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Autonomic and EEG Patterns during Eyes-Closed Rest and Transcendental Meditation (TM) Practice: The Basis for a Neural Model of TM Practice

Frederick Travis[1] and R. Keith Wallace

Maharishi University of Management, Fairfield, Iowa 52557

In this single-blind within-subject study, autonomic and EEG variables were compared during 10-min, order-balanced eyes-closed rest and Transcendental Meditation (TM) sessions. TM sessions were distinguished by (1) lower breath rates, (2) lower skin conductance levels, (3) higher respiratory sinus arrhythmia levels, and (4) higher alpha anterior–posterior and frontal EEG coherence. Alpha power was not significantly different between conditions. These results were seen in the first minute and were maintained throughout the 10-min sessions. TM practice appears to (1) lead to a state fundamentally different than eyes-closed rest; (2) result in a cascade of events in the central and autonomic nervous systems, leading to a rapid change in state (within a minute) that was maintained throughout the TM session; and (3) be best distinguished from other conditions through autonomic and EEG alpha coherence patterns rather than alpha power. Two neural networks that may mediate these effects are suggested. The rapid shift in physiological functioning within the first minute might be mediated by a "neural switch" in prefrontal areas inhibiting activity in specific and nonspecific thalamocortical circuits. The resulting "restfully alert" state might be sustained by a basal ganglia–corticothalamic threshold regulation mechanism automatically maintaining lower levels of cortical excitability.

> . . . our normal waking consciousness, rational consciousness as we call it, is but one special type of consciousness, whilst all about it, parted from it by the filmiest of screens, there lie potential forms of consciousness entirely different. (James, *Varieties of Religious Experiences,* 1961, p. 305)

Over the past three decades, scientific research has probed into the physiological parameters of experiences during meditation practice. Because the functioning of the nervous system underlies and gives rise to specific experiences, physiological patterns may index changes in internal states of conscious. Through these physiological "windows," potentially different forms of consciousness, distinct from ordinary waking, have been extensively investigated during meditation practice (Shapiro & Walsh, 1984; Travis & Wallace, 1997; Mason, Alexander, Travis, Marsh, Orme-Johnson, Gackenback, Mason, Rainforth, & Walton, 1997).

The largest number of studies have been conducted on the Transcendental Meditation (TM) technique,[2] developed by Maharishi Mahesh Yogi (1969). Despite six volumes of research (over 550 studies), there is still controversy over the distinction between simple eyes-closed rest and TM practice. For instance, in 1984, Holmes

[1] To whom correspondence and reprint requests should be addressed at Psychology Department, Maharishi University of Management, Fairfield, IA 52557. E-mail: Ftravis@mum.edu.

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reviewed the literature and reported no differences in heart rate (16 studies), respiration rate (8 studies), electrodermal activity (13 studies), or blood pressure levels (4 studies) during simple eyes-closed rest and meditation practice. However, he looked at many systems of meditation, not just TM practice, and also utilized a ''roll-call'' system of meta-analysis, which ignores effects of number of subjects on statistical outcomes. A later meta-analysis by Dillbeck and Orme-Johnson (1987) focused on studies solely comparing TM practice to eyes-closed rest. In addition, they transformed the experimental differences into ''effect sizes'' and conducted statistics on these effect sizes (Glass, McGaw, & Smith, 1981). This is a more rigorous, reliable method of drawing conclusions from many studies (Hunter & Schmidt, 1990). Dillbeck and Orme-Johnson (1987) reported that: (1) prior to meditation or rest, TM subjects exhibited significantly lower breath rates (22 studies), heart rates (31 studies), plasma lactate levels (9 studies), and fewer spontaneous skin conductance responses (10 studies); and (2) compared to eyes-closed rest, TM sessions were distinguished by significantly lower breath rates, plasma lactate levels, and skin conductance levels (20 studies).

The current study investigated autonomic and EEG patterns during eyes-closed rest and TM sessions. The purpose of this study was not to add one more observation to the existing sizable body of research. Rather, its purpose was to employ a closely controlled design—a single-blind within-subject design with order-balanced, equal-length eyes-closed rest and TM sessions—to identify characteristic parameters of these conditions and then to use these empirical markers to propose physiological mechanisms that may underlie practice of the TM technique. A within-subject design is important in physiological research because of large individual differences in physiological variables (Tebecis, 1975; Travis & Wallace, 1997). Using subjects as their own controls in a counterbalanced design provides maximum power to detect reliable differences between states.

METHODS

Subjects

Twenty subjects, average age 27.8 years (range 17.2 to 48.0 years), were asked to participate in the study. They had been practicing the TM technique for an average of 9.9 years (range 1.9 to 25.5 years). They comprised 13 males and 7 females. All were healthy, and none reported accidents or illnesses that might affect their EEG patterns.

