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ORIGINAL PAPER

Specific Reduction in the Cortisol Awakening Response after Socio-Affective Mental Training

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Abstract

Objectives Psychosocial stress is an inherent part of modern lifestyle, and many suffer from chronic stress exposure and the subsequent development of stress-related diseases. In searching for efficient low-cost interventions to reduce stress, we investigated the effects of regular contemplative mental practice on diurnal cortisol activity as an indicator of the basal, everyday stress load.

Method Data were collected in the context of the *ReSource Project*, an open-label efficacy trial comprising three distinct 3-month training modules targeting attention and interoception (Presence Module), socio-affective (Affect Module) or socio-cognitive abilities (Perspective Module) through dyadic exercises and secularized meditation practices. Diurnal cortisol activity was assayed at four time points: pre-training and after 3, 6, and 9 months. As outcome measures, the cortisol awakening response (CAR), cortisol slope over the course of the day, and total daily cortisol output were computed.

Results Analyses revealed a stable reduction in CAR specifically after the compassion- and care-based Affect Module, contrasted by a CAR increase following the attention- and interoception-based Presence training. Cortisol slope over the day and total daily cortisol output were unaffected by any of the mental trainings.

Conclusions These findings emphasize the necessity for a more granular approach in the investigation of contemplative mental training effects. Not all types of training can be expected to equally beneficial for all types of hardship. Specifically, with regard to the CAR, which represents the anticipatory stress response to the upcoming day, compassion- and care-based qualities rather than bare attention or meta-cognitive skills seem to drive stress reduction.

Preregistration This study is not preregistered.

Keywords Contemplative mental training · Cortisol awakening response · Diurnal cortisol · Hypothalamic–pituitary–adrenal axis · Stress

Chronic psychosocial stress is deemed the health epidemic of the 21st century (WHO; Rosch, 2001). The adverse health effects of chronic stress exposure are mediated by the long-term activation of the main stress systems, namely, sympathetic-adrenal-medullary (SAM) system and hypothalamic–pituitary–adrenal (HPA) axis. Via complex effects on metabolic and immune processes, both are causally involved in the development and maintenance of cardiovascular, metabolic, and autoimmune disorders, among others (Chrousos, 2009; Cohen et al., 2007). In an attempt to lower stress and promote well-being and health, secular meditation-based mental training interventions, such as the Mindfulness-Based Stress Reduction (MBSR) program (Kabat-Zinn, 1994), have gained popularity, even in mainstream clinical and educational settings (Davidson & Kaszniak, 2015). Various health-related benefits have been associated with participation in such mental training interventions (for meta-analyses, see, for example, Grossman et al., 2004; Khoury et al., 2015). Findings from the *ReSource Project* (Singer et al., 2016), our own 9-month mental training study, show a differential positive

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change in well-being, social emotion and social cognition, attention, interoceptive body awareness, reactivity to acute psychosocial stress, and brain plasticity following distinct practice types (for a review, see Singer & Engert, 2019).

When it comes to mental training effects on stress vulnerability, reduced subjective-psychological stress load is the most widely reported outcome (e.g., Khoury et al., 2015). Yet, self-report measures of stress do not reliably correlate with more objective, physiological assessments. Especially after committing to a—sometimes strenuous and challenging (Lumma et al., 2015)—training protocol, demand-effects, and expectancy bias may skew self-reports of stress reduction. In line with the theory suggesting that the health benefits of contemplative mental training are mediated by dampened *physiological* stress activity, particularly reduced secretion of the HPA axis output hormone cortisol (Creswell & Lindsay, 2014), a considerable body of mental training research has focused on stress reactive levels of cortisol. Reduction in cortisol output after acute psychosocial stress was first reported immediately after a single mindfulness-based meditation session following 5 days of practice (Tang et al., 2007). Contrasting the influence of different practice types in the context of our longitudinal *ReSource Project*, we identified reduced cortisol secretion in response to an acute psychosocial laboratory stressor, the Trier Social Stress Test (Kirschbaum et al., 1993), following the 3-month training of either socio-affective or socio-cognitive. No reduction in cortisol stress reactivity was found after an equally long training focusing on present-moment attention and interoception (Engert et al., 2017). Several other studies of psychosocial stress induction found no effects of mindfulness- or compassion-based training on acute cortisol release (Arch et al., 2014; Morton et al., 2020; Rosenkranz et al., 2013).

Other than cortisol levels after acute challenge (which reflect stress reactivity in a highly specific setting), or hair cortisol levels (which reflect systemic long-term HPA-axis activity), diurnal cortisol indices allow for an ecologically valid measure of cortisol variability in daily life. Typically, the diurnal cycle begins with a steep rise in cortisol levels 30–45 min after awakening (Pruessner et al., 1997). This cortisol awakening response (CAR) is a facet distinct from the cortisol circadian rhythm (Wilhelm et al., 2007). There is converging evidence that the CAR represents the physiological enhancement needed to meet the anticipated demands of the upcoming day (Adam et al., 2006; Fries et al., 2009; Kunz-Ebrecht et al., 2004; Rohleder et al., 2007; Schlotz et al., 2004; Thorn et al., 2006), thus mirroring dynamic HPA axis properties. The CAR is followed by a steady decline in cortisol levels until a nadir is reached in the early morning hours (Kirschbaum & Hellhammer, 1989; Pruessner et al., 1997; Wust et al., 2000a, 2000b). Next to the CAR, the most frequently examined indices of diurnal cortisol regulation are the cortisol slope over the course of the day and the total daily cortisol output (Ross et al., 2014). Like the CAR, the diurnal cortisol slope is determined by dynamic HPA axis properties. Total daily cortisol output reflects cumulative tissue exposure to cortisol (Ross et al., 2014).

Findings on mental training-induced changes in diurnal cortisol regulation are heterogeneous to date. Reports of lower diurnal cortisol output stem mainly from mindfulness-based interventions using the MBSR program, for which reductions in CAR and afternoon/evening cortisol levels have been found in healthy and diseased individuals (Brand et al., 2012; Carlson et al., 2004, 2007). These findings are contrasted by numerous null results (for meta-analyses see Pascoe et al., 2017; Sanada et al., 2016). We suggest that the existing inconsistencies stem, at least partially, from the multifaceted nature of mindfulness-based programs, which typically combine various mental practice types, ranging from attention-based, to compassion-based socio-emotional, to meta-cognitive practices (Dahl et al., 2015).

Accordingly, in the current *ReSource* study, we asked whether different mental practice types differed in their effect on diurnal cortisol regulation. CAR, diurnal slope, and daily cortisol output were assessed in a sample of initially $n = 332$ healthy male and female adults at repeated measurement time-points. In detail, participants attended three distinct 3-month modules cultivating Presence (attention and interoceptive awareness), Affect (compassion, prosocial motivation, and dealing with difficult emotions), and Perspective (metacognition and perspective-taking on self and others) (Fig. 1A). Based on classic meditation techniques, Presence resembles typical mindfulness-based interventions (Kabat-Zinn, 1994; Segal et al., 2002). By contrast, Affect and Perspective target intersubjectivity through the training of either emotional-motivational or socio-cognitive skills, also based on daily partner exercises termed dyads (Kok & Singer, 2017).

In light of the previous literature on changes in diurnal cortisol after mindfulness-based training, we expected to find evidence for decreased diurnal cortisol levels after the attention-based Presence Module. We originally assumed that the compassion-based Affect Module would be another candidate for efficient stress-reduction, due to the activation of oxytocin- and opiate-modulated affiliative systems (Depue & Morrone-Strupinsky, 2005; Nelson & Panksepp, 1998), which mediate stress-reducing and anxiolytic effects (Carter, 2014; Drolet et al., 2001). Our previous *ReSource* findings of acute stress reduction following Affect and Perspective modules are in line with this assumption (Engert et al., 2017). Because diurnal and acute stress-induced cortisol levels are not reliably associated (e.g., Kidd et al., 2014; Sugaya et al., 2020), it remained an open question whether the acute psychosocial stress-reducing properties of the Affect and Perspective modules (Engert et al., 2017) would translate to participant's diurnal cortisol activity.

