologies (Gahanna, OH) with a sampling rate of 1000 Hz. Seven spot electrodes were placed on the participant’s thorax (Sherwood et al., 1990) and recorded using BioLab software. The data was processed offline using MindWare Technologies IMP 3.1.6 and HRV 3.1.5 analysis software (Gahanna, OH). Segments of the ECG were inspected by a trained researcher for artifacts and corrected, if necessary. For the impedance cardiography data, the distance between front electrodes was entered manually into the software and normal R peaks with good corresponding dZ/dt cycles were marked to maintain periods of at least one minute. The first two minutes after the task were used for the calculation of recovery index for RMSSD, and minutes 19 and 20 for PEP.

Many forms of contemplative training are associated with changes in breathing (Wielgosz et al., 2016), and the effects of respiration change on stress response can be substantial. We assessed respiration rate (RR) by deriving it from the impedance signal. The scores were created in a similar manner to RMSSD and PEP.

2.4.3. Affective stress response

Negative and positive affect were assessed with the question “How negative/positive are you feeling right now?”, with answers on a scale from 0 (“not at all”) to 10 (“very much”). The answers were collected after the rest period (pre-TSST), at the end of the anticipation period (anticipation), right after the task (task), and 10, 20, and 30 min after the task (post-task 1, post-task 2, and post-task 3, respectively).

2.5. Self-report measures

2.5.1. Individual characteristics

We collected the following individual characteristics: sex, age, education, current occupation, marital status, and income. Discrete categories are presented in Table 1.

| Table 1: Individual characteristics of participants. |
|-----------------------------------------------|
| Individual characteristics | Frequency | MBSR (N = 20) | MBSR-B (N = 21) | WAITLIST (N = 24) | \( \chi^2 (p) \) |
|-----------------------------|-----------|---------------|-----------------|----------------|------------------|
| Sex                        |           |               |                 |                 |                  |
| males                       | 6 (30 %)  | 9 (43 %)      | 8 (33 %)        |                 | 81 (.67)         |
| females                     | 14 (70 %)| 12 (57 %)     | 16 (67 %)       |                 | 6.64 (.58)       |
| Education                   |           |               |                 |                 |                  |
| primary school              | 0         | 0             | 0               |                 |                  |
| secondary school            | 1 (5 %)   | 0             | 0               |                 |                  |
| professional school         | 2 (10 %)  | 0             | 2 (8 %)         |                 |                  |
| gymnasium, pedagogical school, school of commerce | 1 (5 %) | 2 (10 %) | 3 (13 %) |                  |                  |
| university, polytechnical school, HES | 15 (75 %) | 16 (76 %) | 18 (75 %) |                  |                  |
| PhD or other post-grade university degree | 1 (5 %) | 3 (14 %) | 1 (4 %) |                  |                  |
| Occupation                  |           |               |                 |                 |                  |
| student                     | 4 (20 %)  | 8 (38 %)      | 12 (50 %)       |                 | 12.25 (.06)      |
| paid employment             | 9 (45 %)  | 10 (48 %)     | 11 (46 %)       |                 |                  |
| self-employed               | 6 (30 %)  | 1 (5 %)       | 1 (4 %)         |                 |                  |
| unemployed                  | 1 (5 %)   | 2 (9 %)       | 0               |                 |                  |
| retired                     | 0         | 0             | 0               |                 |                  |
| unable to work (disability) | 0         | 0             | 0               |                 |                  |
| Marital status              |           |               |                 |                 |                  |
| single                      | 10 (50 %)| 6 (29 %)      | 12 (50 %)       |                 | 5.80 (.45)       |
| in a relationship           | 6 (30 %)  | 11 (52 %)     | 9 (38 %)        |                 | .87 (.93)        |
| married                     | 4 (20 %)  | 4 (19 %)      | 2 (8 %)         |                 |                  |
| divorced                    | 0         | 0             | 1 (4 %)         |                 |                  |
| Income (CHF)                |           |               |                 |                 |                  |
| 0-39,999                    | 13 (65 %)| 12 (57 %)     | 12 (52 %)       |                 |                  |
| 40,000 - 79,999             | 4 (20 %) | 6 (29 %)    | 7 (31 %)        |                 |                  |
| 80,000 - 100,000 and more   | 3 (15 %) | 3 (14 %)    | 4 (17 %)        |                 |                  |
| Prefer not to say           | 0         | 0             | 1               |                 |                  |
| Prior meditation practice   |           |               |                 |                 |                  |
| 1 h/week                    | 1 (5 %)   | 1 (5 %)       | 0               |                 |                  |
| 2 h/week                    | 1 (5 %)   | 0             | 2 (8 %)         |                 |                  |
| Age (years)                 | M (SD)    | 30.45 (6.14)  | 28.67 (5.83)    | 27.21 (4.56)    | 1.90 (.16)       |
| MBSR                        |           |               |                 |                 |                  |
| MBSR-B                      |           |               |                 |                 |                  |
| WAITLIST                     |           |               |                 |                 |                  |

