Polysomnographic and Subjective Profiles of Sleep Continuity Before and After Mindfulness-Based Cognitive Therapy in Partially Remitted Depression

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Objectives: To examine whether mindfulness meditation (MM) was associated with changes in objectively measured polysomnographic (PSG) sleep profiles and to relate changes in PSG sleep to subjectively reported changes in sleep and depression within the context of a randomized controlled trial. Previous studies have indicated that mindfulness and other forms of meditation training are associated with improvements in sleep quality. However, none of these studies used objective PSG sleep recordings within longitudinal randomized controlled trials of naïve subjects. **Methods:** Twenty-six individuals with partially remitted depression were randomized into an 8-week Mindfulness-Based Cognitive Therapy (MBCT) course or a waitlist control condition. Pre-post measurements included PSG sleep studies and subjectively reported sleep and depression symptoms. **Results:** According to PSG sleep, MM practice was associated with several indices of increased cortical arousal, including more awakenings and stage 1 sleep and less slow-wave sleep relative to controls, in proportion to amount of MM practice. According to sleep diaries, subjectively reported sleep improved post MBCT but not above and beyond controls. Beck Depression Inventory scores decreased more in the MBCT group than controls. Improvements in depression were associated with increased subjective sleep continuity and increased PSG arousal. **Conclusions:** MM is associated with increases in objectively measured arousal during sleep with simultaneous improvements in subjectively reported sleep quality and mood disturbance. This pattern is similar to the profiles of positive responders to common antidepressant medications. **Key words:** Mindfulness-Based Cognitive Therapy, meditation, sleep, arousal, depression.

BDI = Beck Depression Inventory; **EEG** = electroencephalogram; **EMG** = electromyogram; **EOG** = electrooculogram; **HRSD** = Hamilton Rating Scale for Depression; **MBCT** = Mindfulness-Based Cognitive Therapy; **MM** = mindfulness meditation; **NWAK** = number of awakenings; **PSG** = polysomnograph; **RCT** = randomized controlled trial; **REM** = rapid eye movement; **SE** = sleep efficiency; **SOL** = sleep onset latency; **SWS** = slow-wave sleep; **TIB** = time in bed; **TST** = total sleep time; **WASO** = wake after sleep onset.

INTRODUCTION

Mindfulness meditation (MM) training has been associated with improvements in depression symptoms in clinical and nonclinical populations, as well as reductions in the likelihood of relapse and recurrence in individuals with recurrent forms of depression (1–11). MM training has also been associated with improvements in sleep quality, at least by subjective accounts (12–16). Residual sleep disturbance maintains depressive episodes and increases risk for relapse and, therefore, may be the mechanism by which MM improves depression and decreases risk for relapse. However, prior research of meditation effects on sleep has been thwarted by two methodological limitations. First, longitudinal intervention studies have relied on subjective self-reports rather than objective measures of sleep, such as polysomnography (PSG), the "gold standard" of sleep measurement. The few studies that have employed PSG measures of sleep have used cross-sectional designs of experienced meditators rather than longitudinal or randomized controlled trial (RCT) designs in meditation naïve subjects. Second, improvement in sleep quality following MM training has only been found in uncontrolled studies (12–16), although the effect has not been replicated within the context of several RCTs (17–19). Thus, the primary aim of the current study was to address these methodological weaknesses by investigating the effects of mindfulness training on 1) objective laboratory-based PSG measurements of sleep in meditation-naïve individuals with residual sleep complaints at risk for depressive relapse; and 2) within the context of an RCT.

Sleep continuity disturbances are concomitant, prodromal, and residual symptoms of major depression and can be manifested by increased sleep onset latency (initiation insomnia), frequent awakenings, arousals, or increased wake after sleep onset (maintenance insomnia), as well as by increased light sleep (stage 1), less deep sleep (slow-wave sleep [SWS], sleep stages 3 and 4), or a subjective feeling of restlessness or feeling of waking unrefreshed (20–23).

Although sleep disturbances often coincide with or precipitate depressive symptomatology and subside on remission (24), there is evidence that these disturbances may continue to linger despite clinical improvement and are associated with perpetuating mood disturbance and increasing risk for relapse (25–27). Therefore, the treatment of residual sleep abnormalities during partial remission in individuals with a chronic history of depression may be an important step in both decreasing current depression and preventing relapse and recurrence. MM is particularly relevant to sleep-related disorders, because it serves the dual functions of reducing sympathetic hyperarousal (28–30) and decreasing negative emotional states, such as anxiety, stress, depression, worry, and rumination (9,31–36), which are commonly associated with insomnia (37).

In the present study, we investigated the effects of an 8-week course of Mindfulness-Based Cognitive Therapy

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Received for publication July 22, 2009; revision received February 2, 2010.

This study was conducted as part of Willoughby Britton's doctoral dissertation.

This research was supported, in part, by Grants T32-AT001287, MH067553-05 from the National Institutes of Health, the Mind and Life Institute, the American Association for University Women grant, and the Social and Behavioral Sciences Research Institute (W.B.B.).

This was not an industry supported study. The authors have indicated no financial conflicts of interest.

DOI: 10.1097/PSY.0b013e3181dc1bad

0033-3174/10/7205-0001

(MBCT) on both self-reported and objectively measured PSG sleep profiles in individuals with partially remitted chronic depression with some residual sleep complaints. Based on previous reports of improved sleep quality after meditation, we predicted that MBCT would be associated with 1) improved sleep continuity, as manifested by a decrease in a) sleep onset latency (SOL); b) awakenings and arousals; c) wake after sleep onset (WASO); and d) an increase in sleep efficiency; and 2) deeper sleep, as manifested by a) decreased stage 1 sleep; and b) increased SWS.

