Original Paper

Neuropsychobiology

Neuropsychobiology 2012;65:109–118
DOI: 10.1159/000330362

Received: February 9, 2011
Accepted after revision: June 28, 2011
Published online: February 24, 2012

Influence of Mindfulness Practice on Cortisol and Sleep in Long-Term and Short-Term Meditators

Serge Brand[a] Edith Holsboer-Trachsler[a] José Raúl Naranjo[b] Stefan Schmidt[b–e]

[a]Depression Research Unit, Psychiatric Hospital of the University of Basel, Basel, Switzerland; [b]Department of Environmental Health Sciences, University Medical Center Freiburg, Freiburg, [c]Institute for Transcultural Health Studies, European University Viadrina, and [d]Brain, Mind and Healing Programme, Samueli Institute, European Office, Frankfurt, Germany; [e]Heymans Chair of Exceptional Human Experiences, University for the Humanistics, Utrecht, The Netherlands

Key Words
Mindfulness-based stress reduction · Cortisol secretion · Short-term experience · Long-term experience · Sleep quality

Abstract
Background: There is growing scientific interest in assessing the biological correlates of non-pharmacological interventions such as mindfulness. Examinations of the beneficial effects of mindfulness on hypothalamus-pituitary-adrenocortical system activity (HPA SA) and sleep are sparse. The aim of the present study was to explore the impact of long- and short-term meditation experience on HPA SA and sleep. ***Method:*** There were 20 participants, 9 of whom had long-term experience in meditation (mean = 264 months) and 11 novices. Novices underwent an 8-week course in Mindfulness-Based Stress Reduction (MBSR), and cortisol samples were taken in the lab at the beginning and end of the course. To assess the cortisol awakening response, 4 morning cortisol samples were collected. Sleep and mindfulness were assessed by self-rating questionnaires. ***Results:*** Among participants with long-term meditation experience, morning cortisol decreased with length of experience. For novices, after an 8-week introductory MBSR course, morning cortisol levels had decreased, while both sleep and self-attribution of mindfulness significantly improved. Cortisol levels did not, however, change between the beginning and end of individual MBSR sessions. ***Conclusions:*** The pattern of results lends support to the view that MBSR/meditation has a favorable influence both on biomarkers of stress regulation, such as cortisol secretion, and on sleep.

Introduction

In recent years, there has been a substantial growth of scientific interest in both the application and the assessment of mindfulness-based interventions. Indeed, mindfulness-based interventions have been used with both healthy subjects and patients suffering from physical diseases and psychiatric disorders [1–3]. In the late 1980s, J. Kabat-Zinn was challenged by his colleagues at the Med-

S.B. and S.S. contributed equally to this work.

KARGER

Fax +41 61 306 12 34
E-Mail karger@karger.ch
www.karger.com

0302–282X/12/0653–0109$38.00/0

Accessible online at:
www.karger.com/nps

Serge Brand, PhD
Psychiatric Hospital of the University of Basel, Depression Research Unit
Wilhelm Klein-Strasse 27
CH–4012 Basel (Switzerland)
Tel. +41 61 325 5114, E-Mail serge.brand@upkbs.ch

ical Center of the University of Massachusetts over the fact that conventional treatments did not improve the health or quality of life of chronically ill patients [4]. To supplement conventional treatments, Kabat-Zinn introduced training in mindfulness, as derived from the Buddhist tradition and in hatha yoga. The result was the so-called Mindfulness-Based Stress Reduction (MBSR) [5]. Following Kabat-Zinn's seminal work, mindfulness has been defined as a state in which a person is paying total attention to the present moment and is fully aware of inner and outer experiences, though without any judgment [6]. More specifically, in practicing mindfulness one seeks to perceive one's feelings and emotions without reacting to them, to accept oneself as one is and to remain in touch with things as they are, even when things go wrong. The original concept of mindfulness can be found first in Buddhism and has become integrated into several behavioral intervention programs, such as MBSR and Mindfulness-Based Cognitive Therapy [7], Dialectical Behavior Therapy [8] and Acceptance and Commitment Therapy [9, 10].

Numerous studies and meta-analyses have now shown that MBSR and therapeutic approaches derived from it are effective in improving the health status of those suffering from a broad variety of physical diseases, including the psychological correlates of these (e.g. psychological symptoms in cancer; reduction of blood pressure; chronic pain; rheumatoid arthritis; fibromyalgia; psoriasis; tinnitus; HIV; improvements in quality of life, depressive symptoms and fatigue in multiple sclerosis [11]), and psychiatric disorders (e.g. prevention of relapses in major depressive disorders [12]; reduction in depressive and anxiety symptoms in major depressive disorders; significant benefits for patients with several anxiety disorders and with alcohol and substance dependence [1, 2, 13]). The overall pattern, however, indicates that alongside the encouraging results, there are also inconsistent and conflicting findings with regard to the beneficial effect of MBSR upon health status. These may partly be attributed to two main issues. First, despite numerous attempts to provide a coherent definition of mindfulness, an unequivocal and coherent theoretical framework of mindfulness is still lacking [for a review, see Chiesa and Malinowski 14]. Second, there are methodological issues, such as studies using different measures (making it difficult to compare results), unrepresentative samples, lack of control groups, lack of longitudinal studies, cultural differences and differences related to quality of treatment [1, 3; for an extensive overview, see 2]. Specifically, most studies have relied on self-report measures to assess improvements. To counter this, and to provide more objective evidence, functional MRI [15, 16] and assessment of the hypothalamus-pituitary-adrenocortical system activity (HPA SA) have been used with both patients and healthy subjects. Again, though, results based on these approaches have ranged from no difference to highly significant improvements [1, 2].