Description of the TM Technique

The TM technique can be described as a dynamic process (Travis, in press) characterized by (1) attention moving from the active, surface level of thinking and perception to more silent and abstract levels of thought; (2) transcending the subtlest thinking level to a state of fully awake self-awareness without the usual content of thoughts and perceptions, called ''Transcendental Consciousness'' (Maharishi Mahesh Yogi, 1969; Travis & Pearson, in press); and (3) attention moving back to more active levels, propelled by ''stress release'' (physiological accommodation to the silent alert state of Transcendental Consciousness) (Maharishi Mahesh Yogi, 1972). These three phases, which can be physiologically distinguished (Travis & Wallace, 1997), cycle many times in each TM session. In comparison, during eyes-closed rest the attention typically moves on the horizontal level of meaning, rather than systematically transcending to more subtle levels of thinking.

Choice of Physiological Measures

Breath rate, skin conductance, and heart rate were measured in this study, because prior meta-analyses reported their sensitivity to TM practice (Dillbeck & Orme-Johnson, 1987). These three variables index metabolic and sympathetic arousal levels. Heart rate variability in the breath frequency, called respiratory sinus arrhythmia, was also measured in this study. Respiratory sinus arrhythmia is an index of vagal contribution to the respiratory/cardiac cycle (Porges, 1992). Vagal tone reflects "vulnerability to stress" (Porges, 1992) or "degree of physiological adaptability" (Travis, 1996). Higher respiratory sinus arrhythmia levels are correlated with higher survival rates of high-risk preterm neonates (Porges, 1992), enhanced recovery following neurosurgery (Donchin, Constantini, Szold, Byrne, & Porges, 1992), and higher levels of self-reported comfort during aerobic exercise (Travis, 1996). Respiratory sinus arrhythmia levels have not yet been reported during TM practice. We measured respiratory sinus arrhythmia to assess activity of both sympathetic and parasympathetic functioning during eyes-closed rest and TM practice.

EEG was also measured in this study. Frontal and central alpha (8–10 Hz) power and frontal-central alpha coherence have been reported during TM practice in earlier studies (power: Wallace, 1970; Taneli & Krahne, 1987; coherence: Dillbeck & Bronson, 1981; Gaylord, Orme-Johnson, & Travis, 1989). Alpha synchronization (high alpha power and coherence) indicates cortical areas at rest or "cortical idling"; alpha desynchronization (decreased alpha power and alpha coherence and heightened beta power and coherence) indicates cortical areas involved in task processing (Pfurtscheller, 1992). Increased alpha power and coherence over central and frontal cortices could indicate decreased motor and executive processing during TM practice.

Procedure

After the subjects washed their hands with soap and water, Ag/AgCl electrodes were secured to the distal phalanges of the left index and middle fingers (Scerba, Freedman, Raine, Dawson, & Venables, 1992) with 1-cm double-stick collars and 0.05 M NaCl electrode paste, comprising saline solution and Unibase following the recipe provided by Fowles, Christie, Edelberg, Grings, Lykken, and Venables, (1981). EEG electrodes were applied with the Electro-Cap system to homologous frontal, central, and parietal sites (F3, F4, C3, C4, P3, and P4 in the 10–20 system referenced to linked mastoids, with a forehead ground). All impedances were below 5 kohm. Tin electrodes were attached in a Lead II configuration—right wrist to left leg—to record heart rate. Solid-state strain gauge transducers (UFI, Pneumotrace Model 1130) were applied at the zyphoid process and navel to measure thoracic and abdominal breathing. Subjects then moved into a sound-attenuated room with a closed-circuit video monitor and sat in a comfortable chair.

To decrease subject reactivity, the subjects were kept blind to the hypotheses being tested. They were told that this study investigated effects of eyes-closed rest and TM practice on performance on an event-related potential (ERP) task that followed each rest/TM session. The ERP task distracted the subjects' attention from the true hypothesis being tested and lessened sequence effects in the counterbalanced design.

Even with this distraction, some subjects may have realized that physiological patterns during the eyes-closed and TM sessions would also be useful variables to compare, and they may have intentionally (or unintentionally) remained mentally active during the eyes-closed rest period considering this and/or other issues. No subject, however, mentioned this possibility during the debriefing after the experiment, suggesting that subject reactivity did not greatly impact the findings of this study.

The eyes-closed rest and TM sessions were of equal length (10 min), and their order was counterbalanced. For the eyes-closed rest period, subjects were instructed to "Close the eyes, just sit easily." For the TM session, they were given standard instructions to begin the TM technique. The experimenter verbally signaled the subjects to begin and end each condition.

This is a conservative test of possible differences between eyes-closed rest and TM practice. While the TM technique is a specific mental technique involving systematic steps to take the attention to more settled levels of mental functioning (Maharishi Mahesh Yogi, 1969), highly trained subjects (these subjects averaged 9.9 years of practice of the TM technique) can begin to shift into more settled states just by closing the eyes (Farthing, 1992). This shifting to quieter levels of mental functioning may have innocently occurred during the eyes-closed periods, thereby decreasing condition differences. Any observed differences between these two conditions, therefore, would need to be large to be detected. This yielded a conservative test of possible differences between eyes-closed rest and TM practice.