To more closely investigate the potential relationship between sleep and MM, we used minutes of daily MM practice in addition to treatment group assignment in our analyses. To imbed the findings within the context of clinical utility, we also examined the relationships between treatment assignment, MM practice minutes, sleep changes (both objective and subjective), and Beck Depression Inventory (BDI) scores.

MATERIALS AND METHODS

Participants

Participants were recruited through community advertisements for a meditation-based depression-relapse prevention program. A Structured Clinical Interview for Axis I (SCID-I) and Axis II (SCID-II) Disorders, the BDI, and the Hamilton Rating Scale for Depression (HRSD-24) were administered to determine current diagnostic status. The target population was antidepressant-free individuals with a partially remitted, recurrent form of unipolar depression with residual sleep complaints. Participants met the *Diagnostic and Statistical Manual of Mental Disorders, Fourth Edition* criteria for major depression in the last 60 months and had a lifetime history of at least three episodes but were in full or partial remission during the last 8 weeks with varying degree of residual symptoms. Partial remission was defined by a subjectively reported improvement in symptoms in the last 2 months, an HRSD (Hamilton, 1960) score of $\leq$20 and the exclusion of individuals with severely depressed mood (Hamilton or BDI item #1 $>$2), severe anhedonia (Hamilton item #7 $>$3, BDI item #4 $>$2) or active suicidal ideation (Hamilton item #3 $>$2, BDI item #9 $>$1). In addition, all eligible participants reported difficulties with either sleep initiation ($>$30 minutes SOL); sleep maintenance (restless/nonrestorative sleep 2 nights/week), or early awakening (2 mornings/week), but not hypersomnia in the last 2 months.

Participants were excluded if a) they had a history of bipolar disorder, cyclothymia, schizophrenia, schizoaffective disorder, persistent antisocial behavior, or repeated self-harm, borderline personality disorder, organic brain damage; b) current panic, obsessive-compulsive disorder, eating disorder, or substance abuse/dependence; c) they could not read and write in English; d) they were receiving current psychotherapy; e) they already had a regular meditation practice; or f) they had taken antidepressant medication in the last 3 months. Participants were also excluded if they had or suspected an untreated sleep disorder besides insomnia. Two participants with suspected sleep disorders underwent independent PSG screenings with negative results and were allowed to enroll. The study protocol was approved by the University of Arizona Institution Review Board, and all participants provided their written informed consent for research participation. No adverse events occurred during the trial.

Design

Participants completed 3 weeks of sleep diaries and pretreatment questionnaires before baseline assessments in the laboratory. After completion of the adaptation night and baseline assessment in the sleep laboratory, a block randomization procedure was used to assign each block of five participants to the MBCT program or waitlist control condition in a 3:2 ratio (using sealed envelopes) without reference (stratification) to baseline characteristics. All baseline assessments were conducted before randomization; therefore, all participants and research personnel were blind to treatment conditions during this phase of the project. Research personnel who collected any postbaseline data also were blind to treatment conditions. After 8 weeks of treatment or waitlist condition, participants completed a posttreatment questionnaire packet and returned to the laboratory to repeat the study-night procedure (no posttreatment adaptation night). Participants also completed daily sleep diaries for the duration of the treatment or waitlist condition. Waitlisted subjects entered the next available wave of the MBCT program, after completing the second assessment. The experiments were conducted between May 2004 and December 2005 at the Department of Psychology, University of Arizona, Tucson, Arizona.

Measures

Pre- and Posttreatment Assessments

Participants underwent an adaptation night in the sleep laboratory and returned within 1 week for a "study night." Sleep studies were scheduled according to average diary bedtimes and wake times. Participants were asked to abstain from alcohol, caffeine, and other substances that may interfere with sleep for 24 hours before the study. In addition, they were asked to refrain from vigorous exercise within 2 hours of arrival to the study night, to avoid scheduling either appointment after an anticipated stressor (like an examination), and not to alter their regular sleep schedule or take naps the day of the study.

PSG/Electroencephalography (EEG)

In the sleep laboratory, scalp electrodes were applied according to the International 10–20 system at all 19 standard placements as well as reference electrodes placed between Cz and Pz and at the mastoids, A1 and A2. Eye movements (electrooculogram [EOG]) were recorded with electrodes placed at the lower left outer canthus, and upper right outer canthus. Muscle activity (electromyogram [EMG]) was recorded with three electrodes placed on the mentalis and submentalis muscles of the chin. Maximal electrical impedance at bedtime was set at 5 K ohms. All scalp electrodes were referred to a reference electrode that made alternative montages possible offline. All physiological measurements were recorded into the 32-channel AC amplifier system (Grass Polysomnograph, Aurora Model and Twin 3.2 Software, Grass Instrument Division, Astro-Med, Inc., West Warwick, Rhode Island). After biological calibrations, participants were allowed to read until they asked for lights out. Each subject was allowed to sleep ad libitum from their usual bedtime and was continuously monitored by video camera.