Among the biological markers to assess MSBR/meditation, cortisol secretion has gained increased attention as a reliable indicator of HPA SA [17]; cortisol has generally been found to be responsive to interventions intended to reduce stress [17]. To name a few, Carlson et al. [18] assessed 33 outpatients suffering from breast and prostate cancer undergoing an 8-week MBSR program. Results showed that the MBSR program was associated with decreased cortisol secretion along with decreased stress and mood disturbance. Marcus et al. [19] assessed morning cortisol levels of 21 psychiatric outpatients suffering from addictive disorders at the beginning and at the end of an 8-week MBSR program; the authors were able to show that awakening salivary cortisol levels were significantly lower at the end of the 8-week MBSR program. In contrast, Galantino et al. [20] could not find any beneficial effects on cortisol secretion of an 8-week MBSR program for 84 employees. Similarly, Klatt et al. [21] assessed working adults and controls, but observed no change in cortisol secretion either between groups or over a 6-week MBSR course. Robinson et al. [22] assessed plasma cortisol levels of 34 patients suffering from HIV; of these, 24 participated in an 8-week MBSR program, and 10 were assigned to the control group. The authors found neither pre- to post-intervention nor between-group effects. Robert McComb et al. [23] assessed plasma cortisol levels of 18 elderly women with heart disease who were randomly assigned either to the treatment (8-week MBSR program) or control group. Results revealed no significant group differences, though they were suggestive of a reduction in cortisol in the treatment group 8 weeks later [for an extensive overview, see 17]. Finally, Matousek et al. [24] reported an increase in cortisol secretion from pre- to post-measurement in 33 patients who completed a treatment for breast cancer. To sum up, several studies both with patients suffering from various psychiatric and somatic disorders and with healthy people have provided a quite inconsistent picture of the relation between MBSR and HPA SA.

With respect to sleep, it is believed that MBSR may improve sleep by reducing sleep-disrupting dysfunctional thoughts. Within the cognitive-emotional model of insomnia [25], dysfunctional thoughts are considered to be

the main cause of sleep disturbances. However, again no clear-cut pattern of results has emerged so far; some studies have indicated a positive effect of MBSR on sleep, but some have failed to show significant effects [26–30]. The reasons for these inconsistent results remain unclear. As for research on MBSR and cortisol, it is conceivable that methodological issues (e.g. different methods for assessing sleep, non-comparable samples, lack of control groups) may thus far have obscured any consistent pattern.

There is a wealth of evidence showing a close association between increased HPA SA and poor sleep, whether in healthy children [31, 32], adolescents [33], adults [34], infants suffering from infantile colic [35] or patients suffering from depressive symptoms [36–38]. Consequently, it is conceivable that a similar pattern may be found among adult meditators.

To summarize, there is some evidence of beneficial effects of MBSR on HPA SA and sleep, though methodological issues (different sample characteristics, different time frames for salivary collection, and different cortisol assessments) may well be responsible for the lack of clearer conclusions [for an overview, see 17]. Moreover, no evidence is available on the consequences of long-term meditation practice. To counter this, the present study aimed to shed light on the relationship between meditation, MBSR, HPA SA and sleep among long-term practitioners of meditation (Buddhist monks and nuns, mindfulness teachers) and among those with no prior experience of meditation (novices). We believe that the results may be of potential interest both in clinical settings to aid promotion of MBSR as a non-pharmacological intervention alongside standard therapies, as well as in non-clinical settings to foster well-being.

The following five hypotheses were formulated. First, since HPA SA seems to be responsive to stress-reducing interventions [17], we expected lower HPA SA as a function of meditation experience among long-term meditators. Second, we anticipated that an 8-week course in MSBR should reduce HPA SA. Third, we further assumed that cortisol levels would decrease from the beginning to the end of a meditation session and from the very first session to the very last session of an 8-week course. Fourth, following Winbush et al. [29] and Ong and Sholtes [30], we expected improved sleep quality following an 8-week course of MBRS. Fifth, following Buckley and Schatzberg [38] and Steiger [37], we expected an association between HPA SA and sleep. We also anticipated an association between decreased HPA SA, improved sleep and improved mindfulness.

Methods

Sample

The sample consisted of 20 participants divided into two subgroups of long-term and short-term meditators. Nine participants were long-term meditators (mean age = 49.7, SD = 7.50), with an average meditation experience of 264 months (SD = 95.5; range: 144–396 months): 4 from Theravada Buddhist monasteries in Myanmar, Switzerland and Germany, 3 teachers of vipassana meditation and 2 additional practitioners with long-standing meditation experience. Eleven participants were novices (9 females, 2 males; mean age = 40.2 years, SD = 11.43) without any prior experience of MBSR. These novices were recruited for the study after they had subscribed to an MBSR course. They were offered a reduction in course fees for participating in the study.

The purposes of the study were fully explained, and participants gave written informed consent. Next, a brief psychiatric interview (Mini International Neuropsychiatric Interview [39]) was undertaken to rule out possible psychopathological symptoms. The study was performed in accordance with the Declaration of Helsinki, and the experimental protocol was approved by the Ethics Committee of the University Medical Center Freiburg i. Br. (Germany).

Procedure

First, to assess the cortisol awakening response (CAR), morning cortisol samples were gathered as outlined below. Next, for long-term meditators, saliva samples were collected at the beginning and at the end of a single meditation session.

For the novices, saliva samples were gathered at the beginning and at the end of the very first meditation session, as well as at the beginning and end of the last meditation session 8 weeks later.

Meditation sessions took place between 1 and 4 p.m. Additionally, at the beginning and at the end of the 8-week course, participants completed a questionnaire assessing self-perception of mindfulness (Freiburg Mindfulness Inventory) [40], as well as a questionnaire to assess sleep quality (Pittsburgh Sleep Quality Index) [41].