| MBSR | MBSR-B | WAITLIST | \(\chi^2 (p)\) |
|------|--------|----------|----------------|
| (N = 20) | (N = 21) | (N = 24) |                 |

F (p)
6

2.5.2. MBSR-B program check

The MBSR-B program contained an additional module, based on a larger Buddhist framework (see Intervention). In order to assess if participants integrated the materials of the module, we used two measures: (1) the Insight Scale, a validated measure of Buddhist Insight (Gamaïunova et al., 2016; Ireland, 2013), and (2) a questionnaire created based on the content of the module (Buddhist module questionnaire). The Insight questionnaire is a short 4-item scale aimed at assessing participants’ experiences of insight into the universal characteristics of impermanence, suffering, non-self, and emptiness underlying all phenomena. The instrument was designed to be used in the population of meditators, so the instructions were adapted for use by non-meditators. Cronbach’s alpha at pre-test in our sample was .92.

The Buddhist module questionnaire (20 items) focused on three dimensions related to the material taught in the module: First, wisdom, containing two items assessing impermanence (e.g., “All things, whether material or mental, are continually changing from moment to moment.”), suffering (e.g., “Suffering comes from our addictive desire to possess and control things.”), and non-self (e.g., “There is no permanent and unchanging self, or separate essence in living beings.”); second, brahma-viharas, containing two items assessing empathetic joy (mudita, e.g., “I appreciate with great joy the success and good fortune of others.”), compassion (karuna, e.g., “I have compassion for other beings.”), equanimity (upekkha, e.g., “I feel love and kindness for all beings, even to strangers and unpleasant people.”), and loving kindness (metta, e.g., “I feel love and kindness for all beings.”); and third, right conduct, containing two items assessing practice of generosity (dana, e.g., “I offer my resources, time and knowledge to others without expecting anything in return.”), practice of right speech (samma vaca, e.g., “I engage in trivial conversations, or gossip.”), and practice of right action (samma kammanta, e.g., “I intentionally hurt others.”). The items were constructed by two authors on the basis of the program content and discussed with advanced Buddhist practitioners (see the Supplementary Materials, Table S2 for the complete set of items). Internal consistency for the sub scales was acceptable: Cronbach’s alpha = .71 for wisdom, .78 for brahma-viharas, and .62 for conduct.

2.5.3. Practice log

Participants were asked to fill out a practice log distributed in paper format before the intervention program. Each week they reported (1) if they participated in a group session; (2) how many minutes they practiced daily; (3) how much effort they put into their practice weekly on a scale from 1 = “no effort” to 10 = “a lot of effort”; and (4) to what extent it was difficult for them to practice on a scale from 1 = “not difficult at all” to 10 = “very difficult”.

2.5.4. Pre-experimental check

Taking into consideration that both sleep quality and sleep duration can impact experiences of the social environment through alteration of the activity of the HPA axis and SNS (Slavich, 2020), we asked participants to indicate before the TSST session (1) how many hours they slept the night before the experiment and (2) to rate their quality of sleep (from 1 = “very bad” to 5 = “excellent”). To control for the affective state preceding the experiment, participants were asked how they felt at the moment (sleepy, happy, depressed, frustrated, excited), all on a scale from 1 = “not all” to 5 = “a lot”. To account for the previous experiences relating to the task, participants were asked if they had experienced in public speaking and mental arithmetic (yes/no).