Sleep Parameters

Each record was scored in 30-second epochs according to Rechtschaffen and Kales (38) standard sleep stage scoring guidelines from four scalp electrodes, C3/C4, O1/O2, EOG, and EMG. Records were scored by a registered polysomnographic sleep technician, who had an interrater reliability of $>$0.90 with other registered polysomnographic sleep technicians and who had no knowledge of diagnostic status, treatment group, or treatment phase. Interrater reliability for a subset of sleep records in this study was $>$0.95. Sleep stages were calculated into minutes of each stage and a number of other sleep parameters. Sleep onset was defined by the first epoch of any stage of sleep. SOL refers to the time between lights out and sleep onset. Sleep efficiency (SE) is the ratio of total sleep time (TST) to total record time, or time in bed (TIB) from lights out until the final awakening. Arousals were visually scored according to the American Sleep Disorders Association scoring rules (39) and were defined as an abrupt (upward) shift in EEG frequency (including theta, alpha and/or beta frequencies, but not spindles), lasting at least 3 seconds. Ten seconds of sleep must precede the arousal, and an increase in chin EMG must be present if the arousal occurs in rapid eye movement (REM) sleep. Awakenings were defined as two consecutive epochs (i.e., 1 continuous minute) scored as wake ($>$50% or 15 seconds of EEG in the alpha 8–12 Hz range). Because of the focus on sleep continuity, investigations involving REM sleep were beyond the scope of this paper.

Depression

The Beck Depression Inventory (BDI) (40) is a 21-item self-report measure that assesses depressive symptomatology, with an emphasis on cognitive symptoms. The BDI is a widely used measure of depressive symptoms and has excellent psychometric properties (41). Sleep-related items on the BDI

were omitted for correlations with sleep variables but otherwise were retained to convey overall clinical significance. The BDI had an internal consistency coefficient of 0.81 before treatment and 0.90 at posttreatment.

The HRSD-24 is a widely used clinician-administered interview assessment of depressive symptomatology. A modified 31-item version was used (42), although reported HRSD scores are based on the 24-item version. The HRSD and diagnostic interviews were conducted by the first author who was trained in administering the HSRD until an adequate level of reliability (>0.90) with other raters of the same version was achieved. The HRSD-24 had an internal consistency coefficient of 0.77. Because the trained interviewer for the HRSD was also the study therapist and, therefore, would not have been blind to treatment allocation during posttreatment assessments, the BDI and not the HRSD was used for the posttreatment assessment of depressive symptoms.

Sleep Diaries

Estimates of sleep parameters from sleep diaries have been found to be reliable and valid in adults with insomnia (43). Participants kept track of their sleep for a 3-week baseline and for the 9 weeks of the treatment phase. Weekly averages at baseline and posttreatment were used in the analyses with a minimum of 3 days/week of valid data for inclusion. Each morning, the participant recorded a) the number of hours slept (TST); b) the time spent in bed (TIB); c) SOL; d) number of perceived awakenings (NWAK); e) number of minutes awake at each awakening; and f) subjective sleep quality rating. The diary data were then used to calculate sleep efficiency (TST/TIB), and WASO (number of awakenings × minutes of each awakening).

Meditation Practice Logs

Participants in the MBCT group kept track of their daily MM practice during the 8 weeks of active treatment. Diaries included information about formal MM practice, including: a) the type of meditation (body scan, breath awareness, etc.); b) the number of minutes practiced; c) whether they fell asleep during practice; d) use of CD/tape; and e) informal practice (walking, mindful activities). Logs for the preceding week were collected at each class meeting.

Treatment

MBCT is an 8-week group intervention with a psychoeducational and client-centered format (44). Participants attended weekly 3-hour sessions and an all-day silent retreat during the 6th week for a total of nine sessions. Sessions focused on cultivating mindfulness or nonjudgmental present-moment awareness of mental content and everyday activities, including sitting, lying down, breathing, walking, and other simple movements. Homework assignments consisted of practicing MM exercises with the aid of a guided audio CD and completing worksheets related to stress, automatic thoughts, and common reactions to various types of events. A session-by-session description with handouts and homework assignments is available in the MBCT manual (44). The intervention was explicitly aimed at depression symptoms/relapse prevention and not improvement in sleep. Sessions were instructed by the first author, who received extensive training in delivery of the program through the Center for Mindfulness Mindfulness-Based Stress Reduction (MBSR) Instructor Certification Program at the University of Massachusetts Medical School, and through MBCT training with Dr. Zindel Segal, the first author of the MBCT manual. Sessions were taped and supervised by two licensed clinical psychologists.

Statistical Analysis

Before analysis, all variables were examined for outliers, and any outlying cases were excluded from analysis if they had significant influence on the results (as assessed by Cook's Distance scores). Preliminary analyses were used to describe baseline characteristics, severity of sleep disturbance, patient flow/adherence and to investigate any baseline group differences that might affect the main analyses.

The main analyses investigated the effect of treatment on sleep quality, according to two different methods of data collection: overnight PSG recordings (objective laboratory measurement) and sleep diaries (subjective reports). In the main analyses, we conducted separate two-way repeated-measures analyses of variance to examine changes in PSG and diary sleep variables from baseline to posttreatment. PSG sleep variables were two-level within-subject variables (pre, post) variables and consisted of TIB, TST, SE, NWAK, number of arousals, WASO, SOL, stage 1 minutes, and SWS minutes. Diary sleep variables consisted of self-reported TIB, TST, SE, NWAK, WASO, SOL, and subjective quality rating that were the averaged daily entries for the weeks before and after treatment. The between-subjects variable was treatment (MBCT, control). Data were analyzed, using SPSS 14.0 software (SPSS Inc., Chicago, Illinois). Statistical significance was set at α levels <0.05, two-tailed. Because of the exploratory nature of the study and the small sample size, all trends ($p < .10$) that related to main predictions and were associated with large effect sizes (partial η^2 [η_p^2] > 0.14) were reported in order to identify patterns in data that warrant future investigation and reduce Type II error rates. Results are reported as mean ± standard deviation or number/percentage, unless otherwise indicated. Effect sizes were reported as (η_p^2, small = 0.01; medium = 0.06; large = 0.14) (45).