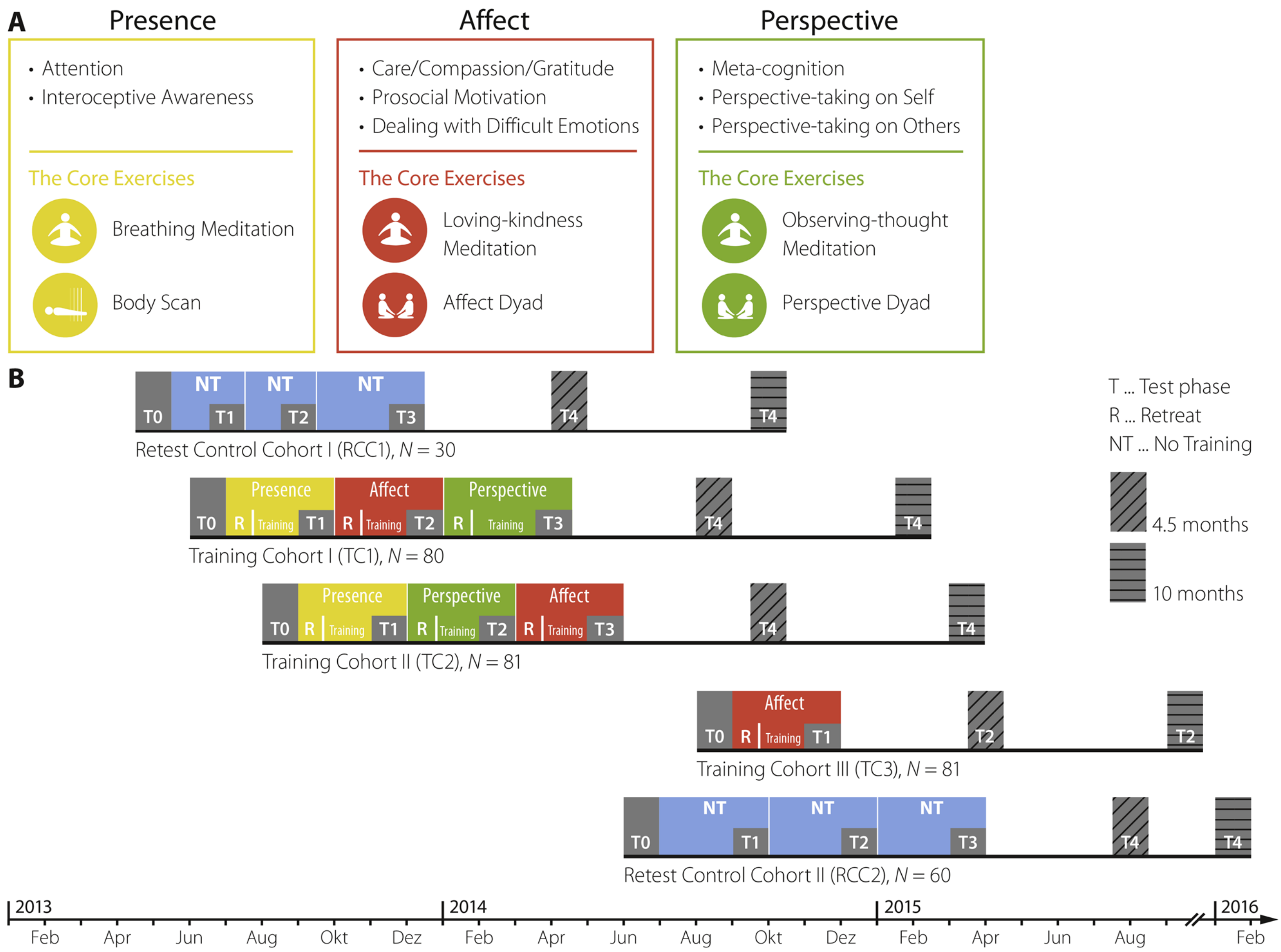

Fig. 1 Study protocol and design. **A** Training modules and core exercises of the *ReSource Project*. In the Presence Module, attention and interoceptive body awareness are trained through the core practices Breathing Meditation and Body Scan. In the Affect Module, social emotions such as compassion, lovingkindness, and gratitude are trained through the core practices Lovingkindness Meditation and Affect Dyad. The Perspective Module targets metacognition and perspective-taking on self and others. Core practices are Observing-thoughts Meditation and Perspective Dyad. **B** Design and timeline of the *ReSource Project*. Two training cohorts, TC1 and TC2, started their training with the mindful attention-based Presence Module. They then underwent the social Affect and Perspective Modules in different orders. The total training time for TC1 and TC2 was 39 weeks (13 weeks per module). TC3 only trained the Affect Module for 13 weeks. The two RCCs completed all testing without taking part in any training. All 4-week testing phases (T0 to T4) are indicated as a grey box per cohort and module. For more detailed information see Chapter 4 in Singer et al. (2016). RCC, retest control cohort; TC, training cohort

Method

Participants

For the *ReSource Project*, 332 healthy participants (197 women, age mean ± *SD*: 40.74 ± 9.24; range: 20 to 55 years) were recruited, and assigned to one of three training cohorts (TC1: $n = 80$; TC2: $n = 81$; TC3: $n = 81$) or a retest control cohort (RCC; $n = 90$). The training cohorts experienced the modules in different orders, thereby acting as mutual active control groups. They were tested at baseline (T0) and after each 3-month module (T1, T2, T3) using diurnal cortisol and experience sampling (Fig. 1B). Aside from very few exceptions around scheduled holidays, diurnal cortisol sampling for all training participants per cohort and testing time-point took place within the 5 weeks testing periods (separated by 14.86 days, on average; two participants were tested after 37 days). Importantly, participants continued their regular practice throughout the entire duration of each testing period. The RCC was tested in two batches, again mostly within the 5 weeks testing periods. Testing days were separated by 14.40 days on average; two participants were tested after 64 days.

The study was conducted at the Max Planck Institute for Human Cognitive and Brain Sciences in Leipzig and a satellite laboratory in Berlin. Participant eligibility was determined through a multi-stage procedure that involved several screening and mental health questionnaires (for details see Chapter 7 in Singer et al., 2016). Subsequently, a face-to-face mental health diagnostic interview with a trained clinical psychologist was scheduled. The interview included a computer-assisted German version of the Structured Clinical Interview for DSM-IV Axis-I disorders, SCID-I DIA-X (Wittchen & Pfister, 1997), and a personal interview for Axis-II disorders, the SCID-II (First et al., 1997; Wittchen et al., 1997). Volunteers were excluded if they fulfilled the criteria for an Axis-I disorder, including psychotic disorder, bipolar disorder, and substance dependency, within the past two years, or an Axis-II disorder at any time in their life. Volunteers taking medication influencing the HPA axis were also excluded. Female hormonal status was assessed via a self-report questionnaire. Among 197 women, 51% ($n=101$) had a natural menstrual cycle, 26% ($n=51$) had no cycle due to menopause or polycystic ovary syndrome, and 17% ($n=33$) took hormonal contraceptives; 6% ($n=12$) women did not answer the questionnaire. Thirty-eight participants (24 women) were cigarette smokers (≤10 cigarettes/day; mean ± *SD*: 15.10 ± 14.50 cigarettes/week).

The *ReSource Project* was registered with the Protocol Registration System of ClinicalTrial.gov under the title "Plasticity of the Compassionate Brain" (Identifier NCT01833104). It was approved by the Research Ethics Boards of Leipzig University (ethic number: 376/12-ff) and Humboldt University Berlin (ethic numbers: 2013–20, 2013–29, 2014–10). Participants gave their written informed consent, could withdraw from the study at any time, and were financially compensated.

Although some of the data reported here have previously been published in the context of other research questions, either at the *ReSource* baseline testing time-point (Engert et al., 2018, assessing associations of different stress markers in complex network analyses; Linz et al., 2018, assessing interactions of daily life cortisol with subjective experience and momentary thought content) or after training (Linz et al., 2022, assessing training-induced changes in daily life experiences using an ecological momentary assessment approach), none of these studies examined training-induced changes in CAR, total daily cortisol output or diurnal slope.

Procedure

In the *ReSource Project*, we investigated the specific effects of commonly used mental training techniques by parceling the training program into three separate modules (Presence, Affect, and Perspective). Each cultivated distinct cognitive and socio-affective capacities (Singer et al., 2016). Participants were divided into two 9-month training cohorts experiencing the modules in different orders, one 3-month Affect training cohort and one retest control cohort. In detail, two training cohorts (TC1, TC2) started their training with the mindfulness-based Presence module. They then underwent Affect and Perspective modules in different orders thereby acting as mutual active control groups. To isolate the specific effects of the Presence module, a third training cohort (TC3) underwent only the 3-month Affect module (Fig. 1B).

As illustrated in Fig. 1A, the core psychological processes targeted in the Presence module are attention and interoceptive awareness, which are trained through the two meditation-based core exercises Breathing Meditation and Body Scan. The Affect module targets the cultivation of social emotions such as compassion, lovingkindness, and gratitude. It also aims to enhance prosocial motivation and dealing with difficult emotions. The two core exercises of the Affect module are Loving-kindness Meditation and Affect Dyad. In the Perspective module participants train meta-cognition and perspective-taking on self and others through the two core exercises Observing-thoughts Meditation and Perspective Dyad. The distinction between Affect and Perspective modules reflects research identifying distinct neural routes to social understanding: One socio-affective route including emotions such as empathy and compassion, and one socio-cognitive route including the capacity to mentalize and take perspective on self and others (for details on the scientific backbone of this division see Singer, 2012).

The two contemplative dyads are partner exercises that were developed for the *ReSource* training (Kok & Singer, 2017). They address different skills such as perspective taking on self and others (Perspective Dyad) or gratitude, acceptance of difficult emotions, and empathic listening (Affect Dyad), but are similar in structure (for details see Singer et al., 2016). In each 10-min dyadic practice, two randomly paired participants share their experiences with alternating roles of speaker and listener. The dyadic format is designed to foster interconnectedness by providing opportunities for self-disclosure and non-judgmental listening (Kok & Singer, 2017; Singer et al., 2016). Our recommendation was to train for a minimum of 30 min (e.g., 10 min contemplative dyad, 20 min classic meditation) on five days per week.