2.6. Analyses

Statistical analyses were performed in R version 4.0.3. Only RMSSD and PEP data have missing values which were treated with multiple imputation (MI) method, using R multivariate imputation by chained equation (MICE) package, version 3.9.0 (Buuren & Groothuis-Oudshoorn, 2010). Five imputations were produced with the predictive mean matching (PMM) method using the full predictor matrix. The percentage of the imputed data was 3.6 % for RMSSD data and 7.3 % for the PEP data. All the missing data were caused by a specific instrument failure which, in each occurrence, caused multiple variables to be missing at once. To test that the data were MCAR (missing completely at random) this specific correlation had to be removed by splitting the data set into several sets containing only a single variable out of the set obtained within a single measurement. Each of these sets was subjected to the Little’s MCAR test (implemented in the package sem prepare 0.6.1) confirming that all the data were MCAR (with the lowest obtained p-value ~ 0.3). All analyses were performed on five imputed datasets separately, leading to the same set of significant results up to a slight numerical difference. In addition, the p values of the ANOVA and pairwise t-tests were pooled, again giving the same set of significant results as single-dataset based analyses (on average, the pooling

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Fig. 2. Details of sampling during the TSST experiment. Note. (A) S1-S6 = saliva samples. (B) Cardiovascular measures were taken continuously; red line represents chunks of the data used for the analyses. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)
increased t-test p values only by 0.002). Since currently there is no firmly established procedure to pool complex analyses used in this work (such as MANOVA) and given the stability of the results with respect to a particular imputation and pooling, for all the analyses we reported results based on the first imputed dataset (for both RMSSD and PEP based data).

Extreme outliers were identified as values higher than Q3 + 3xIQR or below Q1 – 3xIQR (where Q1 is the first quartile, representing a middle number between the smallest number and the median; Q3 is the third quartile, represented by a value between the median and the highest value, and IQR is the interquartile range, defined as the difference between the Q3 and Q1). The extreme outliers were deleted prior to analysis (number of outliers per each variable can be found in Supplementary Materials, Table S8). In the repeated measures analyses of variance (ANOVA), a Greenhouse-Geisser (GG) correction was applied if the assumption of sphericity was violated and ε reported. To control the Family-Wise Error Rate in multiple testing (several ANOVAs and planned contrasts), we used Holm-Bonferroni approach (Holm, 1979) to adjust the p-values while applying the standard alpha level (0.05). Tukey’s HSD (honestly significant difference) or Games-Howell (in case of violation of the assumption of equal variance) post hoc tests were used for exploratory analyses of group differences. Analytical procedures for specific variables are outlined below.

2.6.1. Cortisol and alpha-amylose analyses

Salivary cortisol and alpha-amylose data were log10 transformed prior to analyses at the six time points due to significant non-normality. To check if different phases of the TSST induced physiological changes across the complete sample, we performed one-way repeated measures ANOVAs with cortisol or amylose as a dependent variable and three time points as levels of the within-subjects factor. For cortisol, we used pre-TSST, task (mid-task sample reflecting anticipatory reactivity; Engert et al., 2013), and post-task (reflecting reactivity to the task) as time points. For alpha-amylose, we used pre-TSST, anticipation, and task (reflecting reactivity to the task) as time points.

To compare the effect of training on the TSST-induced changes in salivary cortisol in different periods of the test, we calculated the area under the curve (AUC) with respect to increase (AUCi) for the anticipation, task, and post-task portions of the experiment, using the trapezoid formula (Preussner et al., 2003). For cortisol, the anticipation portion of the task is represented by the area from pre-TSST measure to mid-task, and the task portion from pre-TSST to post-task (10 min after the end of the TSST). For alpha-amylose, the anticipation portion of the task is represented by the area from pre-TSST measure to end anticipation, and the task portion from pre-TSST to task (measurement in the middle of the TSST). The recovery portion for both outcomes is represented by the area from the post-task to the last measurement (30 min after the TSST). Subsequently, we performed a three-step procedure starting with separate multivariate analyses of variance (MANOVAs) both for cortisol and alpha-amylose (with values for anticipation, task, and recovery as separate dependent variables in order to test for group differences at any time point). In case of a significant MANOVA result, we performed one-way ANOVAs for the respective period (anticipation, task or recovery) with the group as a between-subject factor (adjusting for multiple testing with the Holm-Bonferroni approach). In case of a significant MANOVA at a given test phase, we continued with planned contrasts, comparing treatment groups to control. Exploratory post-hoc tests were performed to detect all possible group differences.