Follow-up analyses used Pearson product moment correlation coefficients to examine the relationships between the amount of MM practice, changes in PSG and diary sleep, and changes in depression scores.

RESULTS

Preliminary Analyses

Participant Flow

Twenty-six individuals completed baseline assessment and randomization procedures (14 MBCT, 12 controls) and five dropped out once enrolled (1 MBCT, 4 controls), so that a total of 21 participants completed the 8-week protocol (13 MBCT, 8 controls). One participant was excluded from analysis because of illness during posttreatment laboratory assessment, so that complete data from all time points were available from 20 participants (12 MBCT, 8 controls).

Treatment Attendance and Adherence

Of the 14 MBCT participants, one dropped out after the second class. Of the remaining 13, eight attended all of the nine sessions, four attended eight sessions, one attended seven sessions, and all attended the all-day retreat. Outside of class, the 13 completers engaged in formal MM practice an average of 39.4 ± 12 minutes/day, 5.4 ± 0.77 days/week. According to the goal of 45 minutes/day, 6 days/week of formal MM practice (270 minutes/week = 100%), the mean adherence across all weeks was 78 ± 22% with a range of 131 minutes/week to 308 minutes/week.

Baseline Characteristics

Participants ($n = 26$, 20 female) had a mean age of 47.7 ± 7.6 years (range, 33–64 years). Months of previous depression ranged from 12 to 180 (mean, 60.1 ± 39.6 months). Approximately half of the participants in each group were in remission (as defined by a BDI score of <10) (46). There were no significant differences between treatment groups in age, gender, or duration of previous depression. Although there were no differences in baseline depression scores according to the BDI, controls had significantly higher Hamilton scores, which was caused by two individuals with pain conditions which may have elevated their Hamilton scores, although their BDI scores were <10. Groups did not differ on any diary or PSG sleep measure at baseline. Table 1 presents a summary by treatment group.

TABLE 1. Baseline Characteristics by Treatment Group and Completion Status

	Completers				All			
	MBCT	SD	CON	SD	MBCT	SD	CON	SD
n	13.0		8.0		14.0		12.0	
% female	69.2		87.5		71.4		83.3	
Age	45.4	7.1	48.1	9.6	46.0	7.3	49.8	8.0
BDI	10.3	6.2	8.1	4.8	10.0	6.6	8.9	4.3
dep months	61.1	42.6	62.0	44.6	60.5	41.0	59.6	39.7
% in remission	38.5		62.5		42.9		50.0	
% completers	92.8		66.7					

According to independent sample *t* tests for the whole sample and completers, there were no significant differences between treatment groups in age, BDI scores, or months of previous depression. Similarly, there were no differences in % female, % in remission, or % completers, according to Fisher's Exact Test.

MBCT = Mindfulness-Based Cognitive Therapy; SD = standard deviation; CON = waitlist control; BDI = Beck Depression Inventory; dep months = total number of months of previous depression across all episodes; remission = BDI score of <10.

Baseline Sleep Disturbance

All participants reported some level of residual sleep complaints at the initial screening, including trouble initiating sleep (SOL, >30 minutes, 53.8%), disturbed/nonrestorative (WASO, >30 minutes, 100%) or early morning awakening (>30 minutes before normal time, 65.4%) at least 2 nights/week during the month before the interview. According to sleep diaries, 34.7% of the sample met formal severity and frequency criteria for insomnia, defined as ≥31 minutes of WASO or SOL on ≥3 nights/week during the first week of baseline assessment (47). Seventy percent of the sample had average baseline diary sleep efficiencies <85%, a common cutoff for distinguishing good sleepers from those with insomnia (48). According to PSG, 52% had SEs of <85% (although 76% had PSG SEs of <90%), 68% had WASO ≥31 minutes, and 16% had SOLs ≥31 minutes. Reduced SWS, as defined by <8% of TST (49), was apparent in 88% of the original sample and 85% of completers.

Main Analyses: PSG Data

Repeated pre and post PSG sleep recordings revealed a consistent overall pattern of increased arousal, as demonstrated by increased awakenings, increased stage 1, and suppressed SWS in meditators relative to controls.

Awakenings and Stage 1

The MBCT group showed a marginally significant greater increase in awakenings [$F(1,18) = 3.36$, $p = .08$, $\eta_p^2 = 0.16$] and stage 1 minutes [$F(1,18) = 3.45$, $p = .08$, $\eta_p^2 = 0.16$] than controls. The MBCT group had significant increases in both awakenings [$t(11) = -2.3$, $p = .04$] and stage 1 minutes [$t(11) = -2.5$, $p = .02$], whereas the control had small nonsignificant decreases in both measures.

Slow-Wave Sleep

A significant main effect of time on minutes of SWS indicated general increase in SWS from pre- to posttreatment [$F(1,18) = 9.71$, $p = .006$, $\eta_p^2 = 0.35$]. Controls increased by an average of 13 minutes, whereas the MBCT group increased by less than a minute. A significant two-way (treatment × time) interaction revealed a suppression of SWS in meditators relative to controls [$F(1,18) = 8.75$, $p = .008$, $\eta_p^2 = 0.33$].

Other PSG Measures

As shown in Table 2, there was a main effect of time for SOL, but the effect was mostly carried by controls who decreased their mean SOL by 9 minutes, whereas the MBCT group decreased by 3 minutes. Table 2 also reports a trend-level treatment main effect for WASO minutes, although higher WASO in the MBCT group versus controls approached significance at posttreatment ($p = .08$) but not at baseline ($p = .22$). There was no effect of treatment, time, or treatment × time on TIB, TST, SE, or number of arousals.