Materials

Freiburg Mindfulness Inventory

The short form of the Freiburg Mindfulness Inventory [40] was used to assess self-attribution of mindfulness. The self-completed questionnaire comprises 14 items focusing on thoughts, attitudes and experiences related to the concept of mindfulness. Typical items are 'I am open to the experience of the present moment', 'I see my mistakes and difficulties without judging them' and 'I am able to appreciate myself'. Answers are given on 4-point rating scales ranging from 1 (= rarely) to 4 (= almost always), with higher scores reflecting greater self perception of mindfulness (Cronbach's $\alpha = 0.88$ for long-term meditators and 0.73 for novices).

Assessing Sleep

To assess sleep, the Pittsburgh Sleep Quality Index [41] was employed. This self-completed inventory assesses sleep quality

on various dimensions over the past 4 weeks. It has 9 items, though one consists of 10 sub-items, so participants provide responses to 18 questions in all. Typical items are: 'For the last four weeks, how often didn't you sleep well because …' '… you couldn't fall asleep in the first 30 min?', '… you woke up during the night or early in the morning'. Answers are given on 4-point rating scales with various verbal quantifiers depending on the type of question. Higher overall scores reflect poorer sleep quality (Cronbach's $\alpha = 0.89$ for long-term meditators and 0.90 for novices).

HPA System Assessment at Baseline/CAR

Morning cortisol level, or the CAR, has been shown to be a reliable biological marker for the HPA activity of children, adolescents and adults when measured repeatedly with strict reference to the time of awakening [42–44]. Participants individually collected 4 saliva cortisol samples in the morning at 0, 10, 20 and 30 min after awakening and stored them in the refrigerator. Waking times ranged from 6.00 to 7.00 a.m. Participants were instructed and trained in saliva sampling before the start of the study. Specifically, participants were instructed to keep the cotton swabs in the mouth for about 2 min and to refrain from smoking and from food or beverage intake.

HPA System Assessment at the Beginning and at the End of a Meditation Session

The following saliva samples were all exclusively collected in the laboratory of the University Medical Center Freiburg in Breisgau (Germany), Department of Environmental Health Sciences: one sample on entering the lab, one at the beginning of the first meditation session, and one at the end of this session. For long-term meditators, one meditation session was assessed (cross-sectional), whereas the novices were invited twice to the lab for a meditation session, the first before the start of the MBSR course and the second time after the end of the 8-week course (longitudinal). To keep possible confounders to a minimum [17], assessments took place in the afternoon. In addition, participants were asked to refrain from smoking, food and beverage intake, and strenuous physical activity for 90 min prior to measurements.

Saliva Cortisol Sampling Technique and Cortisol Analysis

Saliva samples obtained as described above were then returned to the laboratory, where they were centrifuged at 4°C (2,000 rpm, 10 min) and stored at –20°C until assay.

Free salivary cortisol concentrations were analyzed using a time-resolved immunoassay with fluorometric detection 'Coat-A-Count' Cortisol RIA from Diagnostics Products Corporation (obtained through H. Biermann GmbH, Bad Nauheim, Germany) as described in detail elsewhere [45]. Intra- and inter-assay variabilities of this assay were less than 3.0 and 3.67%, respectively.

Of the cortisol values sampled at 0, 10, 20 and 30 min after awakening, to compute a reliable estimate of the total amount of hormone release, the area under the concentration time curve (AUC) of the morning cortisol levels (nmol/l) was calculated using trapezoidal integration [35, 46–48]. The AUC total refers to the entire amount of cortisol concentration under the time curve, whereas the AUC basal describes the initial and averaged amount of cortisol secretion over time, as if the HPA system had not been stimulated; accordingly, the AUC net refers to the difference in cortisol secretion between AUC total and basal [48].

Experience with Meditation and MBSR

The 9 long-term practitioners reported an average experience of 264 months (SD = 95.5; range: 144–396 months). They also reported practicing meditation every day for at least 120 min. Novices reported no prior experience in meditation or mindfulness practice prior to enrolment in the study.

MBSR Course

MBSR is an 8-week structured and manualized behavioral intervention program. It was taught in groups of up to 12 participants by a single instructor. Participants took part in one 2.5-hour session every week, and an additional 7-hour all-day session on a weekend. Each session covered specific exercises and topics within the context of mindfulness practice and training. These included various types of formal mindfulness practice, mindful awareness of dynamic yoga postures, and mindfulness during stressful situations and social interactions. The all-day retreat included a combination of previously used and newly introduced mindfulness exercises. On enrolment, participants were asked to commit themselves to daily homework assignments of 45–60 min. The instructors were two women with university level degrees in educational counseling who had undergone MBSR training provided by the UMass Medical Center for Mindfulness, Worcester, Mass., USA. Each had at least 7 years of experience of teaching MBSR. Personal interviews were conducted by each instructor to establish rapport and to help participants formulate realistic individual goals for the intervention. Post-intervention interviews addressed participants' personal experiences.

Statistical Analyses

To compare the scores of long-term meditators on the Freiburg Mindfulness Inventory with normative data, a series of one-sample t tests was performed.

Pre- to post-intervention comparisons were performed with t tests for dependent data, whereas comparisons between participants with long- and short-term experience were performed with t tests for independent samples. To compensate for possible deviations from homogeneity of variances, instead of the classical Student's t test, the more robust Welch test was employed [49, 50].

Test results with a level of $p < 0.05$ were reported as significant. However, we placed more emphasis on effect sizes (d), following Cohen's advice [51–53] that the importance of p values should not be overestimated. Moreover, unlike p values, effect sizes do not vary as a function of sample sizes. Effect sizes for t tests were calculated following Cohen [48], with $0.20 \geq d \geq 0.49$ indicating small (i.e. negligible practical importance), $0.50 \geq d \geq 0.79$ indicating medium (i.e. moderate practical importance), and $d \geq 0.80$ indicating large (i.e. crucial practical importance) effect sizes. Spearman's correlations were computed; a partial correlation was performed to correlate duration of meditational experience and CAR controlling for age.