To check for group differences in RR, we computed percent changes as described above and performed a MANOVA for the corresponding variables. A Pearson’s product-moment correlation was run to test for the association between changes in RR and RMSSD.

2.6.3. Self-report analyses

Group differences in self-report data were tested using Wilcoxon rank sum test and Kruskal-Wallis test for ordinal data, chi-square tests for categorical variables, and ANOVAs and t-tests for continuous variables (in case of violation of homogeneity of variance, robust versions of the tests were applied: Welsh ANOVA or Welsh’s t-test).

To test if different phases of the TSST induced affective changes across the complete sample, we performed one-way repeated measures ANOVAs with negative or positive affect score as a dependent variable and three time points as levels of the within-subjects factor. We used pre-TSST, anticipation, and task time points. To compare the effect of training on the TSST-induced changes in negative and positive affect in different periods of the test, we calculated absolute change variables (delta) for the anticipation, task, and recovery periods of the experiment. The recovery variable represents absolute change from task to post-3 measurement (19 and 20 min after the task). To test the training effect on affective changes, we performed separate MANOVAs for negative and positive affect (with anticipation, task, and recovery as separate dependent variables). In case of a significant MANOVA result, we performed one-way ANOVAs for the respective period with group as a between-subject factor. In case of a significant ANOVA, we continued with planned contrasts, comparing treatment groups to control. Exploratory post-hoc tests were performed to detect all possible group differences.

3. Results

3.1. Preliminary analyses

3.1.1. Individual characteristics

The groups did not differ in age, sex, education, occupation, marital status, or income (Table 1).

3.1.2. MBSR-B program check

Both MBSR and MBSR-B showed a larger pre-post increase in Buddhist Insight (measured by the IS) than WAITLIST, but the difference did not reach significance: \( F(2, 62) = 0.47, \ p = .63, \ \eta^2 = .02 \)
Table 2
Descriptive statistics and group differences in outcome variables.

| Outcome                              | Group descriptors M (SD) | MANOVA/ANOVA p<sup>a</sup> | Contrasts p (adjusted p<sup>b</sup>), Cohen’s d |
|--------------------------------------|--------------------------|-----------------------------|-------------------------------------------------|
| Salivary cortisol (nmol/l)           |                          |                             |                                                 |
| log10 cortisol AUCI (anticipation)   | 1.63 (.21)               | F(6, 112) = 2.34, p = .042, Wilks’ Λ = .79 | p = .023 (.026), d = 0.82, p = .013 (.026), d = 0.78 |
| log10 cortisol AUCI (task)           | 2.11 (.23)               | F(2, 57) = 4.69, p = .013 (.039), η<sup>2</sup> = .14 |                                                 |
| log10 cortisol AUCI (recovery)       | 1.64 (.18)               | F(2, 58) = 2.98, p = .054 (.10), η<sup>2</sup> = .09 |                                                 |
| Alpha-amylose (U/ml)                 |                          |                             |                                                 |
| log10 amylase AUCI (anticipation)    | 2.91 (.28)               | F(6, 112) = 1.01, p = .42, Wilks’ Λ = .90 |                                                 |
| log10 cortisol AUCI (task)           | 3.34 (.20)               |                             |                                                 |
| log10 cortisol AUCI (recovery)       | 3.22 (.16)               |                             |                                                 |
| PEP (ms)                             |                          |                             |                                                 |
| relative percent change (anticipation) | -21.62 (15.03)          | F(6, 106) = 2.62, p = .021, Wilks’ Λ = .76 | p = .034 (.034), d = 0.72, p = .008 (.016), d = 0.88 |
| percent change (anticipation)        | -19.99 (27.11)           | F(2, 59) = 5.33, p = .007 (.007), η<sup>2</sup> = .15 | p = .017 (.017), d = 0.84, p = .002 (.004), d = 1.05 |
| percent change (task)                | -21.22 (40.40)           | F(2, 59) = 7.23, p = .002 (.004), η<sup>2</sup> = .20 |                                                 |
| percent change (recovery)            | -1.70 (8.42)             | F(2, 59) = -0.84, p = .44, η<sup>2</sup> = .03 | p = .007 (.013), d = 0.87, p = .023 (.023), d = 0.70 |
| RMSSD (ms)                           |                          |                             |                                                 |
| percent change (anticipation)        | -19.99 (27.11)           | F(6, 114) = 2.14, p = .053, Wilks’ Λ = .81 | p = .012 (.025), d = 0.82, p = .021 (.025), d = 0.71 |
| percent change (task)                | -20.91 (26.69)           | F(2, 59) = 5.33, p = .007 (.007), η<sup>2</sup> = .15 | p = .002 (.004), d = 1.05 |
| percent change (recovery)            | -21.22 (40.40)           | F(2, 59) = 7.23, p = .002 (.004), η<sup>2</sup> = .20 |                                                 |
| percent change (recovery)            | -1.70 (8.42)             | F(2, 59) = -0.84, p = .44, η<sup>2</sup> = .03 | p = .007 (.013), d = 0.87, p = .023 (.023), d = 0.70 |
| Negative affect                      |                          |                             |                                                 |
| absolute change (task)               | 2.46 (2.40)              | F(6, 114) = 2.61, p = .021, Wilks’ Λ = .77 | p = .079 (.058), p = .002 (.004), d = 0.97 |
| absolute change (recovery)           | 2.79 (3.22)              | F(2, 59) = 4.84, p = .011 (.022), η<sup>2</sup> = .14 | p = .004 (.007), d = .95 |
| Positive affect                      |                          |                             |                                                 |
| absolute change (task)               | 0.13 (2.11)              | F(6, 114) = 2.36, p = .035, Wilks’ Λ = .79 | p = .004 (.008), d = .95 |
| absolute change (recovery)           | -0.96 (1.16)             | F(2, 59) = 5.61, p = .003 (.009), η<sup>2</sup> = .18 | p = .005 (.008), d = 0.95 |