Main Analyses: Sleep Diaries (Table 3)

Time Effects

There were significant main effects for time indicating increased SE [$F(1,18) = 17.4$, $p < .001$, $\eta_p^2 = 0.49$], increased TST [$F(1,18) = 9.75$, $p = .006$, $\eta_p^2 = 0.35$], decreased WASO [$F(1,18) = 9.87$, $p = .006$, $\eta_p^2 = 0.35$], decreased NWAK [$F(1,18) = 9.53$, $p = .006$, $\eta_p^2 = 0.34$], decreased SOL [$F(1,18) = 12.64$, $p = .002$], and trend toward improved subjective sleep quality [$F(1,18) = 3.7$, $p = .07$, $\eta_p^2 = 0.17$] across all participants.

Treatment × Time Interactions

There were no significant treatment effects or treatment × time interactions for diary-based sleep. Controls showed a trend toward a greater reduction in SOL than the MBCT group [$F(1,18) = 3.57$, $p = .08$, $\eta_p^2 = 0.17$]. Given the finding of increased PSG arousal within the MBCT group, it is worth noting that the MBCT group reported significant within-group decreases in diary-based indices of arousal, including SOL [$t(11) = -2.7$, $p = .03$], NWAK [$t(11) = -3.0$, $p = .01$] minutes of WASO, [$t(11) = -3.0$, $p = .02$] and SE [$t(11) = 4.1$, $p = .002$].

Depression Scores

There was a significant two-way (treatment × time) interaction for BDI scores, in which the MBCT group showed a larger decrease than controls over time [$F(1,19) = 7.0$, $p = .02$, $\eta_p^2 = 0.27$]. The MBCT group's mean BDI scores decreased from 10.1 ± 6.4 points by 6.0 ± 6.0 points to 4.1 ± 3.1 points [$t(11) = -3.5$, $p = .005$], whereas control BDI scores increased by 0.33 ± 4.5 points, $p = .83$.

Relationships Between MM Practice, Sleep, and Depression Scores

With both groups combined, there were no correlations between change in depression scores (with sleep items removed) and any subjective or objective sleep variables. There was also no relationship between change in BDI scores and

TABLE 2. Polysomnographic Sleep Data Pre- and Posttreatment

Variable	Treatment	Baseline		Posttreatment		ANOVA *F* Values		
		Mean	SD	Mean	SD	Treatment	Time	Treatment × Time
n	MBCT	12.0		12.0				
	CON	8.0		8.0				
TIB	MBCT	427.8	55.0	443.8	42.9	0.0	2.2	0.1
	CON	423.9	72.2	448.4	43.1			
TST	MBCT	356.8	86.9	372.4	49.1	0.6	1.5	0.1
	CON	370.9	70.0	396.6	50.6			
SE	MBCT	82.4	13.9	83.9	6.3	2.1	0.2	0.0
	CON	87.3	5.3	88.3	6.2			
SOL	MBCT	13.8	13.7	11.1	9.1	0.4	3.5#	1.0
	CON	14.2	15.6	5.3	3.6			
WASO	MBCT	54.1	39.0	59.1	29.0	3.8#	0.2	0.0
	CON	35.0	18.8	37.9	17.0			
NWAK	MBCT	24.2	10.2	36.6	14.0	0.5	1.8	3.4#
	CON	29.0	11.0	27.1	6.3			
Arousals	MBCT	73.1	30.2	96.7	25.7	0.7	1.1	1.6
	CON	95.9	46.5	93.5	35.8			
Stage 1 min	MBCT	24.5	6.3	34.3	13.9	0.1	1.8	3.5#
	CON	29.0	17.7	27.4	10.8			
SWS min	MBCT	13.0	11.7	13.3	13.2	1.4	9.7**	8.8**
	CON	13.8	12.3	26.6	18.7			

* $p < .05$; ** $p < .01$; *** $p < .005$; # $p < .10$; $\eta_p^2 > 0.14$.
ANOVA = analysis of variance; SD = standard deviation; MBCT = Mindfulness-Based Cognitive Therapy; CON = waitlist control; TIB = time in bed; TST = total sleep time (minutes); SE = sleep efficiency (%); SOL = sleep onset latency; WASO = wake after sleep onset (minutes); NWAK = number of awakenings; SWS = slow-wave sleep (minutes).

TABLE 3. Sleep Diary Data Pre- and Posttreatment

Variable	Condition	Baseline		Posttreatment		ANOVA *F* Values		
		Mean	SD	Mean	SD	Treatment	Time	Treatment × Time
n	MBCT	12.0		12.0				
	CON	8.0		8.0				
TIB	MBCT	480.9	51.1	477.8	36.6	1.4	0.1	0.3
	CON	501.4	69.5	508.9	58.0			
TST	MBCT	398.0	60.7	422.6	40.5	0.1	9.8**	0.3
	CON	400.1	54.9	433.6	49.1			
SE	MBCT	82.5	8.3	88.3	6.0	0.8	17.4***	0.0
	CON	80.1	6.4	85.5	6.9			
SOL	MBCT	14.1	4.6	9.8	5.2	2.4	12.6**	3.6#
	CON	23.1	15.5	8.9	4.1			
NWAK	MBCT	1.8	0.9	1.0	1.0	0.0	9.5**	0.4
	CON	1.7	0.9	1.2	0.9			
WASO	MBCT	26.0	32.2	10.5	17.3	0.5	9.9**	1.8
	CON	15.1	14.8	8.9	9.7			
Quality	MBCT	3.0	0.6	3.1	0.5	1.7	3.7#	2.3
	CON	2.5	0.5	3.0	0.3			

* $p < .05$; ** $p < .01$; *** $p < .005$; # $p < .10$; $\eta_p^2 > 0.14$.
ANOVA = analysis of variance; SD = standard deviation; MBCT = Mindfulness-Based Cognitive Therapy; CON = waitlist control; TIB = time in bed (minutes); TST = total sleep time (minutes); SE = sleep efficiency (%); SOL = sleep onset latency (minutes); NWAK = number of awakenings; WASO = wake after sleep onset (minutes).