Statistical analyses were conducted using SPSS 19.0 for Windows.

Table 1. Descriptive and statistical overview of self-attribution of mindfulness, cortisol secretion and sleep quality, separately by meditation experience (long-term experience vs. short-term experience) and time of measurement, mean ± SD

	Experience in meditation		
	long-term	novice	
		start of course	end of course
Sample size	9	11	
Self-attribution of mindfulness (FBI)	47.67 ± 4.92	30.77 ± 5.15	37.64 ± 3.47
Sleep (PSQI)	3.75 ± 2.05	7.72 ± 4.08	5.46 ± 4.04
Cortisol			
CAR, nmol/l			
AUC total	334.93 ± 274.61	308.97 ± 210.32	293.66 ± 201.60
AUC basal	309.83 ± 338.47	258.23 ± 236.19	263.63 ± 235.08
AUC netto	25.09 ± 109.16	55.88 ± 95.97	24.54 ± 79.78
Meditation in lab, μg/dl			
Entry	4.35 ± 2.82	4.00 ± 2.31	3.83 ± 2.40
Beginning	3.60 ± 3.35	2.68 ± 2.43	2.74 ± 2.42
End	3.77 ± 3.43	2.92 ± 2.48	2.69 ± 2.50

CAR = Cortisol awakening response; FBI = Freiburg Mindfulness Inventory; PSQI = Pittsburgh Sleep Quality Index.

Results

Mindfulness

Table 1 gives separate overviews of the experience of mindfulness, cortisol secretion and sleep, by experience of meditation (long- and short-term) and assessment time.

For long-term meditators, the mean score for self-attributed mindfulness was 47.7 (SD = 4.93). Using normative data taken from Walach et al. [40], long-term meditators reported significantly higher scores than a normal population (mean = 34.5, SD = 6.77; $t_8 = 8.00$, $p < 0.001$, $d = 2.25$). Compared to novice meditators at the beginning and at the end of an 8-week course, long-term mediators had higher scores (novices: beginning of the course: $t_{18} = 7.44$, $p < 0.001$, $d = 3.39$; novices: end of the course: $t_{18} = 5.43$, $p < 0.001$, $d = 2.41$). To sum up, long-term meditators had significantly and substantially higher scores for the self-attribution of mindfulness than non-meditators or novices.

For novices, mindfulness scores increased from the start to the end of the 8-week course ($t_{10} = 6.16$, $p < 0.001$, $d = 1.59$). Compared to a normal population (Walach et al. [40]), novices had lower scores at the beginning of the course ($t_{10} = 2.42$, $p = 0.04$, $d = 0.63$), whereas by the end of the course their scores had increased significantly ($t_{10} = 1.18$ $p < 0.001$, $d = 0.61$). For novices therefore, the 8-week MBSR course did raise self-attribution of mindfulness.

Cortisol Secretion

Cortisol Awakening Response

Descriptive data are reported in table 1. For long-term meditators, CAR was negatively correlated with duration of meditation experience: AUC total: $r = -0.59$, $p = 0.03$ (controlling for age: $r_{partial} = -0.66$, $p = 0.03$; fig. 1a); AUC basal: $r = -0.57$, $p = 0.04$ (controlling for age: $r_{partial} = -0.56$, $p = 0.04$; fig. 1b). Higher CAR was also associated with higher cortisol levels in the lab (all $r > 0.60$, all $p < 0.03$).

For novices, CAR decreased significantly from the start to the end of the eight-week course for AUC net ($t_{20} = 2.12$, $p = 0.04$, $d = 0.35$), but not for AUC total ($t_{20} = 1.12$, $p = 0.28$, $d = 0.35$) or AUC basal ($t_{20} = 0.40$, $p = 0.74$, $d = 0.01$). Higher CAR was associated with increased cortisol levels during the meditation session in the lab, though the correlation did not reach statistical significance (all $r < 0.42$, all $p > 0.10$).

Cortisol under Meditation Conditions

Descriptive data are reported in table 1. For long-term meditators, cortisol levels did not change from the begin-

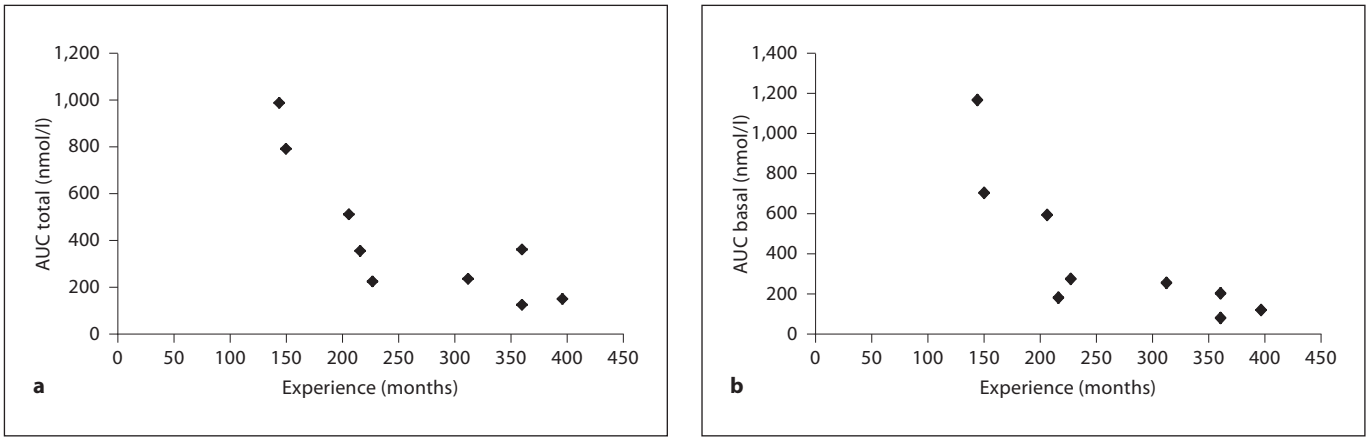

Fig. 1. In long-term meditators, experience negatively correlated with CAR. **a** AUC total: $r_{partial} = -0.66$, $p < 0.05$, controlling for age. **b** AUC basal: $r_{partial} = -0.56$, $p < 0.05$, controlling for age.

ning to the end of a meditation session ($t_8 = 0.45$, $p = 0.66$, $d = 0.05$).