Measures

Salivary Cortisol Sampling Altogether 14 saliva samples (seven per day) were obtained over the course of two consecutive weekdays (Mondays/Tuesdays, Wednesdays/Thursdays, or Thursdays/Fridays, depending on participant availability). In detail, samples were taken at participants' natural waking time (while still in bed; S1) and at 30 min, 60 min, 4, 6, 8, and 10 h after awakening (Fig. 2). Saliva was collected using Salivette collection devices (Sarstedt, Nuembrecht, Germany). Participants were instructed to place collection swabs in their mouths and refrain from chewing for 2 min. They were asked to take nothing by mouth other than water, not brush their teeth during the 10 min before sampling, and not smoke during the 30 min before sampling. If deviating from this guideline, they were asked to thoroughly rinse their mouth with water before taking a sample. Participants otherwise followed their normal daily routine.

To maximize adherence to the sampling protocol, participants were given preprogrammed mobile devices using an in-house application that reminded them to take each (except the first) Salivette at the designated time. Adequate handling of the application was ensured in initial introductory training. Sampling times of the non-morning probes were jittered (+ / − 15 min) to avoid complete predictability. Samples were kept in the freezer until returned to the laboratory, where they were stored at − 30 °C until assay (at the Department of Biological and Clinical Psychology, University of Trier, Germany). Cortisol levels (expressed in nmol/l) were determined using a time-resolved fluorescence immunoassay (Dressendorfer et al., 1992) with intra-/inter-assay variability of 10/12%.

Raw cortisol data were each treated with a natural log transformation to remedy skewed distributions. Across the full sample, any values diverging more than 3 SD from the mean were labeled outliers and winsorized to the respective upper or lower 3 SD boundary to avoid influential cases. Logged and winsorized cortisol data were then averaged across the two sampling days, and the most commonly used summary indices of diurnal cortisol activity were calculated (Ross et al., 2014). The CAR was quantified as a change score from S1 to either the 30- or 60-min post-awakening sample, depending on the individual peak in hormone levels. If participants peaked at S1 rather than at 30 or 60 min thereafter, the 30-min data point was used to operationalize the (inverse) CAR, given that it was always closer in magnitude to S1 than the 60-min data point. The cortisol decline over the course of the day (diurnal slope) was operationalized as a change score from baseline to the final sample of the day (at 600 min after awakening). Total daily cortisol output was operationalized as the area under the curve with respect to ground, AUC_g (Pruessner et al., 2003), which takes into account the difference between the measurements from each other (i.e., the change over time) and the distance of these measures from zero (i.e., the level at which the change over time occurs). Awakening, 240, 360, 480, and 600 min post-awakening cortisol values were included in the calculation of the AUC_g. To prevent it from having an undue influence, the CAR samples at 30 and 60 min were excluded from the total output score calculation. On each sampling day, awakening time and sleep duration were registered using the preprogrammed mobile device immediately upon awakening in parallel to taking the first Salivette. These measures were averaged across the two sampling days to minimize situational influences.

Experience Sampling In addition to diurnal cortisol, participants collected subjective data on stress and affective and cognitive experience during the experience sampling procedure using the above-mentioned app. Focusing on the moment-to-moment changes in cortisol and associated subjective experience, these data have been published elsewhere (Linz et al., 2018, 2022). For the sake of transparency, we nevertheless calculated summary scores for affect, arousal, occurrence of stress, stress intensity, and stress coping, and examined mental training-induced changes therein. The corresponding methodology, statistical analyses, and results are presented in the Supplementary Material.

Data Analyses

Missing Data and Data Replacement Out of 332 original participants, different data points were missing for different measures and testing time-points. Reasons for missingness were exclusion and dropout of participants, and no or erroneous saliva and sleep sampling. Because cortisol and sleep data were averaged across the two sampling days per testing time-point, single missing values were replaced by the available parallel samples of the respective other sampling day. The averaged raw (unlogged) cortisol data per testing time-point and cohort are depicted in Supplementary Fig. S1. The number of missing and available cortisol and sleep data per measure and testing time-point are summarized in Supplementary Table S1, of replaced and non-replaced missing data points for cortisol and sleep data in Table S2, and of missings per subjective experience variable and testing time-point in Table S3.

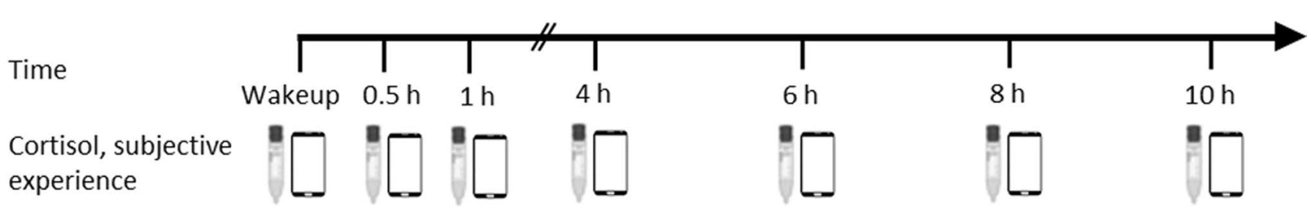

Fig. 2 Experience sampling design. Participants were probed on seven occasions throughout each of two sampling days. Next to cortisol levels collected in saliva, subjective experiences and sleep parameters were collected. Subjective data are reported elsewhere (Linz et al., 2018, 2022).

Main Analysis All analyses were conducted using the Statistical Package for the Social Sciences (SPSS, version 25), and with an α-threshold of ≤ 0.05. For completeness, significant and trend-level results (defined as $0.05 < p < 0.10$) are reported. Hypotheses were tested by means of multivariate linear mixed models (LMMs), which are robust to unbalanced and incomplete data in longitudinal designs, and account for potential within-subject correlation. Since the present study is part of a large-scale investigation (the *ReSource Project*) with numerous sub-projects, the sample sizes of the cohorts could not be tailored to this study specifically. However, our sample size is considerably larger than seen in mental training studies in general, and mental training studies analyzing diurnal cortisol levels in particular.

Training-induced change in CAR, diurnal slope, and AUC_g was operationalized by subtracting values from a set of consecutive training blocks (i.e., T1-T0, T2-T1, T3-T2). These difference scores allowed modeling change directly as a function of the training module that each participant practiced in a respective time interval (or retest). Furthermore, they avoided biasing module change estimates by including different participants before and after a module. Fixed effect factors for module (Presence, Affect, Perspective, retest), interval (T0 to T1, T1 to T2, T2 to T3), and the interaction of module by interval were included in the model. Hereby, we could test whether a potential change was dependent on a specific training module (main effect of module), on the time of testing (main effect of interval), or the sequence in which training modules were taught (module by interval interaction). In the case of a training effect, pairwise least significance difference (LSD) post hoc comparisons were calculated. Post hoc comparisons were not corrected for multiple comparisons because within the multilevel model framework estimates are "shrunk" towards a common mean. This "partial pooling" accounts for the dependence of estimates calculated within the same model without compromising power (Gelman et al., 2012). In all models, we controlled for age and sex given their established effects on cortisol regulation (Ferrari et al., 2001; Hellhammer et al., 2009). Since the cortisol diurnal rhythm can be influenced by both time of awakening and sleep duration (Law et al., 2013; Wust et al., 2000a, 2000b), they were initially included as covariates in all models. Sleep duration was subsequently dropped from analysis because it did not improve model fit indices. Also, given that the direction of the response of a body function depends on the initial level of that function (law of initial value; Wilder, 1957), S1 was entered as an additional covariate for the CAR and diurnal slope models. To facilitate interpretation, continuous predictors were mean-centered. The full model (including S1) was made up of the following terms:

$$\begin{aligned} DV_{ij} = \beta_0 &+ \beta_1 * age_i + \beta_2 * sex_i + \beta_3 * \text{awakening time} \\ &+ \beta_4 * S1 + \beta_{5-7} * module_i + \beta_{8-10} * interval_j \\ &+ \beta_{11-14} * module_i * interval_j + rand(ID) \end{aligned}$$

where DV = dependent variable (CAR, diurnal slope, AUC $_g$); β_0 = intercept; i = subject ID; j = measurement interval (T1—T0, T2—T1, T3—T2); rand(ID) = random intercept per subject.

Results

Our training cohorts TC1 and TC2 underwent 3-months Presence followed by 3-months Affect and 3-months Perspective training, or vice versa, Perspective followed by Affect training. TC3 underwent 3-months Affect training alone (Fig. 1B). Using a linear mixed-effects model, we compared Presence, Affect, and Perspective modules against each other and against the RCC. As dependent variables, difference scores were calculated by subtracting mean CAR, diurnal slope, and AUG_g values before a training block from those after the training block (i.e., T1-T0, T2-T1, T3-T2).

