Exploration of psychological mechanisms of the reduced stress response in long-term meditation practitioners

Gamaiunova, Liudmila; Brandt, Pierre-Yves; Bondolfi, Guido; Kliegel, Matthias

How to cite

GAMAIUNOVA, Liudmila et al. Exploration of psychological mechanisms of the reduced stress response in long-term meditation practitioners. In: Psychoneuroendocrinology, 2019, vol. 104, p. 143–151. doi: 10.1016/j.psyneuen.2019.02.026

This publication URL: https://archive-ouverte.unige.ch/unige:129945
Publication DOI: 10.1016/j.psyneuen.2019.02.026

Exploration of psychological mechanisms of the reduced stress response in long-term meditation practitioners

- Accepted manuscript –

Link to the article : https://doi.org/10.1016/j.psyneuen.2019.02.026

Gamaiunova, Liudmila[1,4]

Brandt, Pierre-Yves[1]

Bondolfi, Guido[2]

Kliegel, Matthias[3,4]

1 Institute of Social Sciences of Religions (ISSR), University of Lausanne, Quartier UNIL-Chamberonne, CH-1015, Lausanne, Switzerland

2 Department of Psychiatry, Department of Psychiatry, Geneva University Hospitals, Rue Gabrielle-Perret-Gentil 4, CH-1205 Geneva, Switzerland.

3 Department of Psychology, University of Geneva, Boulevard du Pont-d'Arve 40, 1204 Geneva, Switzerland

4 Swiss National Center of Competences in Research LIVES–Overcoming vulnerability: life course perspectives, Switzerland

Highlights

- Long-term meditation practitioners have faster cortisol recovery from stress than meditation-naïve controls.
- In comparison to a meditation naïve control group, long-term meditation practitioners experience less self-conscious emotions, but not negative affect, after the exposure to social-evaluative threat, and employ more adaptive cognitive emotion regulation strategies.
- The cognitive emotion regulation strategy of acceptance mediates the relationship between the practice of meditation and cortisol recovery from stress.

Abstract

Previous research links contemplative practices, such as meditation, with stress reduction. However, little is known about the psychological mechanisms underlying this relationship. This study compares the physiological stress response (reactivity and recovery) measured by changes in salivary cortisol, heart rate, heart rate variability, and the associated stress-related ratings in long-term meditation practitioners ($N = 29$) and age- and sex- matched meditation naïve controls ($N = 26$). The participants were administered the Trier Social Stress Test in its active and placebo versions. The results demonstrated that long-term meditation practitioners had faster cortisol recovery from stress, and experienced less shame and higher self-esteem after the exposure to social-evaluative threat. In addition, long-term meditation practitioners scored higher on adaptive cognitive emotion regulation strategies, such as acceptance and positive reappraisal, and lower on maladaptive ones, such as catastrophizing. The cognitive emotion regulation strategy of acceptance mediated the relationship between meditation practice and cortisol recovery. These results suggest that meditation practice is associated with faster recovery from stress due to the employment of adaptive emotion regulation strategy of acceptance, delineating a pathway underlying the positive effects of meditation on stress.

1. Introduction

1.1. Contemplative training and the stress response

Psychosocial stressors activate a distinct response through the limbic-sensitive “processive” stress pathway (Herman and Cullinan, 1997), leading to physiological changes orchestrated primarily by the hypothalamic–pituitary–adrenal axis (HPA) and the sympathomedullary pathway (SAM). The detrimental effects of repeated stress on neurons (Uno et al., 1989) and the negative relationship between psychological stress and a number of physical and mental conditions (Cohen et al., 2007; Roberts et al., 2017; Sapolsky, 2007) have been well documented.

One of the most promising behavioral approaches aiming to attenuate the stress response is contemplative training, which consists of the use of various practices that originated mostly in eastern religious and spiritual traditions. Contemplative practice (CP) is defined as a form of training enacting a process of self-transformation through self-awareness, self-regulation, self-inquiry, and self-transcendence (Davidson and Dahl, 2017; Vago and David, 2012). One of the most studied types of CPs in the context of stress reduction are Buddhist-based meditations, in particular, their clinical applications in the form of mindfulness or compassion cultivating interventions. There is a substantial body of research linking stress reduction with these types of CPs (Carlson et al., 2001; Jain et al., 2007; Shapiro et al., 1998). Yet, the majority of those results should be considered with caution since most of the studies relied only on self-report measures of stress. Far fewer investigations have employed physiological markers of stress, and the results are considerably less coherent; several studies linked CPs with reported physiological changes in response to stress, such as changes in the cardiac parasympathetic and sympathetic response (alpha-amylase) (Arch et al., 2014a), adrenocorticotropic hormone (ACTH) (Hoge et al., 2017), blood pressure (Nyklíček et al., 2013), and cortisol (Rosenkranz et al., 2016). However, several studies have found no association between CPs and the stress-related changes in physiological variables (Gex-Fabry et al., 2012; Nyklíček et al., 2013; Pace et al., 2009) or even reported the opposite effect, i.e., that contemplative training was associated with an increase in salivary cortisol (Creswell et al., 2014).

An important shortcoming of previous research investigating the relationship between CPs and stress is the accent on the reactivity model of the stress response (Brosschot et al., 2005; Linden et al., 1997). Even though the stress-related negative health outcomes are found to be associated with reactivity to a psychological stressor (Cohen et al., 2002; Matthews et al., 1993), it is important to note the prolonged recovery, which results from a failure to shut off the stress response (McEwen, 1998). Recovery represents a separate mechanism underlying the pathophysiology related to stress exposure; for example, neuroendocrine recovery is associated with increased immunity (Epel et al., 1998), and diminished vagal rebound (increase in heart rate variability after the stressor) is linked to risk factors for cardiovascular disease (Mezzacappa et al., 2001). Thus, from a conceptual and clinical perspective, it is essential to consider both reactivity to and recovery from a stressor when evaluating approaches designed to lead to stress reduction.

Another crucial but relatively neglected aspect of research on the relationship between CPs and stress is the investigation of the psychological mechanisms that underlie the CPs effects on stress. Most of the abovementioned studies did not make an attempt to relate stress-induced changes in physiological variables to psychological factors associated with the stress response. The paucity of a psychophysiological theory on possible mechanistic pathways represents an important lacuna in existing research on CPs and stress. Thus, considering that long-term CPs shows a more consistent association with psychobiological stress reduction (Engert et al., 2017) than short contemplative training (Creswell et al., 2014), studies aiming to investigate the mechanisms of the CPs and the stress response association should be conducted in a population of experienced practitioners which was the purpose of the present study.

1.2. Psychological factors of the stress response and contemplative training.

In recent years, initial attempts of delineating the potential mechanisms of contemplative training effects on behavior and health have been proposed, ranging from neurobiological to traditional Buddhist models (see, e.g., Emavardhana and Tori, 1997; Grabovac et al., 2011; Hölzel et al., 2011; Lindsay and Creswell, 2017; Shapiro et al., 2006; Vago and David, 2012). However, research on CPs lacks more targeted theoretical models describing the relationship between contemplative training and a specific outcome, such as the stress response. The psychobiological stress response has been previously linked to a number of psychological factors, such as primary cognitive appraisals (Gaab et al., 2005), self-conscious emotions and cognitions (Kemeny et al., 2004), and emotion regulation (Lam et al., 2009; Zoccola et al., 2008). These psychological variables have not been sufficiently explored as potential mechanisms of the CPs effects on stress.