MM practice in the MBCT group. Correlations between MM practice and changes in sleep and depression scores for the MBCT group ($n = 12$) are reported in Table 4.

MM Practice and PSG Sleep

Figures 1, 2, and 3 show correlations between MM practice and several indices of PSG sleep. MM practice amount was positively correlated with PSG arousals, awakenings and stage 1 minutes and negatively correlated with SWS percent. Thus, several indices of objectively measured PSG arousal/lighter sleep increased with MM practice amount in a linear, dose-dependent manner.

MM Practice and Diary Sleep

MM practice amount was negatively correlated with minutes of WASO so that higher amounts of MM were associated with subjective reports of less time spent awake at night.

TABLE 4. Pearson *r* Correlations Between MM Practice, and Changes in BDI Scores, PSG Sleep, Diary Sleep

	Sleep Change	MM Practice[a]	BDI
PSG	TIB	0.53#	−0.60*
	TST	0.26	−0.57#
	SE	0.10	−0.23
	SOL	0.04	0.40
	WASO	0.08	0.11
	NWAK	0.57*	−0.52*
	Arousals	0.59*	−0.65*
	Stage 1 min	0.80***	−0.63*
	SWS	−0.62*,[b]	0.33
Diary	TIB	−0.37	0.56#
	TST	−0.16	0.20
	SE	0.53#	−0.57#
	SOL	−0.18	0.27
	WASO	−0.61*	0.32
	NWAK	−0.14	0.61*
	Quality	0.02	−0.42

[a] Total cumulative number of formal practice minutes across 8 weeks, unless otherwise specified.
[b] MM practice frequency in average number of practice session per week; SWS refers to percent of total sleep time.
* $p < .05$; ** $p < .01$; *** $p < .005$; # $p < .10$.
MM = mindfulness meditation; BDI = Beck Depression Inventory score (sleep items removed); PSG = polysomnographically recorded sleep; TIB = time in bed; TST = total sleep time (minutes); SE = sleep efficiency (%); SOL = sleep onset latency (minutes); WASO = wake after sleep onset (minutes); NWAK = number of awakenings.

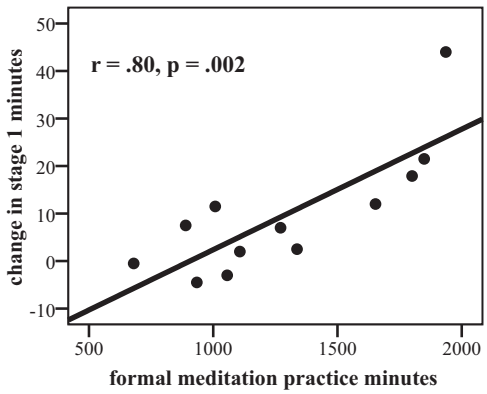

Figure 1. Pearson *r* correlation between total minutes of formal MM practice and change in stage 1 minutes in the MBCT group. MM = mindfulness meditation; MBCT = Mindfulness-Based Cognitive Therapy.

Sleep Changes and Depression Symptoms

Within the MBCT group, changes in BDI scores (with sleep-related items removed) were negatively correlated with changes in PSG awakenings, arousals, and stage 1 minutes so that improvements in depression were associated with increased arousal/awakenings, and stage 1 sleep. In terms of subjective (diary) sleep, changes in depression scores were positively associated with changes in the number of diary awakenings, so that improvements in depression scores were associated with fewer subjectively reported awakenings.

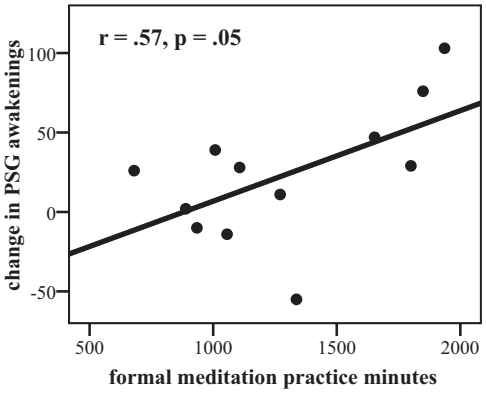

Figure 2. Pearson *r* correlation between total minutes of formal MM practice and change in combined PSG arousals and awakenings in the MBCT group. PSG = polysomnograph; MM = mindfulness meditation; MBCT = Mindfulness-Based Cognitive Therapy.

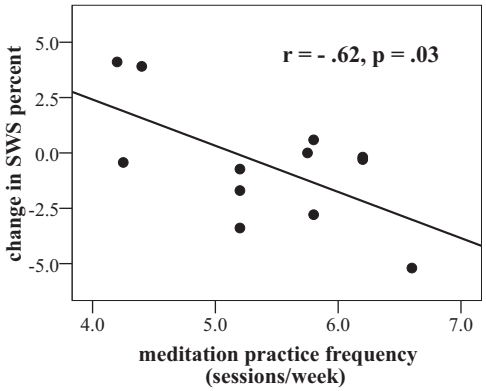

Figure 3. Pearson *r* correlation between frequency of formal MM practice (average number of practice sessions per week) and change in slow-wave-sleep (SWS) percent in the MBCT group. MM = mindfulness meditation; MBCT = Mindfulness-Based Cognitive Therapy.