For novices, cortisol levels neither changed during a meditation session before the start of the course ($t_{10} = 1.62$, $p = 0.14$, $d = 0.30$; marginal increase), nor during a meditation session after the end of the course ($t_{10} = 1.62$, $p = 0.14$, $d = 0.30$; marginal decrease). Aggregating cortisol levels from the first meditation session (i.e. mean of cortisol at the beginning and end of the first session; mean = 2.07, SD = 0.96) and from the last meditation session (i.e. mean of cortisol at the beginning and end of the last session; mean = 1.92, SD = 0.83), cortisol levels remained unchanged ($t_{10} = 0.75$, $p = 0.47$, $d = 0.16$).

Long- and short-term meditators did not differ with respect to cortisol levels when entering the lab, nor before and after a meditation session in the lab (all $t < 1.60$, all $p > 0.13$).

Sleep

Descriptive data are reported in table 1. For long-term meditators, no longitudinal data were gathered. Compared to novices, long-term meditators reported significantly fewer sleep complaints ($t_{19} = 2.50$, $p = 0.02$, $d = 1.29$). For novices, sleep difficulties significantly decreased following the 8-week course ($t_{20} = 2.99$, $p = 0.008$, $d = 0.40$).

Correlations between Mindfulness, Cortisol Secretion and Sleep

Descriptive data are reported in table 1. For long-term meditators, self-attributed mindfulness was negatively associated with sleep disturbances ($r = -0.84$, $p = 0.001$), but not with cortisol secretion (all $r < 0.20$, all $p > 0.25$). Quality of sleep was unrelated to cortisol secretion.

For novices, at the beginning of the 8-week course, self-attribution of mindfulness was negatively associated with sleep disturbances ($r = -0.52$, $p = 0.06$) and CAR ($r = -0.42$, $p = 0.04$). Sleep complaints correlated positively with CAR, though the correlation did not reach statistical significance (all $r < 0.29$, all $p > 0.1$). At the end of the 8-week course, self-attribution of mindfulness was negatively associated with sleep disturbances ($r = -0.53$, $p = 0.05$), but not with CAR (all $r < 0.25$, all $p > 0.1$). Increased sleep complaints were statistically associated with increased CAR (AUC total: $r = 0.49$, $p = 0.04$; AUC basal: $r = 0.68$, $p = 0.02$).

Discussion

The key findings of the present study are that, irrespective of age, long-term meditation experience was associated with lower HPA SA in the morning, as assessed by morning CAR. Moreover, for novices, after a short course in MBSR (8 weeks) CAR was decreased, although cortisol levels before and after meditation sessions did not differ. In addition, poor sleep was associated with increased CAR among both long-term and novice meditators. Last, for novices, mindfulness scores increased significantly after the 8-week course. Thus, the present findings do add to the existing literature in an important way in that to our best knowledge it is the first study to show that after an 8-week course of MBSR, CAR decreases significantly in healthy subjects. Moreover, again to our best

knowledge, this is the first study to show that in long-term meditators, CAR decreases as a function of the duration of meditation experience, irrespective of the age of the participants.

Five hypotheses were formulated and these are now considered in turn.

With the first hypothesis, we anticipated that morning cortisol secretion would be related to meditation experience, and this was supported by the data; among long-term meditators, CAR decreased as a function of meditation experience and this correlation was even more pronounced when controlling for age. Therefore, our data do support the notion that HPA SA seems to be responsive to interventions to reduce stress [17] and, in our opinion, the present data are consistent with studies showing that long-term practice of meditation seems to be associated with improved emotional regulation [e.g. 16].

With the second hypothesis, we expected decreased HPA SA after an 8-week course of MBSR, and data gathered from novices did support this prediction. CAR decreased between the start and the end of the 8-week course. Thus, our data fit well with both the pattern of results observed in long-term meditators and with previous studies. For example, Carlson et al. [18] and Marcus et al. [19] observed decreased cortisol levels in patients after an 8-week MBSR program. By contrast, our data are at odds with studies which failed to observe any beneficial effects of an MBSR program on cortisol secretion [20–24]. Most importantly, to our knowledge, this is the first study reporting the beneficial effects of MBSR on CAR in healthy participants.

Our third hypothesis was that cortisol levels would decrease over the course of a single meditation session and also if meditation sessions from before the course were compared to sessions after the course. However, our data did not support these expectations, and in this respect these data are consistent with the numerous studies that have not found any beneficial effect of an 8-week MBSR course on HPA SA [20–23, for an overview, see 17]. How then can we explain why, after an 8-week course of MBSR, CAR was significantly decreased even though cortisol levels immediately after meditation were not lowered? There are at least four different reasons for this. First, since HPA SA decreases in the second half of the day [54] and since meditation sessions took place in the afternoon, it is conceivable that our data reflect floor effects. Consequently, future research should also employ meditation sessions in the morning. Second, following Kabat-Zinn [4], MBSR and meditation imply a psychic status in which a person is paying total attention to the present moment and is fully aware of inner and outer experiences and, as such, this psychic status is not confounded with the psychophysiological state of relaxation accompanied by decreased cortisol secretion [55]. Third, and supplementary to the second assumption, learning techniques such as MBSR demand a highly controlled focusing of awareness and concentration [56]. Therefore, these cognitive processes are not associated with a decrease in psychophysiological functioning. Fourth, at least during early stages in which novices are learning different methods of relaxation, EEG profiles have shown that participants have difficulty remaining awake [55]. Accordingly, and though highly speculative, it is possible that novices in the present study had similar difficulties and, therefore, unaltered cortisol levels might reflect their efforts to remain awake.