1.2.1 Primary cognitive appraisals

According to the influential stress appraisal theories (e.g., Lazarus and Folkman, 1984), the psychobiological response to stress is partially determined by how the situation is evaluated by a particular individual. It was proposed to differentiate between *primary appraisals*, representing the evaluation of the relevance of a given situation, and *secondary appraisal*, focusing on the coping potential of an individual. In the context of social evaluative threat, primary stress appraisals "threat" and "challenge" have been found to be related to the physiological changes in response to stress (Gaab et al., 2003; Gaab et al., 2005; Mayor and Gamaiunova, 2014).

CPs have the potential to alter the appraisal process. One of the skills trained in various CPs is reperceiving (Shapiro et al., 2006), a mechanism that allows the participant to step back and disidentify from current thoughts or affective states and view the experience more objectively. Additional mechanisms include heightened awareness of the present moment and mindful attention (for a discussion, see Epel et al., 2009). Preliminary empirical evidence suggests the CPs may indeed be associated with attenuated threat appraisal (Weinstein et al., 2009).

1.2.2 Self-conscious emotions and cognitions

Alongside cognitive appraisals, the stress response is associated with affective states (Buchanan et al., 1999). However, this relationship is complex, and defining the affective response in terms of valence and arousal appears to be less useful in studying non-autonomic physiological markers of stress, such as cortisol (Denson et al., 2009). Previous meta-analytical work suggests that general negative affect is poorly correlated with cortisol responses (Dickerson and Kemeny, 2004). The stress response in the context of social evaluation appears to be most related to a particular type of affective state: self-conscious emotions (Leary, 2007; Tracy and Robins, 2004). The social preservation theory (Kemeny et al., 2004) and associated research suggest that self-conscious emotions (shame) and associated cognitions (low self-esteem) are mostly associated with the HPA-axis related physiological changes in response to stress (Dickerson et al., 2004; Gruenewald et al., 2004; Martens et al., 2008; Pruessner et al., 2005).

CPs have been found to be associated with shame reduction (Goldsmith et al., 2014; Woods and Proeve, 2014) and positive effects on self-esteem (Pepping et al., 2013; Rasmussen and Pidgeon, 2011). Some of the proposed mechanisms behind CPs effects on self-conscious emotion and cognition include self-compassion (Woods and Proeve, 2014), nonjudgement (Rasmussen and Pidgeon, 2011), and reduced self-identification (Brown et al., 2008).

1.2.3 Emotion regulation.

Emotion regulation (ER) is the processes by which individuals influence when they have emotions, what type, and how they experience and express them (Gross, 1998). ER represents another important psychological mechanism associated with the stress response (Sapolsky, 2007). Specific ER strategies (for example, perseverative cognition and rumination) can lead to prolonged physiological activation (Brosschot et al., 2005; Zoccola et al., 2008) or impact stress reactivity (Butler et al., 2006; Egloff et al., 2006). Focuses on the cognitive methods of managing emotionally stimulating information Garnefski et al. (2001) framework differentiates several distinct ER dimensions: acceptance, self-blame, blaming others, refocus on planning, positive refocusing, positive reappraisal, rumination, catastrophizing, and perspective taking.

The relationship between CPs and cognitive ER strategies has been previously investigated. Here, CPs have been positively linked to the recurrence to acceptance (Lindsay and Creswell, 2017) and positive reappraisal (Garland et al., 2011; Garland et al., 2009) and negatively related to catastrophizing (Cassidy et al., 2012), rumination (Deyo et al., 2009), and distraction (Jain et al., 2007). However, the complex association of those ER strategies, CPs and the stress response requires further investigation.

1.4. This study

This study addresses several of the open questions in research on the relationship between CPs and the stress response that were identified above. First, the study targeted the dynamics of the stress response, assessing both reactivity to and recovery from a psychological stressor in long-term practitioners of Buddhist meditation (MP) and matched meditation-naive controls (MN). Second, the study investigated group differences in the psychological variables associated with the stress response: primary cognitive appraisals (threat and challenge), self-conscious emotions (shame) and cognitions (self-esteem), and cognitive emotion regulation strategies. Third, the study explored if psychological variables can explain the relationship between contemplative practice and the stress response.

It was hypothesized that MPs will show less reactivity to and more pronounced recovery from stress expressed than MN through changes in salivary cortisol, heart rate (HR), and heart rate variability (HRV). It was further hypothesized that MPs will feel less threat before the stress, will experience less shame and higher self-esteem after the social-evaluative threat, and will score higher in adaptive cognitive emotion regulation strategies (acceptance, positive reappraisal, perspective-taking, positive refocusing) and lower on non-adaptive strategies (rumination, catastrophizing, self-blame, other-blame). The relationship between CPs, psychological variables associated with the stress response, and the physiological stress response, was further explored in secondary mediation analyses. In particular, we predicted that (1) primary cognitive appraisal of threat meditates the relationship between meditation practice and reactivity to stress and that (2) cognitive emotion regulation strategies mediate the relationship between meditation practice and recovery.

2. Methods and materials

2.1. Participants

Participants included 29 long-term meditation practitioners (MP) and 26 age- and gender-matched meditation-naïve (MN) controls. Groups did not differ significantly in descriptive variables, except for the self-reported experience in mental calculation (participants were asked if they have experience in doing mental calculations). Controlling for this variable in the analyses did not change the results. Complete descriptive characteristics and associated tests can be found in Supplementary Data Table 1.

The MN group was recruited through flyers and announcements in community newspapers, and the MP group was recruited mainly through flyers and emails to local Buddhist meditation centers.

The inclusion criteria for MP was the practice of meditation derived from Buddhist traditions for at least 3 years with a regularity of at least 3 hours/week. For MN controls, the inclusion criteria consisted of having no primary experience with any kind of meditation. The exclusion criteria for both groups included prior participation in the Trier Social Stress Test, psychiatric diagnosis, medical conditions, use of medication that could interfere with biological markers of the stress response, and use of hormonal contraceptives (Kirschbaum et al., 1995). The protocol was approved by the local ethics committees for research involving humans.

2.2. Procedures

Participants underwent two laboratory sessions in a counterbalanced order: the stress-inducing Trier Social Stress Test, TSST (Kirschbaum et al., 1993), and a placebo version of this test (Het et al., 2009). After arriving at the lab, the participants were given 10 minutes to rest before they were led to another room and presented to a panel of two judges (male and female) and a camera. After the standard explanation of the task, participants were led back to the first room and given 10 minutes to prepare for the task. After the preparation period, the participants were asked to deliver a task in front of an unfriendly committee, a camera and a microphone. The task consisted of a 5-minute speech followed by a 5-minute math task. If participants were silent during the speech, they were asked to continue; if a mistake was made during the arithmetic task, the participants were asked to restart the task. The placebo version of the TSST was performed following a similar protocol and in the same rooms as the TSST but without the stress-inducing parts of the TSST (committee, video camera, and microphone). Participants were instructed to read out loud a magazine for 5 minutes and count down from 200 aloud. All the participants were only scheduled for the TSST sessions in the afternoon (Kudielka et al., 2004b), and female participants were scheduled for the experimental sessions during the luteal phase of the menstrual cycle (Kirschbaum et al., 1999). The order of the active TSST was counterbalanced in each group. Participants were asked to give subjective ratings of stress during both active and placebo versions of the TSST. During the active version, participants filled out a questionnaire assessing primary cognitive appraisals (anticipation period), state shame, self-esteem, negative affect (right after the stressor), and emotion regulation strategies (during recovery period). A detailed description of the measurements is presented in section 2.4., and the schematic representation of the experiment flow can be found in the Supplementary Materials Figure 2.