DISCUSSION

The effects of MBCT on subjective and objective PSG sleep profiles were investigated in a group of partially remitted depressed individuals in the context of a randomized waitlist controlled trial. Marginally significant trends are discussed if they had large effect sizes. The main findings are the following:

1) Objective PSG sleep profiles following MBCT exhibited signs of increased arousal across several indices, including marginally significant increases in awakenings and stage 1 and a significant decrease in SWS relative to controls.
2) Improvements in subjectively reported sleep were found following MBCT but not over and above the control group.
3) The MBCT group had greater improvements in depression scores than controls; these improvements in depression were associated with increased PSG arousal but decreased self-reported arousal.
4) Amount of MM practice was correlated with increased PSG arousals, awakenings, stage 1 and decreased SWS, in a linear dose-dependent fashion.

Objective PSG Sleep

Contrary to predictions that MM would improve or deepen objectively measured sleep, several findings from this study suggest that mindfulness training had an arousing effect on PSG sleep profiles. First, the MBCT group exhibited a suppression of SWS compared with controls. Second, the MBCT group showed marginally significant increases in awakenings and stage 1 sleep from pre- to posttreatment than controls. Third, there was a significant positive correlation between the amount of MM practice and increases in arousals/awakenings and stage 1, and decreases in SWS.

One possible explanation for lighter sleep in meditators might be that the meditators are actually sleeping during meditation practice (50) and, therefore, may need less sleep or have lighter sleep at night. However, the reported frequency of falling asleep during meditation practice was positively correlated with increases in SWS, such that the more dozing during meditation (and, therefore, less meditation) was associated with deeper nighttime sleep ($r = 0.51$, $p = .09$). Another possible explanation, described by Lutz et al. (51), is that certain forms of contemplative training are traditionally thought to reduce the need for sleep (i.e., homeostatic sleep drive), particularly at "higher doses." Only a few empirical studies (52) can offer data about meditation-related changes in sleep propensity, which is typically measured by SWS, delta power, or daytime sleepiness. Reports of meditation-related effects on SWS are inconsistent and only available from research on experienced meditators. One cross-sectional study of PSG sleep in Transcendental Meditators (53) found less SWS minutes in both long-term (78 ± 43) and short-term meditators (77 ± 31) compared with nonmeditating controls (96 ± 40), but this difference was not statistically significant. In another cross-sectional study of Sudarshan Kriya Yoga (SKY) and Vipassana meditators, Sulekha et al. (54) found that SWS minutes were higher in middle-aged meditators (both SKY and Vipassana) than controls, but they found no differences for younger participants (age, 20–30 years). However, because all subjects with SE of $<85\%$ were excluded from analysis, the effect of subjects with more disrupted sleep is difficult to assess. A within-subjects study (55) of cyclic yoga postures versus supine rest in experienced practitioners also found an increase in SWS minutes, but it is unknown whether a movement-related increase in body temperature (similar to exercise) could be responsible for the subsequent increase in SWS. Because these reports only study PSG sleep in experienced meditators, it is unclear how they related to our findings in PSG sleep *changes* after MM training in naïve subjects.

A few studies have reported an association between meditation and decreased daytime sleepiness, which is also an indicator of sleep propensity. In two of the only meditation studies to use objective PSG measurement of sleep propensity, Elson et al. (56) and Banquet and Sailhan (57) found that meditators were more likely to remain awake and less likely to fall asleep (defined as stage 2 or delta EEG, respectively) than nonmeditator controls during a comparable period of relaxed wakefulness. In a recent study of experienced Vipassana meditators, meditation practice was associated with decreased drowsiness that was associated with decreased frontal delta power (58). Other studies have found a correlation between daily meditation practice amount and/or years of practice experience and lower levels of self-reported drowsiness (59) or feeling more "refreshed" after sleep (17). Other studies (60) cited correlations between increases in self-reported mindfulness questionnaires scores and decreased self-reported sleepiness and tiredness following MM training in insomniacs. Although a meditation-related decrease in sleep propensity has never been empirically demonstrated, these data together suggest that the possibility warrants further investigation.

Increase in Awakenings and Stage 1 Sleep

Marginally significant greater increases in visually scored awakenings and stage 1 minutes were found after MBCT than the control condition. To visually score an epoch as wake, at least 50% of the EEG must be in the alpha range (8–12 Hz). Stage 1 is characterized primarily by theta activity (4–7 Hz) but may also contain up to 50% alpha. Thus, although typically termed by their conventional sleep terms "awakenings" and "stage 1," both of these designations technically represent the appearance of EEG frequencies in the alpha and theta range. Different forms of meditation practices have been repeatedly found to induce acute (state) and long-lasting (trait) increases in alpha and theta power during wake (61) that also persist into nocturnal sleep, resulting in increased stage 1 and attenuating alterations of SWS (53,57). Thus, the neurophysiological EEG changes that accompany meditation during wake may persist beyond meditation and also alter the microarchitecture of sleep. Although the alpha-theta activity during stage 1 sleep and meditation may be distinguishable in terms of topographical scalp distribution and coherence levels (61), these differences are unlikely to be detected by visual sleep stage scoring from four electrode sites C3/C4, O1/O2. Thus, it is possible that what we have termed "increased awakenings" and "stage 1" are trait-like markers or alpha-theta EEG residues of meditation practice, rather than evidence of "disrupted" or "poor sleep." This possibility is further supported by the observation that MM practice amount and MBCT group assignment were associated with increases in stage 1 and NWAK and arousals, but not minutes of WASO, which would also include longer periods of "true wake" that are accompanied by behavioral manifestations (EMG, movement, etc).