Our fourth hypothesis was that there would be an improvement in sleep quality after an 8-week course of MBSR, and our data fully supported this prediction. Therefore, our data fit well with previous research showing a favorable effect of MBSR on sleep [29, 30, 57]. At the same time, our data are at odds with those studies showing no association between mindfulness and sleep [29, for an overview, see 30]. Most importantly, favorable sleep was strongly associated with greater self-attribution of mindfulness among both long-term and novice meditators. Following a cognitive-emotional model of insomnia [25] and the hyperarousal hypothesis [58], dysfunctional thoughts are considered the main cause of sleep disturbances, and our pattern of results suggest that mindfulness counteracts dysfunctional thoughts underlying poor sleep. We did not directly assess dysfunctional thoughts. However, though speculative, we would suggest a direct influence of MBSR on dysfunctional thoughts for the following reason. Dysfunctional thoughts impairing sleep normally focus on stress, ruminating about unresolved problems, and self-concerns [25, 58]. MBSR, among other effects, encourages perception of feelings and emotions without having to react to them, accepting oneself as one is, remaining positively disposed towards oneself when things go wrong, and experiencing moments of inner peace. Therefore, it seems highly conceivable that MBSR improves sleep via improved self-acceptance, reduced perceived stress and reduced stress response.

Our fifth and last hypothesis was that there would be an association between poor sleep quality and increased HPA SA [37, 38], but no such association was found. The reasons remain unclear, though there are two possible explanations. First, the small sample size may have provided insufficient statistical power for the pattern of results anticipated. Second, the association between poor sleep

quality and increased HPA SA has been observed in samples with quite particular kinds of participants. Buckley and Schatzberg [38] and Steiger [37] reported results from psychiatric patients, Hatzinger et al. [31, 32] compared preschoolers classified as poor and very good sleepers, and Brand et al. [35] investigated infants suffering from colic. It is therefore conceivable that, among healthy adults, variations in HPA SA and sleep are too small to allow emergence of the clear-cut pattern observed elsewhere.

To summarize, the strength of the present study is that we applied a design combining a cross-sectional and a longitudinal approach. This resulted in an assessment of CAR both in long-term meditators and in novices before and after an MBSR course. An additional strength is the concomitant assessment of sleep with HPA axis activity.

Despite the new findings, several considerations warrant against generalization, and these data should be interpreted cautiously. First, the sample size is very small, though the effect sizes reported here are independent of sample size. However, it is entirely possible that additional significant results would have emerged with a larger sample. Second, data may potentially be biased because only persons who were willing and able to give saliva samples volunteered to participate in the study. This may be particularly true since the sample itself reflects a high degree of self-selection. However, as Chiesa and Serretti [1] state, this limitation holds for virtually every piece of research in the field of mindfulness techniques and meditation. Third, since meditation sessions took place exclusively during afternoons when diurnal variation in cortisol secretion normally decreases, non-significant pre- to post-meditation differences might be due to floor effects. Consequently, further studies should assess cortisol secretion in the morning when HPA SA is close to its zenith. Fourth, only healthy adults were assessed; therefore, it remains unclear to what extent the pattern of results also holds for patients suffering from physical diseases and psychiatric disorders. Fifth, sleep was only subjectively, and not objectively, assessed, and it would be particularly interesting to examine the influence of mindfulness training both on sleep continuity and sleep architecture, as assessed by sleep EEG. Sixth, the tool to assess mindfulness (i.e. the Freiburg Mindfulness Inventory [40]) may cover both the construct 'mindfulness' as a whole, and the dimensions 'presence' and 'acceptance'. We did not perform further statistical analyses focusing on 'presence' and 'acceptance', nor did we apply alternative assessment tools, thus possibly precluding the emergence of further patterns of results. Last, since no comparable control group was included in the study, strictly speaking it remains unclear whether CAR was reduced specifically by mindfulness training.

Conclusion

For healthy adults, both long- and short-term experience of meditation significantly reduces HPA SA as assessed by salivary CAR. Moreover, meditation is associated with better sleep and higher scores for mindfulness; this holds for both long-term and novice meditators. As an overall consequence, future research should focus on four issues: replicating the present findings, increasing sample sizes, introducing control groups and assessing sleep objectively.

Acknowledgements

We thank Nick Emler (Surrey, UK) for proofreading the manuscript, and the staff of the CortLab in Trier (Germany) for salivary cortisol analyses.

Disclosure Statement

All authors declare no conflicts of interest.

References

1 Chiesa A, Serretti A: Mindfulness based cognitive therapy for psychiatric disorders: a systematic review and meta-analysis. Psychiatry Res 2011;187:441–453.

2 Chiesa A, Serretti A: A systematic review of neurobiological and clinical features of mindfulness meditations. Psychol Med 2010; 40:1239–1252.

3 Grossman P, Niemann L, Schmidt S, Walach H: Mindfulness-based stress reduction and health benefits: a meta-analysis. J Psychosom Res 2004;57:35–43.