2.3. Biological measures

Salivary cortisol. The magnitude of the stress response was measured by changes in salivary cortisol (a marker of the HPA axis activity). Six saliva samples were collected after 10 minutes of rest (t1), at the end of the task preparation period (t2), right after the tasks (t3), and then 10 minutes (t4), 20 minutes (t5), and 30 minutes (t6) after the task using the Salivette sample device (Sarstedt, Nümbrecht, Germany). After each session, the samples were refrigerated and then sent to a laboratory for free cortisol concentration analysis.

Autonomic nervous system (ANS). Heart rate and heart rate variability parameters served as the markers of autonomic activity. The cardiovascular measurements were continuously collected using a Polar RS800CX cardiac monitor (Polar Electro Ltd., Kempele, Finland) (Nunan et al., 2008) at a sampling rate of 1000 Hz. The recorded R-R series was downloaded using Pro Trainer Polar 5 software. Further data processing was done with the help of Kubios HRV – heart rate variability analysis software (Tarvainen et al., 2014). All signals were corrected with the automated artifact correction filter (low) from Kubios HRV. Two-minute intervals were created for the rest period (t1), preparation period (t2), task (average of 1 minute of speech task and 1 minute of math task, t3), right after the task (t4), and then 20 minutes (t5) and 30 minutes (t6) after the task. For those intervals, two time-domain indexes were calculated: heart rate (HR), as an index of general sympathetic nervous system arousal, and the root mean square of successive differences (RMSSD), an index of vagus-mediated heart rate variability (Camm et al., 1996). Due to the recording problems, measures from one of the sessions were missing in 7 participants (3 from the MP group, 4 from the MN group); those participants were excluded from the analyses.

2.4. Self-report measures

The transactional stress questionnaire (PASA) (Gaab et al., 2005) is a 16-item questionnaire intended to measure the primary stress appraisals of threat and challenge as well as secondary appraisals related to the self-concept of one's own abilities and control expectancy. *The State Shame & Guilt Scale (SSGS)* (Marschall et al., 1994) is a self-report measure compromised of 15 items. Five items for each of the three subscales measure state-feelings of shame, guilt, and pride. *The State Self-Esteem Scale* (Heatherton and Polivy, 1991*)* is a 20-item scale that measures a participant's self-esteem at a given point in time. *The Cognitive Emotion Regulation Questionnaire (CERQ)* (Garnefski and Kraaij, 2007; Jermann et al., 2006) is a 36-item questionnaire consisting of the following nine conceptually distinct subscales, each consisting of four items referring to what someone thinks after the experience of threatening or stressful life events: self-blame, other- blame, rumination, catastrophizing, putting into perspective, positive refocusing, positive reappraisal, acceptance, and planning. *Negative and positive affect-PANAS* (Gaudreau et al., 2006; Watson et al., 1988) is a measure of Positive Affect (PA) and Negative Affect (NA), consisting of two 10-items scales. A *Visual Analogue Scale (VAS)* for subjective stress is a measurement instrument that tries to measure a characteristic or attitude that is believed to range across a continuum of values and cannot easily be directly measured. The participants were asked to indicate to what point they were stressed at the moment from 0 "not stressed at all" to 10 "very stressed" at 6 points corresponding to the collection of saliva samples.

2.5. Analyses

The optimal total sample size of N = 53 (effect value of f = 0.4, with a significance level set at α = 0.05, power 1 - β = .80) was calculated prior to the recruitment using G-Power software (Faul et al., 2007). Group difference in demographics variables was tested using t-tests and chi-squares tests. Data were tested for normal distribution using the Kolmogorov-Smirnov and Shapiro-Wilk tests together with the examination of QQ plots. The missing values across the datasets were identified: 16 (2.42%) for cortisol due to insufficient material, 3 (0.52%) for HR and HRV due to the recording problems (final part of the R-R wave missing). Pattern of missing values have been analyzed using little MCAR test, and taking in consideration that the data were missing at random, the expectation maximization technique of imputation was applied (Schafer and Olsen, 1998). Cortisol, HR, RMSSD, and VAS variables were log10 transformed prior to the analyses. Outliers (8 in the cortisol dataset, 17 and 16 for HR and RMSSD datasets respectively) were identified by the boxplots inspection, and analyses were run using datasets with both deleted and winsorized outliers. Analysis of variance (ANOVA) was used for the manipulation tests (placebo vs active TSST) for cortisol, HR, RMSSD, and VAS. Subsequently, 6 time point variables were calculated by subtracting the value of the placebo TSST from the active TSST. Two variables were calculated for cortisol, HR, RMSSD, and VAS: reactivity (highest post-TSST value (t4)-first value (t1) for cortisol, TSST value (t3)-first value (t1) for HR and RMSSD, and pre-TSST (t2) – first value (t1) for VAS; and recovery (highest post-TSST value (t4)-last values (t6) for cortisol, TSST value (t3) – post-TSST value (t4) for HR and RMSSD, and pre-TSST (t2) – last value (t6) for VAS. Analysis of covariance (ANCOVA) was used to test for the group difference in reactivity/recovery, with age, gender and baseline/peak measure as covariates. Prior to all ANOVA and ANCOVA tests, the assumptions for these tests were checked, and the results were corrected by the Greenhouse-Geisser procedure when the assumption of sphericity was violated. T-tests were used to test for the group differences in psychological variables, and the Holm–Bonferroni method was applied to avoid the problem of multiple comparisons (Holm, 1979). Reported correlation coefficients are the Pearson's r values. Mediation analysis was run with the SPSS macro PROCESS (Hayes, 2012). Analyses were performed using SPSS and R software.

3. Results

3.1. Stress manipulation

Stress manipulation effectively induced psychobiological stress response: results of the factorial ANOVAs (condition: active TSST vs placebo TSST X time: t1 to t6) demonstrated changes in salivary cortisol: F (1.92, 103.40) = 31.04, $p < .001$, $\eta p^2 = .37$, heart rate (HR): F (3.68, 173.08) = 18.01, $p < .001$, ηp2 = .28, heart rate variability (HRV): F (3.85, 146.35) = 4.07, p = .004, ηp2 = .10, and subjective rating of stress (VAS): F (3.39, 183.02) = 18.83, $p < .001$, $\eta p^2 = .26$ (Fig. 1a-d). To check if order of the session (active TSST first vs placebo TSST first) had an effect on the psychophysiological changes in the stress response from placebo to active TSST, order was added as a between subject factor. The results of the factorial ANOVAs (condition X time X order) demonstrated that the interaction was not significant for salivary cortisol: F (1.97, 104.23) = 2.77, p =

.07, ηp2 = .05, HR: F (3.67, 168.86) = 1.46, p = .22, ηp2 = .03, ηp2 = .04, HRV F (3.93, 145.410) = 1.39, p = .24, ηp2 = .04, or VAS: F (3.39, 179.301) = .88, p = .47, ηp2 = .02.