Note. WAITLIST = waitlist control group, MBSR = Mindfulness Based Stress Reduction, MBSR-B = modified Mindfulness Based Stress Reduction, PEP = pre-ejection period, RMSSD = the root mean square of successive differences.

* Holm-Bonferroni adjusted p values
N = waitlist control group, MBSR = Mindfulness Based Stress Reduction group, MBSR-B = modified Mindfulness Based Stress Reduction group. Significant outliers (N = 2) are excluded.

(descriptive statistics are available in Supplementary Materials, Table S3).

Similarly, both MBSR and MBSR-B showed a pre-post increase in wisdom (greater for the MBSR-B group), and brahma-viharas, while WAITLIST demonstrated a slight decrease. Scores of right conduct increased only in MBSR-B, while MBSR and WAITLIST showed a decrease (Supplementary Materials, Table S3). The difference in (1) wisdom change score yielded moderate effects size and almost reached statistical significance only between MBSR-B and WAITLIST; (2) brahma-viharas change score yielded large effect sizes and showed statistical significance between MBSR-B and WAITLIST and MBSR and WAITLIST; (3) right conduct change score yielded large effect size and showed statistical significance between MBSR-B and WAITLIST, and moderate effect size between MBSR-B and MBSR (for statistical tests results refer to Supplementary Materials, Table S4).

3.1.3. Practice log

The groups did not differ in the number of attended sessions, minutes of practice during the course, self-reported effort put to practice or difficulty of practice (for statistical tests results refer to Supplementary Materials, Table S5).

3.1.4. Pre-experimental check

The groups did not differ in the number of hours of sleep, perceived sleep quality, and mood before the experiment. Similarly, no group difference was detected in the experience of public speaking and mental arithmetic (for statistical tests results refer to Supplementary Materials, Table S6).

3.2. Stress induction

Sphericity was violated in all variables except negative affect. The TSST elicited statistically significant changes over time in all variables, such as cortisol: F(2, 122) = 11.46, p < .001, η²G = .04, ε = 0.73; sAA: F(2, 122) = 14.01, p < .001, η²G = .02, ε = 0.82; PEP: F(2, 122) = 64.01, p < .001, η²G = .21, ε = 0.90; RMSSD: F(2, 122) = 16.99, p < .001, η²G = .07, ε = 0.67; negative affect: F(2, 122) = 11.98, p < .001, η²G = .06; and positive affect F(2, 122) = 24.99, p < .001, η²G = .09, ε = 0.80 (Supplementary Materials, Fig. S1).