4 Meibert P, Michalak J, Heidenreich T: Achtsamkeitsbasierte Stressreduktion – Mindfulness-Based Stress Reduction (MBSR) nach Kabat-Zinn; in Heidenreich T, Michalak J (eds): Achtsamkeit und Akzeptanz in der Psychotherapie. Tübingen, dgvt, 2004, pp 141–191.

5 Kesper-Grossmann U, Grossmann P: Heilung von innen – Achtsamkeitsmeditation als Medizin. Freiburg, Arbor, 2002.

6 Kabat-Zinn J: Mindfulness meditation: health benefits of an ancient Buddhist practice; in Goleman D, Gurin J (eds): Mind/Body Medicine. New York, Consumer Report Books, pp 259–275.
7 Segal ZV, Williams JMG, Teasdale JD: Mindfulness-Based Cognitive Therapy for Depression: A New Approach to Preventive Relapse. New York, Guilford Press, 2002.
8 Linehan M: Cognitive-Behavioral Treatment of Borderline Personality Disorder. New York, Guilford Press, 2003.
9 Kostanski M, Hassed C: Mindfulness as a concept and a process. Aust Psychol 2008;43:15–21.
10 Kang C, Whittingham K: Mindfulness: a dialogue between Buddhism and clinical psychology. Mindfulness 2010;1:161–173.
11 Grossman P, Kappos L, Gensicke H, D'Souza M, Mohr DC, Penner IK, Steiner C: MS quality of life, depression, and fatigue improve after mindfulness training: a randomized trial. Neurology 2010;75:1141–1149.
12 Segal ZV, Bieling P, Young T, MacQueen G, Cooke R, Martin L, Bloch R, Levitan RD: Antidepressant monotherapy vs sequential pharmacotherapy and Mindfulness-Based Cognitive Therapy, or placebo, for relapse prophylaxis in recurrent depression. Arch Gen Psychiatry 2010;67:1256–1264.
13 Harnett Ph, Whittingham K, Puhakka E, Hodges J, Spry C, Dob R: The short-term impact of a brief group-based mindfulness therapy program on depression and life satisfaction. Mindfulness 2010;1:183–188.
14 Chiesa A, Malinowski P: Mindfulness-based approaches: are they all the same? J Clin Psychol 2011;67:404–424.
15 Ott U, Gard T, Hempel H, Weygandt M, Morgen K, Vaitl D: Investigation of mindfulness meditation practitioners with voxel-based morphometry. Soc Cogn Affect Neurosci 2008;3:55–61.
16 Hölzel BK, Carmody J, Evans KC, Hoge EA, Dusek JA, Morgan L, Pitman RK, Lazar SW: Stress reduction correlates with structural changes in the amygdala. Soc Cogn Affect Neurosci 2010;5:11–17.
17 Matousek RH, Dobkin PL, Pruessner J: Cortisol as a marker for improvement in mindfulness-based stress reduction. Complement Ther Clin Pract 2010;16:13–19.
18 Carlson LE, Speca M, Faris P, Patel KD: 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 Behav Immun 2007;21:1038–1049.
19 Marcus MT, Fine PM, Moeller FG, Khan MM, Pitts K, Swank PR: Change in stress levels following mindfulness-based stress reduction in a therapeutic community. Addict Disord Their Treat 2003;2:63–68.
20 Galantino ML, Baime M, Maguire M, Szapary P, Farrar JT: Association of psychological and physiological measures of stress in health-care professionals during an 8-week mindfulness meditation program: mindfulness in practice. Stress Health 2005;21:255–261.
21 Klatt MD, Buckworth J, Malarkey WB: Effects of low-dose mindfulness-based stress reduction (MBSR-ld) on working adults. Health Educ Behav 2009;36:601–614.
22 Robinson FP, Mathews HL, Witek-Janusek L: Psycho-endocrine-immune response to mindfulness-based stress reduction in individuals infected with the human immunodeficiency virus: a quasiexperimental study. J Altern Complement Med 2003;9:683–694.
23 Robert McComb JJ, Tacon A, Randolph P, Caldera Y: A pilot study to examine the effects of a mindfulness-based stress-reduction and relaxation program on levels of stress hormones, physical functioning, and submaximal exercise responses. J Altern Complement Med 2004;10:819–827.
24 Matousek RH, Pruessner JC, Dobkin PL: Changes in the cortisol awakening response (CAR) following participation in Mindfulness-Based Stress Reduction in women who completed treatment for breast cancer. Complement Ther Clin Pract 2011;17:65–70.
25 Harvey AG: Pre-sleep cognitive activity: a comparison of sleep-onset insomniacs and good sleepers. Br J Clin Psychol 2000;39:275–286.
26 Shapiro SL, Bootzin RR, Figueredo AJ, Lopez AM, Schwartz GE: The efficacy of mindfulness-based stress reduction in the treatment of sleep disturbance in women with breast cancer: an exploratory study. J Psychosom Res 2003;54:85–91.
27 Heidenreich T, Tuin I, Pflug B, Michal M, Michalak J: Mindfulness-based cognitive therapy for persistent insomnia: a pilot study. Psychother Psychosom 2006;75:188–189.
28 Howell AJ, Digdon NL, Buro K, Sheptycki AR: Relations among mindfulness, well-being, and sleep. Pers Individ Dif 2008;45:773–777.
29 Winbush NY, Gross CR, Kreitzer MJ: The effects of mindfulness-based stress reduction on sleep disturbance: a systematic review. Explore 2007;3:585–591.
30 Ong J, Sholtes D: A mindfulness-based approach to the treatment of insomnia. J Clin Psychol 2010;66:1175–1184.
31 Hatzinger M, Brand S, Perren S, Stadelmann S, Von Wyl A, Von Klitzing K, Holsboer-Trachsler E: Electroencephalographic sleep profiles and hypothalamic-pituitary-adrenocortical (HPA) activity in kindergarten children: early indication of poor sleep quality associated with increased cortisol secretion. J Psychiatr Res 2008;42:352–543.
32 Hatzinger M, Brand S, Perren S, Von Wyl A, Von Klitzing K, Holsboer-Trachsler E: Sleep actigraphy pattern and behavioral/emotional difficulties in kindergarten children: association with hypothalamic-pituitary-adrenocortical (HPA) activity. J Psychiatr Res 2010;44:253–261.
33 Capaldi VF, Handwerger K, Richardson E, Stroud LR: Associations between sleep and cortisol responses to stress in children and adolescents: a pilot study. Behav Sleep Med 2005;3:177–192.
34 Friess E, Schmid D, Modell S, Brunner H, Lauer CJ, Holsboer F, Ising M: Dex/CRH-test response and sleep in depressed patients and healthy controls with and without vulnerability for affective disorders. J Psychiatr Res 2008;42:1154–1162.
35 Brand S, Furlano R, Sidler M, Schulz J, Holsboer-Trachsler E: 'Oh, Baby, please don't cry!' In infants suffering from infantile colic hypothalamic-pituitary-adrenocortical (HPA) axis activity is related to poor sleep and increased crying intensity. Neuropsychobiology 2011;64:15–23.
36 Hatzinger M, Hemmeter UM, Brand S, Ising M, Holsboer-Trachsler E: Electroencephalographic sleep profiles in treatment course and long-term outcome of major depression: association with DEX/CRH-test response. J Psychiatr Res 2004;38:453–465.
37 Steiger A: Neurochemical regulation of sleep. J Psychiatr Res 2007;41:537–552.
38 Buckley TM, Schatzberg AF: On the interactions of the hypothalamic-pituitary-adrenal (HPA) axis and sleep: normal HPA axis activity and circadian rhythm, exemplary sleep disorders. J Clin Endocrinol Metab 2005;90:3106–3114.
39 Ackenheil M, Stotz G, Dietz-Bauer R, Vossen A: Mini International Neuropsychiatric Interview. München, Psychiatrische Universitätsklinik, 1999.
40 Walach H, Buchheld N, Buttenmüller V, Kleinknecht N, Schmidt S: Measuring mindfulness – The Freiburg Mindfulness Inventory (FMI). Pers Individ Dif 2006;40:1543–1555.
41 Reynolds CF, Monk TH, Berman SR, Kupfer DJ: The Pittsburgh Sleep Quality Index: a new instrument for psychiatric practice and research. Psychiatry Res 1989;28:193–213.
42 Hellhammer DH, Wüst S, Kudielka BM: Salivary cortisol as a biomarker in stress research. Psychoneuroendocrinology 2009;34:163–171.
43 Pruessner JC, Wolf OT, Hellhammer H, Buske-Kirschbaum A, von Auer K, Jobst S, Kaspers F, Kirschbaum C: Free cortisol levels after awakening: a reliable biological marker for the assessment of adrenocortical activity. Life Sci 1997;61:2539–2549.