A significant main effect of module showed a change in CAR depending on the performed training ($F_{600} = 4.02$, $p = 0.008$), but independent of the time of testing or the training sequence (Table 1, Fig. 3A). Pairwise comparisons revealed a decrease in CAR after Affect training compared to both Presence ($MD = -0.16$, $SE = 0.05$, $d = 0.34$, $p = 0.002$) and Perspective training ($MD = -0.11$, $SE = 0.06$, $d = -0.24$, $p = 0.050$). Due to an unexpected reduction in CAR also in the RCC, the comparison of Affect training with no training

Table 1 Omnibus *F*-tests in a linear mixed model examining training effects on the CAR

	F (df)	*p*
Fixed effects		
Intercept	0.79 (347)	> 0.35
Interval	1.37 (498)	> 0.25
Module	4.02 (600)	0.008
Interval*module	1.77 (618)	> 0.15
S1	578.33 (694)	< 0.001
Age	0.65 (325)	> 0.40
Sex	0 (330)	> 0.99
Awakening time	49.53 (694)	< 0.001
	Estimate (*SE*)	
Covariance parameters		
AR1 diagonal	0.22 (0.01)	
AR1 rho	−0.48 (0.04)	

CAR cortisol awakening response; *S1* awakening sample; *SE* standard error

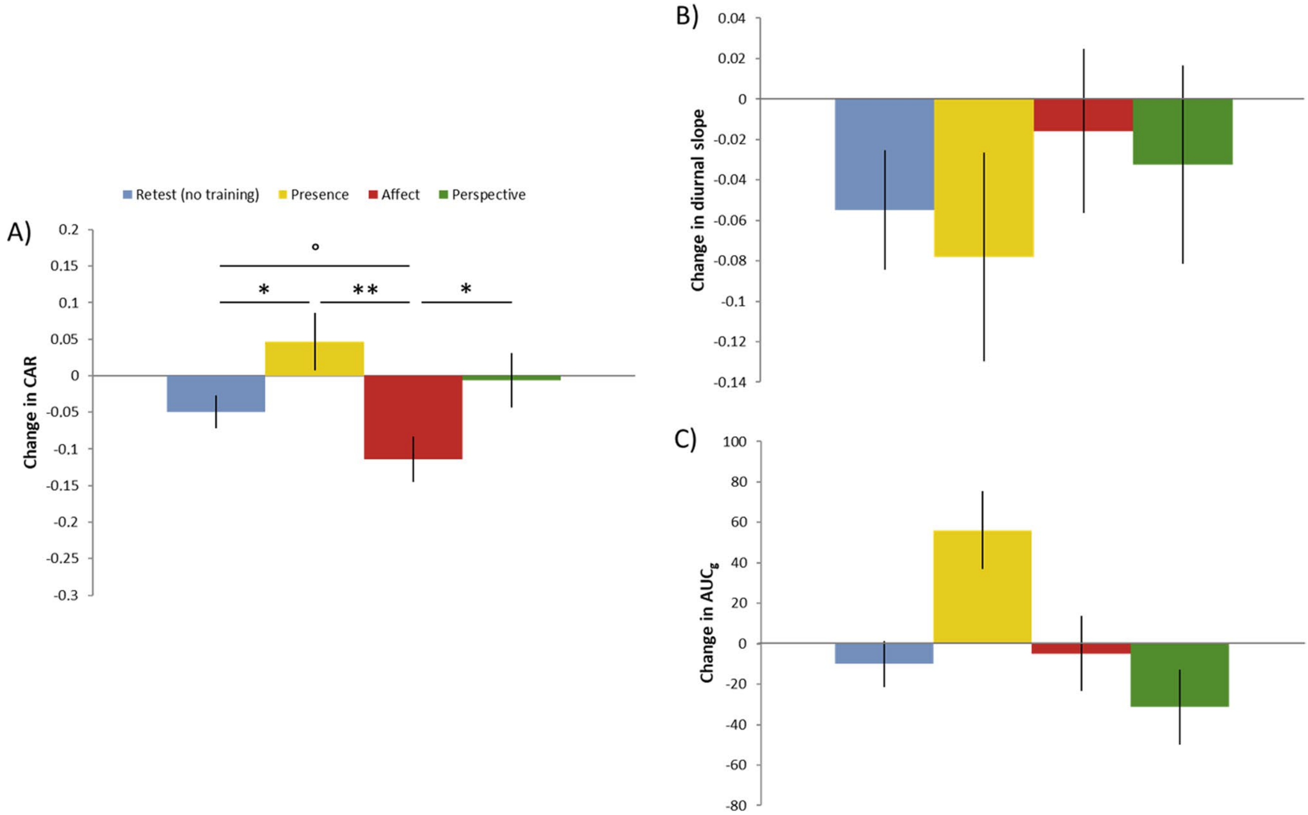

Fig. 3 Effect of mental training on indices of diurnal cortisol activity (T0-T3). **A** There was a decrease in cortisol awakening response (CAR) after Affect training compared to both Presence ($p=0.002$) and Perspective training ($p=0.050$), and marginally compared to retest control ($p=0.089$). After Presence training, the CAR was increased relative to no training ($p<0.035$). No differences in CAR were found when comparing Presence and Perspective training, or Perspective and no training. (**B**) No significant training effects on the cortisol slope over the course of the day and (**C**) the total daily cortisol output (AUC_g) were found. Mean difference scores depicted by the model are plotted; error bars represent standard errors. °: trend at $0.05 \leq p \leq 0.10$; *: significant at $p \leq 0.05$; **: significant at $p \leq 0.01$; ***: significant at $p \leq 0.001$

showed only a marginal effect ($MD=-0.07$, $SE=0.04$, $d=-0.20$, $p=0.089$). Also, after Presence training, the CAR was *increased* relative to no training ($MD=0.10$, $SE=0.05$, $d=0.24$, $p<0.035$). No differences in CAR were found when comparing Presence and Perspective training ($MD=0.05$, $SE=0.06$, $d=0.11$, $p>0.35$), or Perspective and no training ($MD=0.04$, $SE=0.04$, $d=0.13$, $p>0.30$).

Visual inspection of CAR change trajectories in all training cohorts over time (Fig. 4) revealed a stable pattern of change with decreased CARs after three months of only Affect training in TC3, after three months of Affect training following prior Presence training in TC1, and after three months of Affect training following prior Presence and Perspective training in TC2. Likewise, the established increase in CAR after Presence training occurred in both major training cohorts (TC1 and TC2).

Given the unexpected pattern of CAR change in the RCC (i.e., a steep reduction from T0 to T1; see Fig. 4), we ran an exploratory analysis which separately considered change from T1 to T3 (see Supplementary Material). This allowed us to evaluate the effect of Affect and Perspective training against a more stable control group and showed a significant CAR decrease after Affect relative to no training (see Supplementary Table S4 and Fig. S2).

The cortisol decline over the day (diurnal slope) was neither affected by the type of training or the time of testing (Table 2 A, Fig. 3B). There was a marginal effect of the training sequence, however, with TC1 and TC2 showing opposite developments depending on whether Affect was trained before or after the Perspective Module ($F_{591}=2.49$, $p=0.059$). Although non-significant, we show this sequence effect in supplementary Fig. S3 for informative purposes. For the AUC_g, neither type of training, time of testing, nor training sequence influenced the total daily cortisol output (Table 2 B, Fig. 3C).

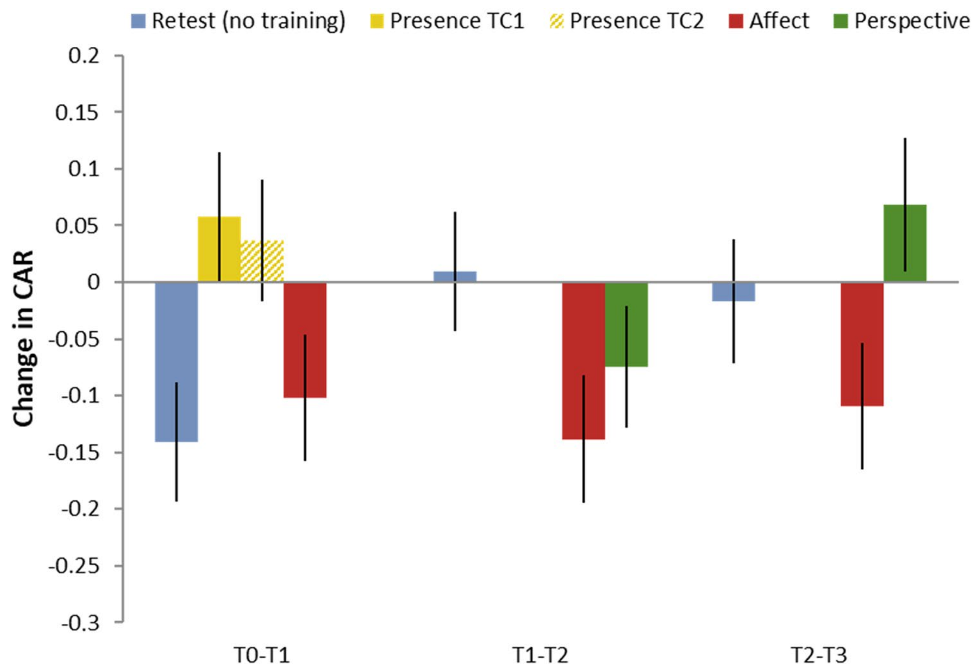

Fig. 4 Mean CAR change trajectories in all training cohorts over time. There was a stable pattern of change with decreased CARs after three months of only Affect training in TC3, as well as after three months of Affect training following prior Presence training in TC1 and after three months of Affect training following prior Presence and Perspective training in TC2. Also, the established increase in CAR after Presence training was reliably seen in both major training cohorts (TC1 and TC2)

Table 2 Omnibus *F*-tests in a linear mixed model examining training effects on (A) diurnal slope and (B) total daily cortisol output