3.2.1. Respiration rate

The correlation between change in RMSSD and respiration rate was not significant for the anticipation period (r(60) = −.22, p = .085) and for the task period (r(60) = −.16, p = .21). The difference between MBSR, MBSR-B and WAITLIST in respiration rate across all task periods was not statistically significant, F(6, 114) = 0.70, p = .65, Wilk’s Λ = .93. Taking these results into consideration, we did not include respiration rate variable in the analysis of group differences in RMSSD.

3.3. Main analyses

3.3.1. HPA axis (salivary cortisol)

The difference between MBSR, MBSR-B and WAITLIST in dependent variables was statistically significant, but follow-up tests showed that statistically significant differences among the groups could be observed only for the AUCi anticipation. Post-hoc tests demonstrated that during anticipation, MBSR had lower cortisol AUCi than WAITLIST, and the same pattern was observed comparing MBSR-B group and WAITLIST (Table 2, Fig. 3).

3.3.2. SAM system (sAA)

The difference between MBSR, MBSR-B, and WAITLIST in dependent variables was not statistically significant (Table 2).

3.3.3. ANS (PEP)

The difference between MBSR, MBSR-B, and WAITLIST in dependent variables was statistically significant. Follow-up tests showed that statistically significant difference between groups could be observed in changes to task, with MBSR showing lesser relative percent of decrease in PEP than WAITLIST. Equally, statistically significant difference between groups could be observed in changes to task, with MBSR showing lesser relative percent of decrease in PEP than WAITLIST, as well as MBSR-B
showing lesser relative percent of decrease in PEP than WAITLIST (Table 2, Fig. 4A). No effect for recovery was observed in either group.

3.3.4. ANS (RMSSD)

The difference between MBSR, MBSR-B and WAITLIST in dependent variables was statistically significant. Follow-up tests showed that statistically significant differences among groups could be observed in changes to all the three phases. Groups showed statistically significant relative percent decrease in RMSSD from pre-task to anticipation, with MBSR showing lesser relative percent of decrease in RMSSD than WAITLIST, as well as MBSR-B showing lesser relative percent of decrease in RMSSD than WAITLIST. Equally, statistically significant differences between groups could be observed in changes to task, with MBSR showing lesser relative percent of decrease in RMSSD period than WAITLIST, as well as MBSR-B showing lesser relative percent of decrease in RMSSD than WAITLIST. Similarly, group changes were observed in recovery, but only the MBSR-B group showed a statistically significant difference from the WAITLIST (Table 2, Fig. 4B).

3.3.5. Affect

The difference between MBSR, MBSR-B, and WAITLIST in dependent variables was statistically significant for both negative and positive affect (Table 2).

Follow-up tests revealed that there was a statistically significant difference in increase of negative affect from pre-task to anticipation, with both MBI groups showing lesser increase in negative affect, but only MBSR-B showing a statistically significant difference with WAITLIST (Table 2, Fig. 4C). Equally, statistically significant differences between groups could be observed in changes to task, with MBSR showing lesser increase in negative affect than WAITLIST, as well as MBSR-B showing lesser increase in negative affect than WAITLIST (Table 2, Fig. 4C).

Concerning positive affect, a statistically significant group difference was observed only in changes to the task period, with MBSR showing lesser positive affect decrease than WAITLIST, as well as MBSR-B showing lesser positive affect decrease than WAITLIST (Table 2, Fig. 4D).

3.3.6. Exploratory analyses of group differences

We did not detect any group differences between MBSR and MBSR-B directly, but in several variables only the MBSR-B group (and not MBSR) was significantly different from control in the full pairwise analysis (Supplementary Materials, Table S7).

4. Discussion

The main strength of this study lies in a comprehensive approach which takes into consideration several factors: we tested the effects of MBIs on various stress response systems, addressed temporal dynamics by expanding measurement of the stress response to anticipation and recovery, and explored whether SG-MBI produces larger stress-attenuating effect. We found that MBIs produce a stress-attenuating
effect in response to social-evaluative threat across multiple physiological and experiential response systems. Furthermore, we demonstrated that stress-attenuating effects of MBIs are present already during the anticipatory period and extend till the recovery phase for one of the variables. This observation suggests that contemplative practices are effective in the reduction of prolonged stress activation. Finally, we found a preliminary indication that SG-MBIs (represented in this study by a program with an additional module based on Buddhist practices) could have a more pronounced effect on some parameters, such as HRV and negative affect.