44 Clow A, Thorn L, Evans P, Hucklebridge F: The awakening cortisol response: methodological issues and significance. Stress 2004; 7:29–37.
45 Dressendoerfer RA, Kirschbaum C, Rohde W, Stahl F, Strasburger CJ: Synthesis of a cortisol-biotin conjugate and evaluation as a tracer in an immunoassay for salivary cortisol measurement. J Ster Biochem Mol Biol 1992;43:683–692.
46 Forsythe AI, Keenan TA, Organick EI, Stenberg W: Computer Science: A First Course. New York, Wiley, 1969.
47 Hatzinger M, Brand S, Perren S, von Wyl A, von Klitzing K, Holsboer-Trachsler E: Hypothalamic-pituitary-adrenocortical (HPA) activity in kindergarten children: importance of gender and associations with behavioral/emotional difficulties. J Psychiatr Res 2007;41:861–870.
48 Heuser I, Yassouridis A, Holsboer F: The combined dexamethasone/CRH test: a refined laboratory test for psychiatric disorders. J Psychiatr Res 1994;28:341–356.
49 Welch BL: The generalization of 'Student's' problem when several different population variances are involved. Biometrika 1947;34: 28–35.
50 Scheffé H: Practical solutions to the Behrens-Fisher problem. J Am Stat Assoc 1970;65: 1501–1508.
51 Cohen J: Statistical Power Analysis for the Behavioral Sciences, ed 2. Hillsdale, Lawrence Erlbaum Associates, 1988.
52 Cohen J: A power primer. Psychol Bull 1992; 112:155–159.
53 Cohen J: The earth is round ($p < 0.05$). Am Psychol 1994;49:997–1003.
54 Weitzman ED, Fukushima D, Negeire C, Roffwarg H, Gallagher TF, Hellman L. Twenty-four hour pattern of episodic secretion of cortisol in normal subjects. J Clin Endocrinol Metab 1971;33:14–22.
55 Petermann F, Vaitl D: Introduction to relaxation; in Petermann F, Vaitl D (eds): Entspannungsverfahren – Das Praxishandbuch Practical introdution to methods of relaxation, ed 4. Weinheim, Beltz/PVU, 2004.
56 Cahn BR, Polich J: Meditation states and traits: EEG, ERP, and neuroimaging studies. Psychol Bull 2006;132:180–210.
57 Schmidt S, Grossman P, Schwarzer B, Jena S, Naumann J, Walach H: Treating fibromyalgia with mindfulness-based stress reduction: results from a 3-armed randomized controlled trial. Pain 2011;152:361–369.
58 Riemann D, Spiegelhalder K, Feige B, Voderholzer U, Berger M, Perlis M, Nissen C: The hyperarousal model of insomnia: a review of the concept and its evidence. Sleep Med Rev 2010;14:19–31.