	(A) Diurnal slope		(B) AUC_g	
	F (df)	*p*	*F (df)*	*p*
Fixed effects				
Intercept	1.42 (337)	> 0.20	1.58 (313)	> 0.20
Interval	1.64 (487)	> 0.15	0.86 (473)	> 0.40
Module	0.31 (580)	> 0.80	1.64 (534)	> 0.15
Interval*module	2.49 (591)	0.059	0.65 (565)	> 0.55
S1	391.33 (659)	< 0.001	-	-
Age	0.84 (316)	> 0.35	0.36 (292)	> 0.55
Sex	0.42 (319)	> 0.50	1.51 (300)	> 0.20
Awakening time	14.02 (659)	< 0.001	15.23 (628)	< 0.001
	Estimate (*SE*)		Estimate (*SE*)	
Covariance parameters				
AR1 diagonal	0.36 (0.02)		47,251.37 (2980.79)	
AR1 rho	−0.50 (0.04)		−0.45 (0.05)	

AUC_g area under the curve with respect to ground, indicative of total daily cortisol output; *S1* awakening sample; *SE* standard error

Discussion

Identifying ways to reduce stress and develop a healthier lifestyle is of critical importance in the current stress-ridden times. We conducted a large-scale 9-month longitudinal study, the *ReSource Project* (Singer et al., 2016), to test whether there is evidence for reduced diurnal cortisol activity after long-term mental training. Compared to the majority of contemplative mental training interventions, the *ReSource Project* is unique in that training was extended beyond the typical 8 weeks of secular mindfulness-based programs (Kabat-Zinn, 1994; Segal et al., 2002). Moreover, different practice types – namely, present-moment attention-based, socio-affective, and socio-cognitive practice – were separated into three independent 3-months training modules (termed Presence, Affect, and Perspective). This allowed for the systematic investigation into the specific effects of each practice type.

We found training effects on the CAR, but not the diurnal slope or total daily cortisol output. Specifically, the training of compassion, prosocial motivation, and dealing with difficult emotions in the Affect Module reduced the typical rise in cortisol shortly after awakening. Although relative to the control group, this effect was only marginal, visual inspection of CAR change trajectories in all training cohorts over time suggests that it was reliably found after three months of only Affect training (in TC3); after 6 months of Affect and Presence training; and after nine months of Affect, Perspective, and Presence training (in TC1 and TC2, respectively). The training of attention- and interoception-based mindfulness practices in the 3-month Presence Module contrarily increased the CAR consistently in both major training cohorts.

The current result of a reduced CAR complements earlier *ReSource* studies showing reduced cortisol reactivity to a standardized psychosocial stress paradigm (Engert et al., 2017), and reduced systemic cortisol levels measured in hair (Puhlmann et al., 2021), both also following the Affect Module. From a mechanistic perspective, we suggest that Affect training stimulates care- and affiliation-based systems that are associated with positive affect (Klimecki et al., 2013; McCall & Singer, 2012), and modulated by oxytocin and opiates (Depue & Morrone-Strupinsky, 2005; Nelson & Panksepp, 1998). Because these neuropeptides are additionally involved in stress regulation (Carter, 2014; Drolet et al., 2001), they are prime candidates to mediate stress reduction following compassion-based practice. In line with this view, in an earlier ReSouce study, we observed a positive association between oxytocin receptor genes, prosocial behavior, and vagal nerve regulation abilities (Bornemann et al., 2019).

The selectivity with which we observed a stress-reducing effect on the CAR *only* after Affect training also stands in *contrast* to our earlier findings. Thus, reduced cortisol stress reactivity following a psychosocial laboratory stressor occurred after Affect and Perspective training alike (Engert et al., 2017), and reduced hair cortisol levels emerged independent of training type after six months of training duration (Puhlmann et al., 2021). This pattern of training effects points to the different functional roles of the targeted cortisol indices. Both the CAR and the acute psychosocial stress response reflect dynamic properties of HPA axis regulation, yet in relation to very different stimuli. In the acute psychosocial stress response, an individual is confronted with a real challenge. In our earlier study, this challenge was posed by the unsupportive members of a psychosocial evaluation committee, trained to elicit fear of negative social judgement, in the Trier Social Stress Test (Kirschbaum et al., 1993). The CAR, on the other hand, is considered a response to the anticipated demands of the upcoming day (Fries et al., 2009). Higher CAR has been reported on working days relative to weekends (Kunz-Ebrecht et al., 2004; Schlotz et al., 2004; Thorn et al., 2006), and on days of upcoming competitions relative to non-competition days (Rohleder et al., 2007). When confronted with a psychosocial threat induced by others, socio-cognitive and socio-affective abilities seem to be equally helpful for successful coping. In fact, regular self-disclosure, non-judgemental empathic listening, and shared humanity, as practiced with a partner in the daily contemplative dyads of both Affect and Perspective modules (Kok & Singer, 2017), may have "immunized" participants against the stress of negative social judgement. When confronted with a threat generated in our own minds, however, the social ability to understand the intentions and emotions of others may be less helpful. Rather, activation of the care system owing to the cultivation of gratitude, self-compassion, and the ability to deal with difficult emotions through acceptance, as specifically trained in the Affect Module, may be key to reducing the anticipated stress load at the beginning of a new day.

Other than CAR and acute stress response, hair cortisol levels represent the cumulative stress load building up over time, which likely reflects the low-grade and continuous strain inherent to various daily hassles (Almeida, 2005; DeLongis et al., 1982; Lazarus & Folkman, 1984). As found by Puhlmann et al. (2021), this type of chronic stress is equally buffered by all three mental training techniques implemented in the *ReSource Project*.

The cultivation of attention and nonjudgemental moment-to-moment awareness in the Presence Module caused an increase in CAR. This finding challenges both, the notion that present-moment and attention-based meditation techniques are a stress remedy, and earlier reports of reduced CAR after mindfulness-based interventions using the MBSR program (Brand et al., 2012). Yet, they are not completely surprising giving findings of increased cortisol stress reactivity after a 3-day mindfulness training (Creswell & Lindsay, 2014), and a lack of reduction in cortisol reactivity to a standardized psychosocial laboratory stressor (Engert et al., 2017). We suggest from these results that the training of attention and interoceptive awareness *alone* may not be the optimal strategy for cortisol stress reduction in situations of acute challenge (no matter whether this challenge happens in real-life social interactions or is anticipated in our minds). On the contrary, if conceptualized as "bare attention" (Bodhi, 2011; Purser & Milillo, 2015), without an ethical or socio-affective "anchor", mindfulness practice may even amplify physiological stress responses, likely due to heightened attention towards body- and stress-related signals. These reflections conform to a recent two-step model proposed in the context of mindfulness training, the Monitor and Acceptance Theory (MAT; Lindsay & Creswell, 2017, 2019), which suggests that stress reduction via mindfulness training develops through the initial cultivation of attentional and interoceptive abilities (i.e., Monitoring), followed by the learning of emotional tools that help manage the amplified receptivity to internal signals, (i.e., Acceptance). In more detail, the MAT posits that as Monitoring is learnt, attentional salience to positive *and* negative states as well as to one's physiological conditions is enhanced. As a consequence, emotion agitation and symptom exacerbation may occur. By gradually cultivating Acceptance skills, individuals are believed to learn how to better control their internal states. Only then, stress reduction can take place.

It is interesting to note in this context that some scholars have expressed concern that the omission of Buddhist ethical principles from basic attention-based mindfulness practice may encourage self-indulgence and have a limited capacity to promote wellbeing—because the very behaviors that may perpetuate ill-being remain unaddressed (Greenberg & Mitra, 2015; Monteiro et al., 2015). Importantly, mindfulness-based intervention programs, such as MBSR (Kabat-Zinn, 1994) and MBCT (Segal et al., 2002), typically go beyond the scope of the attention-related mindfulness techniques cultivated in the Presence Module (and inspired by classical Shamata practices in contemplative traditions). Besides the practice of present-moment attention and interoceptive awareness (through, for example, Breathing Meditation and Body Scan), they include practices targeting emotional and cognitive capacities (such as Loving-kindness Meditation and Observing-thoughts Mediation) (Dahl et al., 2015). Furthermore, the non-judgement and acceptance cultivated in MBSR, and similar 8-week programs, often implicitly introduce care-based, socio-emotional qualities even in basic practices such as Breathing Meditation and Body Scan.

Our above interpretation of the CAR suggests that a lower CAR is adaptive, and, vice versa, a higher CAR is maladaptive. This is a somewhat simplified view. Just as the acute stress response is adaptive in that it prepares us to properly react to a stressor at hand, the CAR is suggested to prepare us for the anticipated demands of the upcoming day (Adam et al., 2006; Fries et al., 2009; Kunz-Ebrecht et al., 2004; Rohleder et al., 2007; Schlotz et al., 2004; Thorn et al., 2006). In other words, the problem is not a single high CAR, but may rather develop as a consequence of a permanently increased CAR. To that effect, an increased CAR has been linked to job and general life stress (Chida & Steptoe, 2009), depression (Boggero et al., 2017), and borderline personality disorder (Rausch et al., 2021). Matters are complicated by the fact that a permanently decreased CAR may likewise be maladaptive, or else a consequence of different disease states. Thus, a blunted CAR has been found in long-term academic stress (Giglberger et al., 2022), posttraumatic stress disorder (Boggero et al., 2017), and first-episode psychosis (Misiak et al., 2021). In sum, the question of whether a higher or lower CAR is more adaptive seems to depend on various factors. In combination with other *ReSource* findings showing a reduction in different cortisol indices after the Affect Module (i.e., acute cortisol reactivity in Engert et al., 2017; hair cortisol levels in Puhlmann et al., 2021), we suggest that the current findings indicate an adaptive effect of Affect training on the CAR.