- figure 1 -

3.2. Group differences in response to stress

The results of the univariate tests (reactivity or recovery as dependent variable) demonstrated that the groups did not differ in stress reactivity measured by changes in cortisol: F (1, 55) = 1.164, p = .286, ηp2 = .02; HR: F (1, 48) = .463, p = .500, ηp2 = .01; HRV: F (1, 47) = .129, p = .721, ηp2 < .01, or VAS: F (1, 55) = .28, p = .594, ηp2 = .01. The group difference was detected only in cortisol recovery F (1, 52) = 18.145, p < .001 (adjusted p = .004), ηp2 = .28 (MP: M = .83, SD = .11; MN: M = .72, SD = .09) (figure 2). Recovery measured by changes in HR, HRV and VAS was not different between the groups: F (1, 48) = .495, p = .495, ηp2 = .01; F (1, 45) = 2.763, p = .104, ηp2 = .07; F (1, 55) = .869, p = .356, ηp2 = .02.

- figure 2 -

3.3. Group differences in anticipatory cognitive appraisals, affect, and emotion regulation

After adjusting for multiple comparisons, the group difference remained significant for the post-stressor state shame t(53) = -3.31, p = .009, d = .61, state self-esteem t(53) = 3.14, p = .009, d = .84, and emotion regulation strategies of catastrophizing t(53) = -3.20, p = .018, d = .88, acceptance t(53) = 4.56, p < .001, d = 1.24, and positive reappraisal t(53) = 4.10, p < .001, d = 1.13. Full tests results can be found in Table 1. Figure can be found in Supplementary Materials, figure 1.

3.4. Mediation analysis

For the mediation analysis, the variable that demonstrated group difference was chosen as the outcome variable: cortisol decline (recovery). Group served as the predictor variable. Only the variables associated with both predictor and outcome variables have been introduced as mediators (Baron and Kenny, 1986). Three variables showed to be associated with both the predictor (X) and outcome (Y) variables: acceptance (X: r(51) = .53, p < .001, Y: r(51) = .46, p = .001), positive refocusing (X: r(51) = -.31, p = .022, Y: r(51) = -.32, p = .019), catastrophizing (X: r(51) = -.41, p =

.002, Y: $r(51) = -.29$, $p = .035$). Mediation model included three mediators and two covariates: age and gender. Results demonstrated that only acceptance remained associated with both the predictor and the outcome variable ($b = .011$, $SE = .005$, $t = 2.168$, $p = .035$). Group was no longer a significant predictor of cortisol recovery after controlling for the mediators, thus supporting mediation hypothesis (figure 4). The significance of the indirect effect was tested using bootstrapping procedure. These results demonstrated that the indirect coefficient was significant, $b = .043$, $SE = .022$, 95% BCI = .0097, .0970. The mediator (acceptance) could account for almost a half of the total effect $P_M = .49$.

figure 3

4. Discussion

The results of this study suggest that long-term MP benefit from a more adaptive psychophysiological response to social-evaluative stress than nonmeditators. These findings extend the existing evidence linking CPs with a reduced psychobiological response to stress (Engert et al., 2017; Hoge et al., 2017; Rosenkranz et al., 2016). An important contribution of this study consists of the evaluation of both reactivity to and recovery from stress, with the present results suggesting that contemplative training is particularly related to the recovery phase of the stress response. Those findings nicely dovetail with an earlier study using autonomic nervous system (ANS) markers of the stress response (Goleman and Schwartz, 1976), where CPs were associated with faster recovery from stress but not reactivity. Conceptually, those findings are in line with theories addressing the role of psychological mechanisms of the stress response. For instance, Brosschot et al. (2005) suggest that prolonged physiological activation expressed in higher anticipatory reactivity and longer recovery is related to perseverative cognition, defined as the repeated or chronic activation of the cognitive representation of stress-related content (Brosschot and Thayer, 2003). It is plausible that contemplative training helps to reduce repeated activation of stress-related content during stress through the use of adaptive ER strategies.

Similarly, preservative cognition affects the anticipatory phase of the stress response; in this study, we measured only reactivity to the task, but possible differences might exist on the level of anticipatory prestress reactivity. It has been proposed that anticipatory endocrine activation has a separate predictive value for psychological health (Engert et al., 2013), and we have preliminary evidence relating CPs with decreased anticipatory stress (Britton et al., 2012; Mayor and Gamaiunova, 2014).

This study was the first to look at the association between CPs and experience of self-conscious emotions and cognition after social-evaluative stress. As predicted, long-term meditators experienced significantly less shame and had higher self-esteem after the stress test. Most importantly, the groups did not differ in negative affect. The self is complexly involved in the creation of the affective response, but not all affective experiences rely on self, i.e., certain stimuli evoke emotions automatically (Leary, 2003). The stress-inducing protocol used in this study potently evokes general negative affect due to its novelty and unpredictability, which can explain why the groups did not differ in negative affect. Self-conscious emotions, on the other hand, are experienced when actual or ideal self-representation is shattered (Tracy and Robins, 2004), and this type of affective experience is more correlated to the attachment to one's self-representation. CPs rooted in Buddhism often lead to an important change in self-image, where self is seen as less solid and cohesive than before (Epstein, 1988). Those changes in self-representation help to process an ego-threatening experience in a less defensive way (Brown et al., 2008) and have beneficial effects on self-esteem (Rasmussen and Pidgeon, 2011). The results of this study are consistent with empirical evidence from previous research linking CPs and shame (Goldsmith et al., 2014; Woods and Proeve, 2014).

In this study, we further investigated the relationship between CPs and emotion regulation. We assessed group differences in both adaptive and maladaptive cognitive emotion regulation strategies. In line with previous research (Garland et al., 2011), MPs scored higher on positive reappraisal, an ER strategy that permits reconstruction of a stressful event as meaningful or beneficial. However, mindfulness practice is linked to noncognitive processing (Vago and David, 2012), and the association between mindfulness and cognitive reappraisal remains unclear. Taking into consideration that meditators in this study belonged to different traditions and engaged in CPs that go beyond mindfulness, it is possible that certain types of CPs (for example, analytical meditation in the Tibetan tradition) more greatly affect the use of cognitive processing of stressful stimuli. The group difference was equally found in acceptance, a crucial component of several contemplative approaches.

Acceptance can be defined as a mental attitude of nonjudgment and receptivity toward internal and external experiences (Lindsay and Creswell, 2017). From the set of negative emotion regulation strategies, the group difference was found only in catastrophizing, supporting previous research results linking an important component of contemplative practices, mindfulness, and catastrophizing (Cassidy et al., 2012; de Boer et al., 2014).

A core contribution of our study to the previous research on CPs and stress was testing a mediation model that links CPs and recovery from stress. Our results suggest that CPs affect the stress response only through specific ER strategies. Even though meditators scored higher on reappraisal, this emotion regulation strategy was not a mediator in the relationship between CPs and stress recovery. Reappraisal has been previously found to be positively associated with the ANS changes in response to negative emotions (Mauss et al., 2007), but the association with HPA-axis changes differs (Lam et al., 2009). In this study, only acceptance was found to be a mediator in the CPs and stress response relationship. These findings echo previous results demonstrating that participants instructed to only monitor their experience did not show the same reduction in physiological markers of the stress response as those who also followed acceptance instructions (Lindsay et al., 2018). Similar results were reported in Engert et al. (2017), where CPs modules that included training of the acceptance attitude resulted in significant physiological stress reduction. Conceptually, it can be concluded that acceptance is efficient in attenuating the perseverative thoughts about a stressor allowing efficient recovery of allostatic systems and reducing HPA-axis activation after the threat is gone. From the neurobiological perspective, the attenuation of the HPA-axis output can be related to the reduced activity of the amygdala, linked to the HPA-axis through the hypothalamus (Sullivan et al., 2004). Previous research suggests that CPs are associated with increased activity in the brain areas linked to the attenuation of the amygdala (Hölzel et al., 2011; Lieberman et al., 2007).