4.1. Stress response systems

Several psychophysiological response systems affected by stress were tested for effects of the MBIs: HPA axis, SAM, ANS, and affect. Concerning the HPA axis, significant effects were observed for the biomarker cortisol, but only in the anticipatory period and with a small effect size, suggesting the overall effects of contemplative training on the stress-related HPA-axis activity are rather modest. This observation might provide clues to interpret rather inconclusive literature on the effects of MBIs on the neuroendocrine pathway in response to social-evaluative threat (Morton et al., 2020); several studies which failed to detect the MBIs effects on the HPA axis ignored anticipatory reactivity and focused only on the task reactivity only.

In terms of the ANS, results demonstrated that the effects of MBIs are detectable both for the SNS and the PNS, with larger effect sizes for the PNS. This represents an important finding, taking into consideration that autonomic changes produced by psychological stressors are dependent on individual differences, with some people showing predominant sympathetic activation, vagal withdrawal, or a reciprocal pattern of response (Berntson et al., 1991). This study is one of the few up to date to detect the MBIs effects on the HPA axis ignored anticipatory reactivity and focused only on the task reactivity only.

4.2. Temporal dynamics of the stress response

Another important feature of this study is the attempt to differentiate the stress-reducing effects of MBIs during different phases of stress, including both anticipatory activation and recovery. The importance of addressing anticipation and recovery in stress research has been underlined for the HPA axis (Engert et al., 2013; Juster et al., 2012) and the ANS (Brosschot et al., 2005; Linden et al., 1997) due to the idea that prolonged activity explains unique variance in psychological health. In addition, anticipatory reactivity before stress might determine the magnitude of response when the stress comes (Pulupolus et al., 2018, 2020).

In this study, the effects of MBIs on anticipatory stress were detected across almost all physiological systems leading to attenuated responses of the HPA axis, ANS (SNS/PNS), and negative affect. The effect on recovery was observed in HRV for MBSR-B. These findings suggest that the stress-attenuating effects of MBIs go beyond reducing stress reactivity and diminish prolonged stress activation related to social-evaluative threat. These results are congruent with previous reports linking contemplative practice with a reduction in prolonged stress activation (Britton et al., 2012; Gamaiunova et al., 2019) though focus on anticipatory and recovery in MBIs and stress research is still rare. On the level of self-report, we observed the effects of MBIs on stress-induced changes in both negative and positive affect. MBSR-B showed lesser TSST-induced increase in negative affect during the anticipation period and the task, and MBSR during the task. As for positive affect, both MBIs showed lesser TSST-induced decrease during the anticipation and the task. Positive affect during stress represents an interesting area of research, resulting in questions such as how positive emotions appear or maintained during distressing events and what their stress-buffering role is (Folkman & Moskowitz, 2000). A series of studies (Fredrickson & Levenson, 1998; Fredrickson et al., 2000; Robles et al., 2009) suggests that positive emotions are associated with faster physiological recovery from distress. The mechanisms can be explained by the broaden-and-build theory (Fredrickson, 1998): In contrast to negative emotions, which narrow individuals’ thought–action repertoires, positive emotions broaden those repertoires, allowing a wider than typical range of actions and thoughts. The effects of MBIs on the increase in positive emotions were demonstrated in previous research (Fredrickson et al., 2017; Geschwind et al., 2011), and our study adds to the literature, suggesting that MBIs lead to a significantly lesser decrease in positive affect in the context of social-evaluative threat.

4.3. Differences between programs

This study aimed to explore the magnitude of effects of two MBIs, the
The small sample size did not permit the direct comparison of the sample size, effects of MBIs were observed across multiple measures. treatment groups, but the estimations of the effects compared to control our a priori sample size estimations. However, regardless of the reduced sample size, effects of MBIs were observed across multiple measures. The small sample size did not permit the direct comparison of the treatment groups, but the estimations of the effects compared to control gave us preliminary indications on the potential add-on effects of SG-MBIs.

4.3.1. Limitations
This study has several limitations: First, our sample size was small. The attrition resulted in the final number of participants being inferior to our a priori sample size estimations. However, regardless of the reduced sample size, effects of MBIs were observed across multiple measures. The small sample size did not permit the direct comparison of the treatment groups, but the estimations of the effects compared to control gave us preliminary indications on the potential add-on effects of SG-MBIs.