The lack of significant findings for diurnal cortisol slope and total daily cortisol output suggests a divergence in the sensitivity of different diurnal cortisol indices to training effects. In general, it seems that effects are maximized if the HPA axis is in a state of challenge. Also, cortisol levels after awakening may be less confounded by the diverse influences of the day (e.g., food intake, exercise), and thus less noisy altogether. Importantly, a marginal sequence effect for diurnal cortisol slope did occur, suggesting differential module effects depending on the sequence in which Affect and Perspective training were administered in the two main training cohorts. Given that we had no a priori hypothesis regarding this finding or sequence effects in general, we refrain from further interpretation of this marginal effect, however.

Limitations and Future Research

There are several limitations to our study. Non-adherence to the strict saliva sampling guidelines in ambulatory settings significantly impacts the resulting CAR measurements (Kudielka et al., 2003). In this regard, it needs to be acknowledged that our data do not fully conform to the consensus guidelines on the assessment of the CAR (Stalder et al., 2016), which were published after study conception. Most importantly, we failed to verify participants' exact sampling times, and deviations from the guidelines were not assessed. Since consequently the possibility of non-adherence-related confounding cannot be excluded (Stalder et al., 2016), CAR data should be treated with some caution. The issue of non-adherence was nevertheless addressed through an experience sampling approach based on mobile phones handed out to our participants. As indicated by the low proportion of missing data, these devices seem to have improved adherence by reminding participants of an upcoming sampling time-point. Also, with regard to the 51 women without menstrual cycles in our sample, we did not assess the concrete condition responsible for their lack of a cycle (e.g., menopause, polycystic ovary syndrome).

In sum, the present investigation provides evidence that mental training, specifically the care-based training of gratitude, lovingkindness, (self)-compassion, prosocial motivation, and dealing with difficult emotions in the Affect Module, has beneficial effects on diurnal cortisol activity, measured in terms of the cortisol response to awakening. In addition, our results show an increase in CAR with the training of attention and interoceptive awareness in the Presence Module. With the CAR, we capture an indicator of HPA axis regulation that is particularly sensitive to the anticipation of stress and associated with psychopathology:

depression (e.g., Dedovic et al., 2010; Lamers et al., 2013; Vreeburg et al., 2009), PTSD (Wessa et al., 2006), and psychosis (Mondelli et al., 2010). Together with previous *ReSource* findings on the acute psychosocial stress response (Engert et al., 2017) and hair cortisol/cortisone levels (Puhlmann et al., 2021), an increasingly comprehensive picture emerges of how mental training influences different aspects of stress experience and underlying HPA axis regulation. Thus, we suggest that dynamic properties of the axis profit from practice that goes beyond bare present-moment attention and body interoception. More specifically, acute stress elicited in an interpersonal context seems to be buffered equally well by socio-affective and socio-cognitive exercises as practiced in the Affect and Perspective modules (Engert et al., 2017). Anticipatory stress as reflected in the cortisol response to awakening seems to be efficiently reduced only by socio-affective training. Finally, tonic HPA axis activity seems to profit from mental training per se, independent of practice type. The systematic uncovering of such granularity in both stress markers and types of mental practice is an essential condition for the adaptation of intervention programs toward the needs of specific sub-populations. Targeting different types of stress experiences with different types of contemplative mental practices may be key to more successful stress reduction, and the consequent prevention of stress-associated diseases.

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Author Contribution Veronika Engert: experimental design, data curation, data analysis, writing—original draft. Katja Hoehne: data analysis, writing—review and editing. Tania Singer: funding acquisition, conceptualization and development *ReSource Project*, experimental design, writing—review and editing.

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Data Availability The data presented in this study are available on reasonable request from the senior author.

Declarations

Ethics All procedures performed were in accordance with the 1964 Helsinki Declaration and its later amendments. The study was approved by the Research Ethics Boards of Leipzig University and Humboldt University Berlin.

Informed Consent Informed consent was obtained from all participants included in the study.

Conflict of Interest The authors declare no competing interests.

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References

Adam, E. K., Hawkley, L. C., Kudielka, B. M., & Cacioppo, J. T. (2006). Day-to-day dynamics of experience–cortisol associations in a population-based sample of older adults. *Proceedings of the National Academy of Sciences of the United States of America, 103*(45), 17058–17063. https://doi.org/10.1073/pnas.0605053103

Almeida, D. M. (2005). Resilience and vulnerability to daily stressors assessed via diary methods. *Current Directions in Psychological Science, 14*(2), 64–68. https://doi.org/10.1111/j.0963-7214.2005.00336.x

Arch, J. J., Brown, K. W., Dean, D. J., Landy, L. N., Brown, K. D., & Laudenslager, M. L. (2014). Self-compassion training modulates alpha-amylase, heart rate variability, and subjective responses to social evaluative threat in women. *Psychoneuroendocrinology, 42*, 49–58. https://doi.org/10.1016/j.psyneuen.2013.12.018

Bodhi, B. (2011). What does mindfulness really mean? A Canonical Perspective. *Contemporary Buddhism, 12*(1), 19–39. https://doi.org/10.1080/14639947.2011.564813

Boggero, I. A., Hostinar, C. E., Haak, E. A., Murphy, M., & Segerstrom, S. C. (2017). Psychosocial functioning and the cortisol awakening response: Meta-analysis, P-curve analysis, and evaluation of the evidential value in existing studies. *Biological Psychology, 129*, 207–230. https://doi.org/10.1016/j.biopsycho.2017.08.058

Bornemann, B., Kovacs, P., & Singer, T. (2019). Voluntar upregulation of heart rate variability through biofeedback is improved by mental contemplative training. *Scientific Reports, 9*(1), 7860. https://doi.org/10.1038/s41598-019-44201-7

Brand, S., Holsboer-Trachsler, E., Naranjo, J. R., & Schmidt, S. (2012). Influence of mindfulness practice on cortisol and sleep in long-term and short-term meditators. *Neuropsychobiology, 65*(3), 109–118. https://doi.org/10.1159/000330362

Carlson, L. E., Speca, M., Faris, P., & Patel, K. D. (2007). One year pre-post intervention follow-up of psychological, immune, endocrine and blood pressure outcomes of mindfulness-based stress reduction (MBSR) in breast and prostate cancer outpatients. *Brain, Behavior, and Immunity, 21*(8), 1038–1049. https://doi.org/10.1016/j.bbi.2007.04.002

Carlson, L. E., Speca, M., Patel, K. D., & Goodey, E. (2004). Mindfulness-Based Stress Reduction in relation to quality of life, mood, symptoms of stress and levels of cortisol, dehydroepiandrosterone sulfate (DHEAS) and melatonin in breast and prostate cancer outpatients. *Psychoneuroendocrinology*, *29*(4), 448–474. https://doi.org/10.1097/01.PSY.0000074003.35911.41

Carter, C. S. (2014). Oxytocin pathways and the evolution of human behavior. *Annual Review of Psychology, 65*, 17–39. https://doi.org/10.1146/annurev-psych-010213-115110

Chida, Y., & Steptoe, A. (2009). Cortisol awakening response and psychosocial factors: A systematic review and meta-analysis. *Biological Psychology, 80*(3), 265–278. https://doi.org/10.1016/j.biopsycho.2008.10.004

Chrousos, G. P. (2009). Stress and disorders of the stress system. *Nature Reviews Endocrinology, 5*(7), 374–381. https://doi.org/10.1038/nrendo.2009.106

Cohen, S., Janicki-Deverts, D., & Miller, G. E. (2007). Psychological stress and disease. *JAMA, 298*(14), 1685–1687. https://doi.org/10.1001/jama.298.14.1685

Creswell, J. D., & Lindsay, E. K. (2014). How does mindfulness training affect health? A mindfulness stress buffering account. *Current Directions in Psychological Science, 23*(6), 401–407. https://doi.org/10.1177/0963721414547415

Dahl, C. J., Lutz, A., & Davidson, R. J. (2015). Reconstructing and deconstructing the self: Cognitive mechanisms in meditation practice. *Trends in Cognitive Sciences, 19*(9), 515–523. https://doi.org/10.1016/j.tics.2015.07.001

Davidson, R. J., & Kaszniak, A. W. (2015). Conceptual and methodological issues in research on mindfulness and meditation. *The American Psychologist, 70*(7), 581–592. https://doi.org/10.1037/a0039512

Dedovic, K., Engert, V., Duchesne, A., Lue, S. D., Andrews, J., Efanov, S. I., Beaudry, T., & Pruessner, J. C. (2010). Cortisol awakening response and hippocampal volume: Vulnerability for major depressive disorder? *Biological Psychiatry, 68*(9), 847–853. https://doi.org/10.1016/j.biopsych.2010.07.025

DeLongis, A., Coyne, J. C., Dakof, G., Folkman, S., & Lazarus, R. S. (1982). Relationship of daily hassles, uplifts, and major life events to health status. *Health Psychology, 1*(2), 119–136. https://doi.org/10.1037/0278-6133.1.2.119