Contrary to our predictions, we did not find any group differences in the stress-related changes in HR and HRV. It was previously proposed that certain outcomes of CPs (such as equanimity) are associated with more adaptive vagal cardiovascular reactivity (Desbordes et al., 2015). However, research results from the studies assessing this relationship are also inconsistent (Engert et al., 2013; Nyklíček et al., 2013; Shearer et al., 2016). The inconsistencies in findings can be explained by several reasons. First, studies use different indexes of HRV; more assessments using similar protocols and indexes are needed to draw a preliminary conclusion on the CPs effects on the parasympathetic system. Another possible explanation are the different effects of various types of contemplative training on HRV. This idea is supported by previous research in which self-compassion, but not focused attention training, resulted in more adaptive RSA (Arch et al., 2014b). A limitation of the present study – a non-homogeneous group of meditators – could be responsible for masking the effects of contemplative training on the HRV.

The difference between the HPA axis and ANS-related changes in response to stress echoes previous research results by Engert et al. (2017) who suggest that the discrepancy could be explained by the difference in the reactivity of the HPA and ANS systems, with HPA axis activity being determined by internal evaluation and autonomic activity being a sign of general arousal irrespective of its valence. Buddhism-rooted contemplative training, especially in the settings where meditation is coupled with the study of Buddhist philosophy, targets primarily ego-threatening aspects of stressful experience and less so the arousal.

Contrary to our prediction, no significant group difference was found in primary cognitive appraisals. In this study, we only used a self-report measure of anticipatory cognitive appraisal. Future studies should use physiological markers, such as cardiac output and total peripheral resistance that permit to differentiate between threat and challenge appraisals (Tomaka et al., 1993).

One of the main limitations of the study is its observational design. Taking into consideration that the groups were not randomized to receive a meditation treatment, the recovery effect obtained could in principle be related to the self-selection in engaging in or maintaining CPs. In addition, most of the participants from the meditation group belong to a meditation community, and the effects of possible social support or other factors related to a broader practice framework cannot be excluded. Another limitation is a nonhomogeneity of the meditators group; participants belonged to meditation communities derived from various Buddhist traditions, and existing research suggests that various types of contemplative practices can have different effects on the stress response (Engert et al., 2017). An important limitation of this study that should be taking in consideration while interpreting the results, is its small sample size, which is further reduced due to missing subjects for the ANS data.

In terms of future research, the present study underlines the importance of extending research protocols to disentangling both anticipatory and recovery phases. It will be equally essential to study both ANS and HPA-axis related changes in response to stress, as the two systems are not activated in a similar manner. Further, we propose to continue exploring the psychological mechanisms that underlie the effects of CPs on stress. In particular, we suggest going beyond measures of general negative affect and including the assessment of discrete emotions of both positive and negative valence. Research on ER and CPs also requires further development. We suggest investigating how different types of CP affect choice and the ability to use ER strategies in the context of stress.

Taken together, this study adds important conceptual insights to the existing literature linking CPs with the psychobiological stress response and offers an exploration of the possible mechanisms of this relationship. Specifically, it shows that emotion regulation strategy of acceptance is a potential mechanism linking long-term CPs and physiological recovery from stress.

Acknowledgements

The study was supported by the Cogito Foundation, grant number 15-126-R to PYB and MK, partially by the doc. Mobility fellowship of the Swiss National Science Foundation to LG, and support of the Faculty of Theology and Religious Studies, University of Lausanne.

We thank Dr. Tomas Zimmermann, Haoyang Lu, Sonia Lopez, Carine Karlen, Hannah Perekhoda, and Eric Bonvin for the assistance in data collection and data processing.

----------------------------- Tables and figures ------------------------------------

Table 1 Group difference in psychological variables.

Variable	Group/*N*	*M (SD)*	95% BCa[1]	*t* (df)	*p* (adjusted *p*)[2]	*d*
Cognitive appraisals						
Threat	MP/29	2.53 (0.92)	[2.18, 2.90]	*.21*(53)	.838 (.838)	.06
	MN/26	2.47 (1.05)	[2.12, 2.93]			
Challenge	MP/29	4.28 (0.92)	[3.95, 4.60]	*1.69*(53)	.098 (.196)	.52
	MN/26	3.81 (1.13)	[3.40, 4.21]			
Affect						
State shame	MP/29	5.41 (1.09)	[5.09, 5.81]	*-3.31*(53)	.003 (.009)**	.61
	MN/26	6.85 (2.03)	[6.08, 7.64]			
Negative affect	MP/29	25.66 (3.88)	[24.32, 27.06]	*.55* (53)	.586 (.586)	.15
	MN/26	24.95 (5.57)	[22.74, 26.92]			
State self-esteem	MP/29	60.76 (5.32)	[58.92, 62.59]	*3.14*(53)	.003 (.009)**	.84
	MN/26	55.54 (6.97)	[52.40, 58.23]			
Emotion regulation						
Self-blame	MP/29	10.55 (3.13)	[9.34, 11.84]	*.89* (53)	.377 (1.000)	.24
	MN/26	9.82 (2.96)	[8.87, 10.89]			
Other-blame	MP/29	6.87 (1.87)	[6.29, 7.52]	*-2.01*(53)	.050 (.200)	.53
	MN/26	8.23 (3.09)	[7.10, 9.42]			
Rumination	MP/29	12.48 (2.57)	[11.50, 13.48]	*.36*(53)	.718 (1.000)	.10
	MN/26	12.19 (3.26)	[11.00, 13.51]			
Catastrophizing	MP/29	5.21 (1.21)	[4.79, 5.64]	*-3.20*(53)	.003 (.018)*	.88
	MN/26	7.04 (2.69)	[6.08, 7.97]			
Acceptance	MP/29	15.83 (3.28)	[14.64, 17.11]	*4.56*(53)	.000 (<.001)***	1.24
	MN/26	11.88 (3.10)	[10.71, 13.14]			
Positive refocusing	MP/29	8.11 (3.20)	[7.06, 9.17]	*-2.29*(53)	.026 (.130)	.61
	MN/26	10.46 (4.37)	[8.85, 12.30]			
Perspective taking	MP/29	13.38 (3.31)	[12.23, 14.53]	-*.03*(53)	.974 (1.000)	.01
	MN/26	13.41 (3.99)	[11.74, 14.93]			
Positive reappraisal	MP/29	17.48 (1.94)	[16.78, 18.14]	*4.10*(53)	.000 (<.001)***	1.13
	MN/26	13.85 (4.12)	[12.36, 15.43]			

[1] Bootstrap results are based on 1000 bootstrap samples, [2] p-values are adjusted using the Holm-Bonferroni method, [3] *$p < .05$, **$p < .01$, ***$p < .001$

Figure 1. Change in salivary cortisol, subjective measure of stress, heart rate, heart rate variability in active and control versions of the TSST. bpm = beats per minute, msec = milliseconds, rmssd = root mean square of successive differences, vas = visual analogous scale.