Second, the TSST protocol in this study was modified: the anticipation phase was increased. Modifications of the protocol can reduce the comparability of the results across studies (Labuschagne et al., 2019).

Third, measurement of the manipulation of an additional module indicated only partial success. While the pre-post changes in ethics were statistically different from WAITLIST only in the MBSR-B group, the difference in wisdom between those groups fell slightly above the threshold of statistical significance after the appropriate corrections were applied. Although these results can be explained by insufficient statistical power, they may also highlight the challenges inherent in teaching wisdom in such a short curriculum. Regardless this limitation and taking in consideration comparable times of practice in both groups, larger effect for ethics and partially for wisdom in MBSR-B, we can suggest that the effects of MBSR-B were attributable to their participation in the modified intervention.

4.3.2. Future directions
Testing the effects of different MBIs on the stress response to social-evaluative threat, both separately and in combined curriculums, represents an important direction in the field. As mindfulness was discussed as being a necessary preliminary practice for developing other states, such as compassion or loving-kindness (Hoffman et al., 2011), it remains to be determined how much of mindfulness or concentration training is necessary before starting other types of meditations and if the current terminology (MBIs) is adequate for the programs that have other practices in its core.

Based on the results of this study, we suggest testing more ethics and wisdom-based SG-MBIs, including analytical meditations, a type of contemplative practices which includes systematic investigation and analysis of a particular topic or concept. Further, the design and implementation of SG-MBIs should address important open questions, such as the ratio of mindfulness and additional practices, the training of intervention providers, and ethical considerations, among others (Baer, 2015; Bayot et al., 2020; Shonin et al., 2014). Development of appropriate measures, able to capture changes in wisdom-related constructs is also of the utmost importance.

We suggest further exploration of the effects of MBIs with respect to temporal dynamics, in particular prolonged stress activity, including early anticipation and longer recovery. Several theories explaining the potential mechanisms of prolonged stress, such as perseverative cognition, have solid foundations and the effect of MBIs on stress attenuation through those mechanisms can be experimentally tested.

Measures of different physiological response systems should be coupled with self-report wherever possible as a multilevel assessment helps to avoid bias introduced by methodological differences across studies. Furthermore, we suggest increasing methodological rigor in the ANS assessments during the TSST and adequate reporting: the original protocol includes postural changes that have significant effects on cardiovascular indices, which may partially explain the large discrepancies in HRV or PEP across studies. Taking into consideration that contemplative practices can be associated with altered breathing (Anahi et al., 2014; Wielgosz et al., 2016), we further suggest accompanying stress measurements by breathing indices regardless of our finding showing no difference in RR among the treatment groups. Our results can be explained by (1) lack of explicit breathing-altering instructions in the MBSR curriculum (in comparison to such programs as the Guided Respiration Mindfulness Therapy; Lalande et al., 2017), and (2) by current lack of evidence that practice-induced RR changes in short-term practitioners go beyond formal meditative sessions (Wielgosz et al., 2016). In future studies, widely used assessment of RR can be enhanced; for example, exhalation to inhalation ratio which was proposed to be an important modulator of autonomic patterns (Bae et al., 2021).

5. Conclusions
Regardless of the abovementioned limitations, this study contributes to the research on the effects of MBIs on the stress response to social-evaluative threat. First, this study demonstrates that the stress-buffering effects are observed across different psychophysiological response systems though not with the same magnitude: the largest effects are indicated for the PNS. Second, preliminary evidence is provided that a contemplative training has the potential to reduce prolonged stress activation, such as anticipatory stress and prolonged recovery. Finally, this study gives preliminary indications that SG-MBIs might have add-on effects on the stress attenuation.

CRediT authorship contribution statement

Luidmila Gamaiunova: Conceptualization, Methodology, Formal analysis, Investigation, Project administration, Data curation, Visualization, Funding acquisition, Writing – original draft. Sylvia D. Kreibig: Methodology, Resources, Writing – review & editing. Elise Dan-Glauser: Methodology, Resources, Writing – review & editing. Nicolas Pellerin: Conceptualization, Methodology, Writing – review & editing. Pierre-Yves Brandt: Conceptualization, Methodology, Supervision, Funding acquisition, Writing – review & editing. Matthias Kliegel: Conceptualization, Methodology, Supervision, Funding acquisition, Writing – review & editing.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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