Subjectively Reported Sleep

According to sleep diaries, MBCT effects on sleep replicated previous findings: MBCT was associated with statistically significant improvements in a number of subjectively reported sleep continuity indices, including SOL, NWAK, WASO, and SE. However, these improvements were not significant above and beyond those shown by waitlist controls. These findings are consistent with the conclusions by Winbush et al. (62): Improvements in subjectively reported sleep

following mindfulness training have been found in uncontrolled studies but disappear when a control group is added in the context of an RCT. This pattern of findings suggests, as echoed by Ong et al. (63), that "mindfulness meditation . . . might not have strong effects on sleep." Both groups filled out daily sleep diaries for 12 weeks, and repeated assessment is known to produce improvement in subjectively reported sleep (i.e., the Hawthorne Effect) (64) and, therefore, may underlie the improvement in diary sleep in both groups.

Depression and Sleep Changes

The MBCT group showed a greater reduction in depression symptoms than controls. Improvements in depression scores in this group were associated with increased objectively measured awakenings but decreased subjectively reported awakenings. Although we can only speculate on the meaning of these findings, it is worth noting that this paradoxical pattern of improved mood and subjective sleep quality with a concomitant increase in objectively measured arousal is common to patients who respond to antidepressant medications (65,66), which may suggest that mindfulness training may affect similar systems as antidepressant medications (i.e., monoamine neurotransmitters). Supporting the idea of a monoaminergic mechanism, several studies have suggested that some forms of meditation (either acutely after practice or chronically meditators versus controls) are associated with increases in norepinephrine, serotonin, and dopamine (67–72), which would have similar effects on sleep as antidepressants, i.e., an increase in cortical arousal and improvement in mood.

What are the clinical implications of meditation-related increases in neurophysiological arousal during sleep? At least in this case, meditation-related arousal in PSG sleep was associated with improvements in depressive symptoms. This finding is consistent with the antidepressant literature and with findings that sleep may be depressogenic (73) and that sleep deprivation has antidepressant effects (74). This finding is also consistent with findings that meditation practice increases dopamine (70) and that dopamine release is associated with the antidepressant effects of sleep deprivation (74).

Issues of Dosage and Types of Practice

There was a positive relationship between the amount of MM practice and several indices of PSG arousal. The arousing effects of MM practice were more evident at "higher doses," approximately $\geq$30 minutes per day, $\geq$5 days per week. However, the dose-response relationship may be more accurately described as nonmonotonic rather than strictly linear. That is, it is possible that lower doses of MM practice may have a sedating or soporific effect, whereas higher doses may have an arousing effect. An earlier study (16) from our laboratory found that as little as 5–10 minutes/day, 2–3 days/week of MM practice was associated with a large (74-minute) increase in (subjectively reported) TST in adolescent substance abuse outpatients. A nonmonotonic or bidirectional dose-response relationship may underlie the inconsistent findings of meditation effects on sleep in the literature. Estimates of "dosage" are further confounded by the heterogeneity of meditation practices that are combined within standardized "mindfulness-based" treatment packages, such as MBSR and MBCT. Although "mindfulness" is often presented as a single-entity intervention, in reality, these programs offer a variety of practices, including varying amounts of focused awareness, open monitoring, yoga/mindful movement, and compassion/loving-kindness practices. Each of these practices are hypothesized to have different neural underpinnings and different cognitive, affective and behavioral consequences (51), and are likely to have differential effects on sleep and arousal systems. Therefore, it is imperative that future research not only obtain detailed measurement of actual (rather than prescribed) meditation practice amount (preferably an objective measure) but also make efforts to separate the effects of different types of practice, not merely statistically, but through single-practice research designs.

The present study has several limitations, most notably the lack of statistical power due to the small sample size and the relatively large number of analyses conducted. The resulting possibility of Type 1 error inflation necessitates that the current findings be viewed as a preliminary pattern in need of further study, rather than a verified outcome. The use of a partially remitted depression sample limits the ability to generalize to more depressed samples or other clinical or nonclinical populations. The use of an 8-week mindfulness course limits the ability to speculate on the effects of other forms of meditation or the effects of longer durations of training. Because MBCT uses a variety of meditative techniques, it is difficult to sort out which techniques are related to which outcomes. In addition, varying levels of mood and sleep disturbance at baseline may have diluted the effects of treatment. Future attempts to select participants on baseline characteristics targeted for treatment will reduce variability. It would also be desirable if future studies employed multiple PSGs before, during, and after training, as well as at several follow-up time points to increase reliability, investigate the time course of effects, and establish the clinical significance in regard to relapse and recurrence rates.

Based on the hypothesis that improvements in sleep may be important for MM's therapeutic effects on depression, the aim of this study was to investigate the effects of MBCT on both subjective and objective PSG sleep profiles in an RCT of partially remitted depressed individuals with sleep complaints. Although residual depression symptoms improved following MBCT, results from both subjective and objective sleep measurements do not support the hypothesis that MM is beneficial for sleep. In contrast, subjective measures of sleep showed no effect beyond waitlisted controls, and objective measures of sleep suggested a pattern of increased arousal compared with controls, including increased awakenings, stage 1 and decreased SWS that correlated with MM practice amount. This pattern of increased alpha-theta EEG activity during sleep was associated with clinical improvements and, thus, may be better described as a persisting trait-like EEG pattern due to medi-

tation practice, rather than poor sleep quality, although further research is needed to clarify these distinctions.

We thank Drs. Mary Carskadon and Christine Acebo for their thoughtful comments and feedback on earlier versions of this manuscript. We give special thanks to the research assistants at the University of Arizona Sleep Research Laboratory for their time and effort.

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