Figure 2. Group differences in the stress response (reactivity and recovery) measured by salivary cortisol. Reactivity is indexed as a change from baseline to t4 (20 minutes after the beginning of the speech task). Recovery is indexed as a change from t4 to t6 (40 minutes after the beginning of the speech task). Age, gender and t1 (baseline measure) for reactivity and t4 for recovery were included as covariates in the model. Winsorizing the outliers did not change the pattern of the results.

Figure 3. Unstandardized regression coefficients for the relationship between group and cortisol recovery as mediated by cognitive emotion regulation strategies: acceptance, catastrophizing, positive refocusing. The direct effect of group on the cortisol recovery controlling for the mediators is in parenthesis. $^*p < .05$, $^{**}p < .01$, $^{***}p < .001$

References

Arch, J.J., Brown, K.W., Dean, D.J., Landy, L.N., Brown, K., Laudenslager, M.L., 2014a. Self-compassion training modulates alpha-amylase, heart rate variability, and subjective responses to social evaluative threat in women. Psychoneuroendocrinology 42, 49-58.

Britton, W.B., Shahar, B., Szepsenwol, O., Jacobs, W.J., 2012. Mindfulness-Based Cognitive Therapy Improves Emotional Reactivity to Social Stress: Results from a Randomized Controlled Trial. Behavior Therapy 43, 365-380.

Brosschot, J.F., Pieper, S., Thayer, J.F., 2005. Expanding stress theory: Prolonged activation and perseverative cognition. Psychoneuroendocrinology 30, 1043-1049.

Brosschot, J.F., Thayer, J.F., 2003. Heart rate response is longer after negative emotions than after positive emotions. International Journal of Psychophysiology 50, 181-187.

Brown, K.W., Ryan, R.M., Creswell, J.D., Niemiec, C.P., 2008. Beyond me: Mindful responses to social threat, in: Wayment, H.A., Bauer, J.J. (Eds.), Transcending self-interest: Psychological explorations of the quiet ego. American Psychological Association, Washington DC, pp. 75-84.

Buchanan, T.W., al'Absi, M., Lovallo, W.R., 1999. Cortisol fluctuates with increases and decreases in negative affect. Psychoneuroendocrinology 24, 227-241.

Butler, E.A., Wilhelm, F.H., Gross, J.J., 2006. Respiratory sinus arrhythmia, emotion, and emotion regulation during social interaction. Psychophysiology 43, 612-622.

Camm, A., Malik, M., Bigger, J., Breithardt, G., Cerutti, S., Cohen, R., Coumel, P., Fallen, E., Kennedy, H., Kleiger, R., 1996. Heart rate variability: standards of measurement, physiological interpretation and clinical use. Task Force of the European Society of Cardiology and the North American Society of Pacing and Electrophysiology. Circulation 93, 1043-1065.
Carlson, L.E., Ursuliak, Z., Goodey, E., Angen, M., Speca, M., 2001. The effects of a mindfulness meditation-based stress reduction program on mood and symptoms of stress in cancer outpatients: 6-month follow-up. Support Care Cancer 9, 112-123.
Cassidy, E.L., Atherton, R.J., Robertson, N., Walsh, D.A., Gillett, R., 2012. Mindfulness, functioning and catastrophizing after multidisciplinary pain management for chronic low back pain. Pain 153, 644-650.
Cohen, S., Hamrick, N., Rodriguez, M.S., Feldman, P.J., Rabin, B.S., Manuck, S.B., 2002. Reactivity and Vulnerability to Stress-Associated Risk for Upper Respiratory Illness. Psychosomatic Medicine 64, 302-310.
Cohen, S., Janicki-Deverts, D., Miller, G.E., 2007. Psychological stress and disease. JAMA 298, 1685-1687.
Creswell, J.D., Pacilio, L.E., Lindsay, E.K., Brown, K.W., 2014. Brief mindfulness meditation training alters psychological and neuroendocrine responses to social evaluative stress. Psychoneuroendocrinology 44, 1-12.
Davidson, R.J., Dahl, C.J., 2017. Varieties of contemplative practice. JAMA Psychiatry 74, 121-123.
de Boer, M.J., Steinhagen, H.E., Versteegen, G.J., Struys, M.M., Sanderman, R., 2014. Mindfulness, acceptance and catastrophizing in chronic pain. PloS one 9, e87445.
Denson, T., Spanovic, M., Miller, N., 2009. Cognitive appraisals and emotions predict cortisol and immune responses: a meta-analysis of acute laboratory social stressors and emotion inductions. Psychological bulletin 135, 823-853.
Desbordes, G., Gard, T., Hoge, E.A., Hölzel, B.K., Kerr, C., Lazar, S.W., Olendzki, A., Vago, D.R., 2015. Moving beyond mindfulness: defining equanimity as an outcome measure in meditation and contemplative research. Mindfulness 6, 356-372.
Deyo, M., Wilson, K.A., Ong, J., Koopman, C., 2009. Mindfulness and rumination: does mindfulness training lead to reductions in the ruminative thinking associated with depression? EXPLORE: The Journal of Science and Healing 5, 265-271.
Dickerson, S.S., Kemeny, M.E., 2004. Acute Stressors and Cortisol Responses: A Theoretical Integration and Synthesis of Laboratory Research. Psychological Bulletin 130, 355-391.
Dickerson, S.S., Kemeny, M.E., Aziz, N., Kim, K.H., Fahey, J.L., 2004. Immunological effects of induced shame and guilt. Psychosomatic Medicine 66, 124-131.
Egloff, B., Schmukle, S.C., Burns, L.R., Schwerdtfeger, A., 2006. Spontaneous emotion regulation during evaluated speaking tasks: associations with negative affect, anxiety expression, memory, and physiological responding. Emotion 6, 356.
Emavardhana, T., Tori, C.D., 1997. Changes in Self-Concept, Ego Defense Mechanisms, and Religiosity Following Seven-Day Vipassana Meditation Retreats. Journal for the Scientific Study of Religion 36, 194-206.
Engert, V., Efanov, S.I., Duchesne, A., Vogel, S., Corbo, V., Pruessner, J.C., 2013. Differentiating anticipatory from reactive cortisol responses to psychosocial stress. Psychoneuroendocrinology 38, 1328-1337.
Engert, V., Kok, B.E., Papassotiriou, I., Chrousos, G.P., Singer, T., 2017. Specific reduction in cortisol stress reactivity after social but not attention-based mental training. Science Advances 3.