Depue, R. A., & Morrone-Strupinsky, J. V. (2005). A neurobehavioral model of affiliative bonding: Implications for conceptualizing a human trait of affiliation. *The Behavioral and Brain Sciences, 28*(3), 313–395. https://doi.org/10.1017/S0140525X05000063

Dressendorfer, R. A., Kirschbaum, C., Rohde, W., Stahl, F., & Strasburger, C. J. (1992). Synthesis of a cortisol-biotin conjugate and evaluation as a tracer in an immunoassay for salivary cortisol measurement. *The Journal of Steroid Biochemistry and Molecular Biology, 43*(7), 683–692. https://doi.org/10.1016/0960-0760(92)90294-s

Drolet, G., Dumont, E. C., Gosselin, I., Kinkead, R., Laforest, S., & Trottier, J. F. (2001). Role of endogenous opioid system in the regulation of the stress response. *Progress in Neuro-Psychopharmacology & Biological Psychiatry, 25*(4), 729–741. https://doi.org/10.1016/s0278-5846(01)00161-0

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*(10), e1700495. https://doi.org/10.1126/sciadv.1700495

Engert, V., Kok, B. E., Puhlmann, L., Stalder, T., Kirschbaum, C., Apostolakou, F., Papanastasopoulou, C., Papassotiriou, I., Pervanidou, P., Chrousos, G. P., & Singer, T. (2018). Exploring the multidimensional complex systems structure of the stress response and its relation to health and sleep outcomes. *Brain, Behavior, and Immunity, 73*, 390–402. https://doi.org/10.1016/j.bbi.2018.05.023

Ferrari, E., Cravello, L., Muzzoni, B., Casarotti, D., Paltro, M., Solerte, S. B., Fioravanti, M., Cuzzoni, G., Pontiggia, B., & Magri, F. (2001). Age-related changes of the hypothalamic-pituitary-adrenal axis: Pathophysiological correlates. *European Journal of Endocrinology, 144*(4), 319–329. https://doi.org/10.1530/eje.0.1440319

First, M. B., Gibbon, M., Spitzer, R. L., Williams, J. B. W., & Benjamin, L. S. (1997). *Structured Clinical Interview for DSM-IV Axis II Personality Disorders (SCID-II)*. American Psychiatric Press.

Fries, E., Dettenborn, L., & Kirschbaum, C. (2009). The cortisol awakening response (CAR): Facts and future directions. *International Journal of Psychophysiology, 72*(1), 67–73. https://doi.org/10.1016/j.ijpsycho.2008.03.014

Gelman, A., Hill, J., & Yajima, M. (2012). Why we (usually) don't have to worry about multiple comparisons. *Journal of Research on Educational Effectiveness, 5*, 189–211. https://doi.org/10.1080/19345747.2011.618213

Giglberger, M., Peter, H. L., Kraus, E., Kreuzpointner, L., Zänkert, S., Henze, G. I., Bärtl, C., Konzok, J., Kirsch, P., Rietschel, M., Kudielka, B. M., & Wüst, S. (2022). Daily life stress and the cortisol awakening response over a 13-months stress period - Findings from the LawSTRESS project. *Psychoneuroendocrinology, 141*, 105771. https://doi.org/10.1016/j.psyneuen.2022.105771

Greenberg, M. T., & Mitra, J. L. (2015). From mindfulness to right mindfulness: The intersection of awareness and ethics. *Mindfulness, 6*(1), 74–78. https://doi.org/10.1007/s12671-014-0384-1

Grossman, P., Niemann, L., Schmidt, S., & Walach, H. (2004). Mindfulness-based stress reduction and health benefits: A meta-analysis. *Journal of Psychosomatic Research, 57*(1), 35–43. https://doi.org/10.1016/S0022-3999(03)00573-7

Hellhammer, D. H., Wust, S., & Kudielka, B. M. (2009). Salivary cortisol as a biomarker in stress research. *Psychoneuroendocrinology, 34*(2), 163–171. https://doi.org/10.1016/j.psyneuen.2008.10.026

Kabat-Zinn, J. (1994). *Wherever you go, there you are: Mindfulness meditation in everyday life*. Hyperion.

Khoury, B., Sharma, M., Rush, S. E., & Fournier, C. (2015). Mindfulness-based stress reduction for healthy individuals: A meta-analysis. *Journal of Psychosomatic Research, 78*(6), 519–528. https://doi.org/10.1016/j.jpsychores.2015.03.009

Kidd, T., Carvalho, L. A., & Steptoe, A. (2014). The relationship between cortisol responses to laboratory stress and cortisol profiles in daily life. *Biological Psychology, 99*, 34–40. https://doi.org/10.1016/j.biopsycho.2014.02.010

Kirschbaum, C., & Hellhammer, D. H. (1989). Salivary cortisol in psychobiological research: An overview. *Neuropsychobiology, 22*(3), 150–169. https://doi.org/10.1159/000118611

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*(1–2), 76–81. https://doi.org/10.1159/000119004

Klimecki, O. M., Leiberg, S., Lamm, C., & Singer, T. (2013). Functional neural plasticity and associated changes in positive affect after compassion training. *Cerebral Cortex, 23*(7), 1552–1561. https://doi.org/10.1093/cercor/bhs142

Kok, B. E., & Singer, T. (2017). Effects of contemplative dyads on engagement and perceived social connectedness over 9 months of mental training: A randomized clinical trial. *JAMA Psychiatry, 74*(2), 126–134. https://doi.org/10.1001/jamapsychiatry.2016.3360

Kudielka, B. M., Broderick, J. E., & Kirschbaum, C. (2003). Compliance with saliva sampling protocols: Electronic monitoring reveals invalid cortisol daytime profiles in noncompliant subjects. *Psychosomatic Medicine, 65*(2), 313–319. https://doi.org/10.1097/01.psy.0000058374.50240.bf

Kunz-Ebrecht, S. R., Kirschbaum, C., Marmot, M., & Steptoe, A. (2004). Differences in cortisol awakening response on work days and weekends in women and men from the Whitehall II cohort. *Psychoneuroendocrinology, 29*(4), 516–528. https://doi.org/10.1016/s0306-4530(03)00072-6

Lamers, F., Vogelzangs, N., Merikangas, K. R., de Jonge, P., Beekman, A. T., & Penninx, B. W. (2013). Evidence for a differential role of HPA-axis function, inflammation and metabolic syndrome in melancholic versus atypical depression. *Molecular Psychiatry, 18*(6), 692–699. https://doi.org/10.1038/mp.2012.144

Law, R., Hucklebridge, F., Thorn, L., Evans, P., & Clow, A. (2013). State variation in the cortisol awakening response. *Stress, 16*(5), 483–492. https://doi.org/10.3109/10253890.2013.817552

Lazarus, R. S., & Folkman, S. (1984). *Stress, appraisal, and coping*. Springer.

Lindsay, E. K., & Creswell, J. D. (2017). Mechanisms of mindfulness training: Monitor and Acceptance Theory (MAT). *Clinical Psychology Review, 51*, 48–59. https://doi.org/10.1016/j.cpr.2016.10.011

Lindsay, E. K., & Creswell, J. D. (2019). Mindfulness, acceptance, and emotion regulation: Perspectives from Monitor and Acceptance Theory (MAT). *Current Opinion in Psychology, 28*, 120–125. https://doi.org/10.1016/j.copsyc.2018.12.004

Linz, R., Singer, T., & Engert, V. (2018). Interactions of momentary thought content and subjective stress predict cortisol fluctuations in a daily life experience sampling study. *Scientific Reports, 8*(1), 15462. https://doi.org/10.1038/s41598-018-33708-0

Linz, R., Puhlmann, L., Engert, V., & Singer, T. (2022). Investigating the impact of distinct contemplative mental trainings on daily life stress, thoughts and affect-Evidence from a nine-month longitudinal ecological momentary assessment study. *Psychoneuroendocrinology, 142*, 105800. https://doi.org/10.1016/j.psyneuen.2022.105800

Lumma, A. L., Kok, B. E., & Singer, T. (2015). Is meditation always relaxing? Investigating heart rate, heart rate variability, experienced effort and likeability during training of three types of meditation. *International Journal of Psychophysiology, 97*(1), 38–45. https://doi.org/10.1016/j.ijpsycho.2015.04.017

McCall, C., & Singer, T. (2012). The animal and human neuroendocrinology of social cognition, motivation and behavior. *Nature Neuroscience, 15*(5), 681–688. https://doi.org/10.1038/nn.3084

Misiak, B., Pruessner, M., Samochowiec, J., Wiśniewski, M., Reginia, A., & Stańczykiewicz, B. (2021). A meta-analysis of blood and salivary cortisol levels in first-episode psychosis and high-risk individuals. *Frontiers in Neuroendocrinology, 62*, 100930. https://doi.org/10.1016/j.yfrne.2021.100930

Mondelli, V., Dazzan, P., Hepgul, N., Di Forti, M., Aas, M., D'Albenzio, A., Di Nicola, M., Fisher, H., Handley, R., Marques, T. R., Morgan, C., Navari, S., Taylor, H., Papadopoulos, A., Aitchison, K. J., Murray, R. M., & Pariante, C. M. (2010). Abnormal cortisol levels during the day and cortisol awakening response in first-episode psychosis: The role of stress and of antipsychotic treatment. *Schizophrenia Research, 116*(2–3), 234–242. https://doi.org/10.1016/j.schres.2009.08.013