Epel, E., Daubenmier, J., Moskowitz, J.T., Folkman, S., Blackburn, E., 2009. Can meditation slow rate of cellular aging? Cognitive stress, mindfulness, and telomeres. Annals of the New York Academy of Sciences 1172, 34-53.
Epel, E.S., McEwen, B.S., Ickovics, J.R., 1998. Embodying psychological thriving: Physical thriving in response to stress. Journal of Social Issues 54, 301-322.
Epstein, M., 1988. The deconstruction of the self: Ego and 'egolessness' in Buddhist insight meditation. The Journal of Transpersonal Psychology 20, 61-69.
Faul, F., Erdfelder, E., Lang, A.-G., Buchner, A., 2007. G* Power 3: A flexible statistical power analysis program for the social, behavioral, and biomedical sciences. Behavior research methods 39, 175-191.
Gaab, Blättler, N., Menzi, T., Pabst, B., Stoyer, S., Ehlert, U., 2003. Randomized controlled evaluation of the effects of cognitive–behavioral stress management on cortisol responses to acute stress in healthy subjects. Psychoneuroendocrinology 28, 767-779.
Gaab, J., Rohleder, N., Nater, U.M., Ehlert, U., 2005. Psychological determinants of the cortisol stress response: the role of anticipatory cognitive appraisal. Psychoneuroendocrinology 30, 599-610.
Garland, E., Gaylord, S., Fredrickson, B., 2011. Positive Reappraisal Mediates the Stress-Reductive Effects of Mindfulness: An Upward Spiral Process. Mindfulness 2, 59-67.
Garland, E., Gaylord, S., Park, J., 2009. The Role of Mindfulness in Positive Reappraisal. EXPLORE: The Journal of Science and Healing 5, 37-44.
Garnefski, N., Kraaij, V., 2007. The Cognitive Emotion Regulation Questionnaire. European Journal of Psychological Assessment 23, 141-149.
Garnefski, N., Kraaij, V., Spinhoven, P., 2001. Negative life events, cognitive emotion regulation and emotional problems. Personality and Individual Differences 30, 1311-1327.
Gaudreau, P., Sanchez, X., Blondin, J.-P., 2006. Positive and Negative Affective States in a Performance-Related Setting: Testing the Factorial Structure of the PANAS Across Two Samples of French-Canadian Participants. European Journal of Psychological Assessment 22, 240-249.
Gex-Fabry, M., Jermann, F., Kosel, M., Rossier, M.F., Van der Linden, M., Bertschy, G., Bondolfi, G., Aubry, J.-M., 2012. Salivary cortisol profiles in patients remitted from recurrent depression: One-year follow-up of a mindfulness-based cognitive therapy trial. Journal of psychiatric research 46, 80-86.
Goldsmith, R.E., Gerhart, J.I., Chesney, S.A., Burns, J.W., Kleinman, B., Hood, M.M., 2014. Mindfulness-based stress reduction for posttraumatic stress symptoms: building acceptance and decreasing shame. Journal of evidence-based complementary & alternative medicine 19, 227-234.
Goleman, D.J., Schwartz, G.E., 1976. Meditation as an intervention in stress reactivity. Journal of Consulting and Clinical Psychology 44, 456.
Grabovac, A.D., Lau, M.A., Willett, B.R., 2011. Mechanisms of Mindfulness: A Buddhist Psychological Model. Mindfulness 2, 154-166.
Gross, J.J., 1998. The emerging field of emotion regulation: an integrative review. Review of general psychology 2, 271.
Gruenewald, T.L., Kemeny, M.E., Aziz, N., Fahey, J.L., 2004. Acute Threat to the Social Self: Shame, Social Self-esteem, and Cortisol Activity. Psychosomatic Medicine 66, 915-924.
Hayes, A.F., 2012. PROCESS: A versatile computational tool for observed variable mediation, moderation, and conditional process modeling [White paper]. Retrieved from http://www.afhayes.com/ public/process2012.pdf.

Heatherton, T.F., Polivy, J., 1991. Development and validation of a scale for measuring state self-esteem. Journal of Personality and Social psychology 60, 895.

Herman, J.P., Cullinan, W.E., 1997. Neurocircuitry of stress: central control of the hypothalamo–pituitary–adrenocortical axis. Trends in neurosciences 20, 78-84.

Het, S., Rohleder, N., Schoofs, D., Kirschbaum, C., Wolf, O.T., 2009. Neuroendocrine and psychometric evaluation of a placebo version of the 'Trier Social Stress Test'. Psychoneuroendocrinology 34, 1075-1086.

Hoge, E.A., Bui, E., Palitz, S.A., Schwarz, N.R., Owens, M.E., Johnston, J.M., Pollack, M.H., Simon, N.M., 2017. The effect of mindfulness meditation training on biological acute stress responses in generalized anxiety disorder. Psychiatry research.

Holm, S., 1979. A simple sequentially rejective multiple test procedure. Scandinavian journal of statistics, 65-70.

Hölzel, B.K., Lazar, S.W., Gard, T., Schuman-Olivier, Z., Vago, D.R., Ott, U., 2011. How Does Mindfulness Meditation Work? Proposing Mechanisms of Action From a Conceptual and Neural Perspective. Perspectives on Psychological Science 6, 537-559.

Jain, S., Shapiro, S., Swanick, S., Roesch, S., Mills, P., Bell, I., Schwartz, G.R., 2007. A randomized controlled trial of mindfulness meditation versus relaxation training: Effects on distress, positive states of mind, rumination, and distraction. ann. behav. med. 33, 11-21.

Jermann, F., Van der Linden, M., d'Acremont, M., Zermatten, A., 2006. Cognitive Emotion Regulation Questionnaire (CERQ): Confirmatory factor analysis and psychometric properties of the French translation. European Journal of Psychological Assessment 22, 126-131.

Kemeny, M.E., Gruenewald, T.L., Dickerson, S.S., 2004. Shame as the Emotional Response to Threat to the Social Self: Implications for Behavior, Physiology, and Health. Psychological Inquiry 15, 153-160.

Kirschbaum, C., Kudielka, B.M., Gaab, J., Schommer, N.C., Hellhammer, D.H., 1999. Impact of gender, menstrual cycle phase, and oral contraceptives on the activity of the hypothalamus-pituitary-adrenal axis. Psychosomatic medicine 61, 154-162.

Kirschbaum, C., Pirke, K.-m., Hellhammer, D.H., 1995. Preliminary evidence for reduced cortisol responsivity to psychological stress in women using oral contraceptive medication. Psychoneuroendocrinology 20, 509-514.

Kirschbaum, C., Pirke, K.M., Hellhammer, D.H., 1993. The 'Trier Social Stress Test' – A Tool for Investigating Psychobiological Stress Responses in a Laboratory Setting. Neuropsychobiology 28, 76-81.

Kudielka, B.M., Schommer, N.C., Hellhammer, D.H., Kirschbaum, C., 2004. Acute HPA axis responses, heart rate, and mood changes to psychosocial stress (TSST) in humans at different times of day. Psychoneuroendocrinology 29, 983-992.

Lam, S., Dickerson, S.S., Zoccola, P.M., Zaldivar, F., 2009. Emotion regulation and cortisol reactivity to a social-evaluative speech task. Psychoneuroendocrinology 34, 1355-1362.

Lazarus, R.S., Folkman, S., 1984. Stress, Appraisal, and Coping. Springer, New York, NY.

Leary, M.R., 2003. The self and emotion: The role of self-reflection in the generation and regulation of affective experience, in: R. J. Davidson, K. R. Scherer, Goldsmith, H.H. (Eds.), Series in affective science. Handbook of affective sciences Oxford University Press, New York, NY, pp. 773-786.

Leary, M.R., 2007. How the self became involved in affective experience: Three sources of self-reflective emotions, in: Tracy, J.L., Robins, R.W., Tangney, J.P. (Eds.), The self-conscious emotions: Theory and research. Guilford Press, New York, NY, US, pp. 38-52.