Monteiro, L. M., Musten, R. F., & Compson, J. (2015). Traditional and contemporary mindfulness: Finding the middle path in the tangle of concerns. *Mindfulness, 6*(1), 1–13. https://doi.org/10.1007/s12671-014-0301-7

Morton, M. L., Helminen, E. C., & Felver, J. C. (2020). A systematic review of mindfulness interventions on psychophysiological responses to acute stress. *Mindfulness, 11*(9), 2039–2054. https://doi.org/10.1007/s12671-020-01386-7

Nelson, E. E., & Panksepp, J. (1998). Brain substrates of infant-mother attachment: Contributions of opioids, oxytocin, and norepinephrine. *Neuroscience and Biobehavioral Reviews, 22*(3), 437–452. https://doi.org/10.1016/s0149-7634(97)00052-3

Pascoe, M. C., Thompson, D. R., Jenkins, Z. M., & Ski, C. F. (2017). Mindfulness mediates the physiological markers of stress: Systematic review and meta-analysis. *Journal of Psychiatric Research, 95*, 156–178. https://doi.org/10.1016/j.jpsychires.2017.08.004

Pruessner, J. C., Wolf, O. T., Hellhammer, D. H., Buske-Kirschbaum, A., von Auer, K., Jobst, S., Kaspers, F., & Kirschbaum, C. (1997). Free cortisol levels after awakening: A reliable biological marker for the assessment of adrenocortical activity. *Life Sciences, 61*(26), 2539–2549. https://doi.org/10.1016/s0024-3205(97)01008-4

Pruessner, J. C., Kirschbaum, C., Meinlschmid, G., & Hellhammer, D. H. (2003). Two formulas for computation of the area under the curve represent measures of total hormone concentration versus time-dependent change. *Psychoneuroendocrinology, 28*(7), 916–931. https://doi.org/10.1016/s0306-4530(02)00108-7

Puhlmann, L. M. C., Vrticka, P., Linz, R., Stalder, T., Kirschbaum, C., Engert, V., & Singer, T. (2021). Contemplative mental training reduces hair glucocorticoid levels in a randomized clinical trial. *Psychosomatic Medicine, 83*(8), 894–905. https://doi.org/10.1097/PSY.0000000000000970

Purser, R. E., & Milillo, J. (2015). Mindfulness revisited: A buddhist-based conceptualization. *Journal of Management Inquiry, 24*(1), 3–24. https://doi.org/10.1177/1056492614532315

Rausch, J., Flach, E., Panizza, A., Brunner, R., Herpertz, S. C., Kaess, M., & Bertsch, K. (2021). Associations between age and cortisol awakening response in patients with borderline personality disorder. *Journal of Neural Transmission, 128*(9), 1425–1432. https://doi.org/10.1007/s00702-021-02402-3

Rohleder, N., Beulen, S. E., Chen, E., Wolf, J. M., & Kirschbaum, C. (2007). Stress on the dance floor: The cortisol stress response to social-evaluative threat in competitive ballroom dancers. *Personality and Socical Psychology Bulletin, 33*(1), 69–84. https://doi.org/10.1177/0146167206293986

Rosch, J. P. (2001). The quandry of job stress compensation. *Health and Stress, 3*, 1–4.

Rosenkranz, M. A., Davidson, R. J., Maccoon, D. G., Sheridan, J. F., Kalin, N. H., & Lutz, A. (2013). A comparison of mindfulness-based stress reduction and an active control in modulation of neurogenic inflammation. *Brain, Behavior, and Immunity, 27*(1), 174–184. https://doi.org/10.1016/j.bbi.2012.10.013

Ross, K. M., Murphy, M. L. M., Adam, E. K., Chen, E., & Miller, G. E. (2014). How stable are diurnal cortisol activity indices in healthy individuals? Evidence from three multi-wave studies. *Psychoneuroendocrinology, 39*, 184–193. https://doi.org/10.1016/j.psyneuen.2013.09.016

Sanada, K., Montero-Marin, J., Alda Diez, M., Salas-Valero, M., Perez-Yus, M. C., Morillo, H., Demarzo, M. M., Garcia-Toro, M., & Garcia-Campayo, J. (2016). Effects of mindfulness-based interventions on salivary cortisol in healthy adults: A meta-analytical review. *Frontiers in Physiology, 7*, 471. https://doi.org/10.3389/fphys.2016.00471

Schlotz, W., Hellhammer, J., Schulz, P., & Stone, A. A. (2004). Perceived work overload and chronic worrying predict weekend-weekday differences in the cortisol awakening response. *Psychosomatic Medicine, 66*(2), 207–214. https://doi.org/10.1097/01.psy.0000116715.78238.56

Segal, Z. V., Williams, J. M. G., & Teasdale, J. D. (2002). *Mindfulness-based cognitive therapy for depression*. Guilford Press.

Singer, T. (2012). The past, present and future of social neuroscience: A European perspective. *NeuroImage, 61*(2), 437–449. https://doi.org/10.1016/j.neuroimage.2012.01.109

Singer, T., & Engert, V. (2019). It matters what you practice: Differential training effects on subjective experience, behavior, brain and body in the ReSource Project. *Current Opinion in Psychology, 28*, 151–158. https://doi.org/10.1016/j.copsyc.2018.12.005

Singer, T., Kok, B. E., Bornemann, B., Zurborg, S., Bolz, M., & Bochow, C. (2016). *The ReSource Project. Background, design, samples, and measurements* (2nd ed.). Max Planck Institute for Human Cognitive and Brain Sciences.

Stalder, T., Kirschbaum, C., Kudielka, B. M., Adam, E. K., Pruessner, J. C., Wust, S., Dockray, S., Smyth, N., Evans, P., Hellhammer, D. H., Miller, R., Wetherell, M. A., Lupien, S. J., & Clow, A. (2016). Assessment of the cortisol awakening response: Expert consensus guidelines. *Psychoneuroendocrinology, 63*, 414–432. https://doi.org/10.1016/j.psyneuen.2015.10.010

Sugaya, N., Izawa, S., Ogawa, N., Shirotsuki, K., & Nomura, S. (2020). Association between hair cortisol and diurnal basal cortisol levels: A 30-day validation study. *Psychoneuroendocrinology, 116*, 104650. https://doi.org/10.1016/j.psyneuen.2020.104650

Tang, Y. Y., Ma, Y., Wang, J., Fan, Y., Feng, S., Lu, Q., Yu, Q., Sui, D., Rothbart, M. K., Fan, M., & Posner, M. I. (2007). Short-term meditation training improves attention and self-regulation. *Proceedings of the National Academy of Sciences of the United States of America, 104*(43), 17152–17156. https://doi.org/10.1073/pnas.0707678104

Thorn, L., Hucklebridge, F., Evans, P., & Clow, A. (2006). Suspected non-adherence and weekend versus week day differences in the awakening cortisol response. *Psychoneuroendocrinology, 31*(8), 1009–1018. https://doi.org/10.1016/j.psyneuen.2006.05.012

Vreeburg, S. A., Hoogendijk, W. J., van Pelt, J., Derijk, R. H., Verhagen, J. C., van Dyck, R., Smit, J. H., Zitman, F. G., & Penninx, B. W. (2009). Major depressive disorder and hypothalamic-pituitary-adrenal axis activity: Results from a large cohort study. *Archives of General Psychiatry, 66*(6), 617–626. https://doi.org/10.1001/archgenpsychiatry.2009.50

Wessa, M., Rohleder, N., Kirschbaum, C., & Flor, H. (2006). Altered cortisol awakening response in posttraumatic stress disorder. *Psychoneuroendocrinology, 31*(2), 209–215. https://doi.org/10.1016/j.psyneuen.2005.06.010

Wilder, J. (1957). The law of initial value in neurology and psychiatry: Facts and problems. *Journal of Nervous and Mental Disease, 125*, 73–86. https://doi.org/10.1097/00005053-195701000-00009

Wilhelm, I., Born, J., Kudielka, B. M., Schlotz, W., & Wust, S. (2007). Is the cortisol awakening rise a response to awakening? *Psychoneuroendocrinology, 32*(4), 358–366. https://doi.org/10.1016/j.psyneuen.2007.01.008

Wittchen, H. U., & Pfister, H. (1997). *Diagnostisches Expertensystem für psychische Störungen (DIA-X)*. Swets & Zeitlinger.

Wittchen, H. U., Zaudig, M., & Fydrich, T. (1997). *SKID-Strukturiertes Klinisches Interview für DSM-IV*. Hogrefe.

Wust, S., Federenko, I., Hellhammer, D. H., & Kirschbaum, C. (2000). Genetic factors, perceived chronic stress, and the free cortisol response to awakening. *Psychoneuroendocrinology, 25*(7), 707–720. https://doi.org/10.1016/s0306-4530(00)00021-4

Wust, S., Wolf, J., Hellhammer, D. H., Federenko, I., Schommer, N., & Kirschbaum, C. (2000). The cortisol awakening response – normal values and confounds. *Noise & Health, 2*(7), 79–88.

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