Lieberman, M.D., Eisenberger, N.I., Crockett, M.J., Tom, S.M., Pfeifer, J.H., Way, B.M., 2007. Putting feelings into words. Psychological science 18, 421-428.
Linden, W., Earle, T., Gerin, W., Christenfeld, N., 1997. Physiological stress reactivity and recovery: conceptual siblings separated at birth? Journal of psychosomatic research 42, 117-135.
Lindsay, E.K., Creswell, J.D., 2017. Mechanisms of mindfulness training: Monitor and Acceptance Theory (MAT). Clinical Psychology Review 51, 48-59.
Lindsay, E.K., Young, S., Smyth, J.M., Brown, K.W., Creswell, J.D., 2018. Acceptance lowers stress reactivity: Dismantling mindfulness training in a randomized controlled trial. Psychoneuroendocrinology 87, 63-73.
Marschall, D., Sanftner, J., Tangney, J.P., 1994. The state shame and guilt scale. Fairfax, VA: George Mason University.
Martens, A., Greenberg, J., Allen, J.J., 2008. Self-esteem and autonomic physiology: Parallels between self-esteem and cardiac vagal tone as buffers of threat. Personality and Social Psychology Review 12, 370-389.
Matthews, K.A., Woodall, K.L., Allen, M.T., 1993. Cardiovascular reactivity to stress predicts future blood pressure status. Hypertension 22, 479-485.
Mauss, I.B., Cook, C.L., Cheng, J.Y., Gross, J.J., 2007. Individual differences in cognitive reappraisal: Experiential and physiological responses to an anger provocation. International Journal of Psychophysiology 66, 116-124.
Mayor, E., Gamaiunova, L., 2014. Using wearable technology for psychophysiological experiments: Gender roles and cognitive appraisal impact cardiac response to socio-evaluative stress, Wireless Mobile Communication and Healthcare (Mobihealth), 2014 EAI 4th International Conference on, pp. 15-18.
McEwen, B.S., 1998. Stress, adaptation, and disease: Allostasis and allostatic load. Annals of the New York Academy of Sciences 840, 33-44.
Mezzacappa, E.S., Kelsey, R.M., Katkin, E.S., Sloan, R.P., 2001. Vagal rebound and recovery from psychological stress. Psychosomatic medicine 63, 650-657.
Nunan, D., Jakovljevic, D.G., Donovan, G., Hodges, L.D., Sandercock, G.R.H., Brodie, D.A., 2008. Levels of agreement for RR intervals and short-term heart rate variability obtained from the Polar S810 and an alternative system. European Journal of Applied Physiology 103, 529-537.
Nyklíček, I., Mommersteeg, P.M.C., Van Beugen, S., Ramakers, C., Van Boxtel, G.J., 2013. Mindfulness-based stress reduction and physiological activity during acute stress: A randomized controlled trial. Health Psychology 32, 1110-1113.
Pace, T.W., Negi, L.T., Adame, D.D., Cole, S.P., Sivilli, T.I., Brown, T.D., Issa, M.J., Raison, C.L., 2009. Effect of compassion meditation on neuroendocrine, innate immune and behavioral responses to psychosocial stress. Psychoneuroendocrinology 34, 87-98.
Pepping, C.A., O'Donovan, A., Davis, P.J., 2013. The positive effects of mindfulness on self-esteem. The Journal of Positive Psychology 8, 376-386.
Pruessner, J.C., Baldwin, M.W., Dedovic, K., Renwick, R., Mahani, N.K., Lord, C., Meaney, M., Lupien, S., 2005. Self-esteem, locus of control, hippocampal volume, and cortisol regulation in young and old adulthood. Neuroimage 28, 815-826.
Rasmussen, M.K., Pidgeon, A.M., 2011. The direct and indirect benefits of dispositional mindfulness on self-esteem and social anxiety. Anxiety, Stress, & Coping 24, 227-233.
Roberts, A.L., Malspeis, S., Kubzansky, L.D., Feldman, C.H., Chang, S.C., Koenen, K.C., Costenbader, K.H., 2017. Association of trauma and posttraumatic stress disorder with incident systemic lupus erythematosus in a longitudinal cohort of women. Arthritis & Rheumatology 69, 2162-2169.

Rosenkranz, M.A., Lutz, A., Perlman, D.M., Bachhuber, D.R.W., Schuyler, B.S., MacCoon, D.G., Davidson, R.J., 2016. Reduced stress and inflammatory responsiveness in experienced meditators compared to a matched healthy control group. Psychoneuroendocrinology 68, 117-125.

Sapolsky, R.M., 2007. Stress, stress-related disease, and emotional regulation, in: Gross, J.J. (Ed.). Guilford Press, New York, NY, US, pp. 606-615.

Schafer, J.L., Olsen, M.K., 1998. Multiple imputation for multivariate missing-data problems: A data analyst's perspective. Multivariate behavioral research 33, 545-571.

Shapiro, S., Carlson, L.E., Astin, J.A., Freedman, B., 2006. Mechanisms of mindfulness. Journal of Clinical Psychology 62, 373-386.

Shapiro, S., Schwartz, G., Bonner, G., 1998. Effects of Mindfulness-Based Stress Reduction on Medical and Premedical Students. J Behav Med 21, 581-599.

Shearer, A., Hunt, M., Chowdhury, M., Nicol, L., 2016. Effects of a brief mindfulness meditation intervention on student stress and heart rate variability. International Journal of Stress Management 23, 232.

Sullivan, G., Apergis, J., Bush, D., Johnson, L.R., Hou, M., Ledoux, J., 2004. Lesions in the bed nucleus of the stria terminalis disrupt corticosterone and freezing responses elicited by a contextual but not by a specific cue-conditioned fear stimulus. Neuroscience 128, 7-14.

Tarvainen, M.P., Niskanen, J.-P., Lipponen, J.A., Ranta-Aho, P.O., Karjalainen, P.A., 2014. Kubios HRV–heart rate variability analysis software. Computer methods and programs in biomedicine 113, 210-220.

Tomaka, J., Blascovich, J., Kelsey, R.M., Leitten, C.L., 1993. Subjective, physiological, and behavioral effects of threat and challenge appraisal. Journal of Personality and Social Psychology 65, 248.

Tracy, J.L., Robins, R.W., 2004. Putting the Self Into Self-Conscious Emotions: A Theoretical Model. Psychological Inquiry 15, 103-125.

Uno, H., Tarara, R., Else, J.G., Suleman, M.A., Sapolsky, R.M., 1989. Hippocampal damage associated with prolonged and fatal stress in primates. Journal of Neuroscience 9, 1705-1711.

Vago, D., David, S., 2012. Self-awareness, self-regulation, and self-transcendence (S-ART): a framework for understanding the neurobiological mechanisms of mindfulness. Frontiers in Human Neuroscience 6.

Watson, D., Clark, L.A., Tellegen, A., 1988. Development and validation of brief measures of positive and negative affect: The PANAS scales. Journal of Personality and Social Psychology 54, 1063-1070.

Weinstein, N., Brown, K.W., Ryan, R.M., 2009. A multi-method examination of the effects of mindfulness on stress attribution, coping, and emotional well-being. Journal of Research in Personality 43, 374-385.

Woods, H., Proeve, M., 2014. Relationships of mindfulness, self-compassion, and meditation experience with shame-proneness. Journal of Cognitive Psychotherapy 28, 20-33.

Zoccola, P.M., Dickerson, S.S., Zaldivar, F.P., 2008. Rumination and cortisol responses to laboratory stressors. Psychosomatic medicine 70, 661-667.