Apparatus

EEG was recorded during the 10-min eyes-closed rest and TM sessions with a 0.1-Hz high-pass and a 100-Hz low-pass filter and 5 μV/mm sensitivity. Heart rate was recorded on the same amplifiers with 3.0- and 100-Hz filter settings and 15 μV/mm sensitivity. Electrodermal activity (skin resistance) was recorded on a DC amplifier with a constant 10-μA current across the electrodes and a sensitivity of 1.0 kohm/cm. A circuit was built that supplied a constant current of 0.05 mA to the two strain gauges (Ogilvie & Houghton, 1982), whose output was fed through AC amplifiers with 0.1- and 100-Hz filter settings and 15 mV/cm sensitivity. All signals were digitized on-line at 256 points/s and stored for later analyses using EEGSYS, a standardized research acquisition and analysis package developed in conjunction with researchers at NIH (Hartwell, 1995).

Data Quantification

All data were averaged and compared across the 10-min periods. The data were also averaged over the 1st, 5th, and 10th minutes of both periods. These three timepoints were selected to compare the temporal unfolding of physiological variables during eyes-closed rest and TM practice.

Autonomic variables. Breath rate was manually counted on the paper records. Skin resistance levels were calculated and converted to skin conductance levels according to Dawson, Schell, and Filion (1990). Respiratory sinus arrhythmia was calculated as the difference between the inspiratory-related shortest heart period and the expiratory-related longest heart period in beats/minute (Grossman, Karemaker, & Wieling, 1991). Heart period was calculated as the inverse of the heart rate calculated over each period and was expressed in milliseconds. Heart period was used because it is more normally distributed and more linearly reflects changes in autonomic activation of the heart from a baseline than does heart rate (Quigley & Berntson, 1996).

EEG data. The scalp-recorded EEG was visually examined for eye and movement artifacts. These artifacts were manually marked and excluded from the spectral analyses. The data were conditioned with a Hanning window, transformed into six bipolar pairs involving frontal, central, and parietal electrodes (F3–C3, C3–P3, F3–P3, F4–C4, C4–P4, and F4–P4) to remove the effect of the common reference (Fein, Raz, Brown, & Merrin, 1988; Travis, 1994a), and spectral analyzed (fast Fourier transformation) in 1-s epochs, giving 1.0-Hz resolution. Coherence spectra were calculated for three pairs: F3C3–C3P3, F4C4–C4P4, F3C3–F4C4. We focused on these pairs, because coherence changes during TM practice have been most often reported between these areas (Levine, Hebert, Haynes, & Strobel, 1977; Gaylord et al., 1989).

Due to high intersubject variability in EEG during TM practice reported in earlier studies, the spectral estimates were not arbitrarily averaged into conventional broadband 4-Hz-wide bins (theta, alpha, etc.). Rather, the frequency of peak amplitude[3] in narrow 1-Hz bands was identified in the amplitude spectrum for each subject in each condition. The amplitude and coherence estimates in these 1-Hz bands were compared between conditions.

Statistical Analyses

The period averages and 1-min averages were first tested for normality. As suggested by Hair, Anderson, Tatham, and Black (1992, p. 43), skewness values greater than 1.200 (for 16 subjects) indicate significant deviation from normality at the $p = .05$ level. Only the distribution for percentage EEG significantly differed from normality (negatively skewed) and was transformed with the recommended log transformation (Hair et al., 1992). A repeated-measures ANOVA was used to test for condition differences between the 10-min period averages. Next, condition-change scores were calculated ($TM_{values} - EC_{values}$) for the 1st, 5th, and 10th minutes. A repeated-measures ANOVA tested significant differences in condition-change scores over these three 1-min periods. Greenhouse Geisser corrected p values were reported for all ANOVAs. If significant main effects were seen for condition but not for condition-change scores, then it might indicate a significant change in state in the first minute that maintained itself over the 10-min session. If significant main effects were

[3] EEGSYS reports the results of its spectral analysis in "base-to-peak equivalent voltages." Its analysis program calculates power (average of the summed sine and cosine components squared) and then estimates a continuous sine wave whose power equals the calculated power of the data. The base-to-peak equivalent voltages are the base-to-peak amplitudes of that estimated sine wave.

seen for condition-change scores but not for condition, then it would suggest that eyes-closed rest and TM practice involve similar changes in physiology over the 10-min periods.

RESULTS

Four subject's data could not be analyzed (three males and one female). One record contained too many movement artifacts; data for the second subject was lost due to equipment problems; two subjects went to sleep during TM practice[4] as determined by alpha dropout, slow eye movements (seen in the frontal leads), vertex waves, and sleep spindles by the end of the 10-min recording session. Data from these two subjects were discarded because they would contaminate a comparison of TM practice and eyes-closed rest. None of the other 16 subjects showed evidence of sleep (stage 1 or otherwise) during their 10-min sessions. Autonomic and EEG data were analyzed for these remaining 16 subjects.

Analysis of Autonomic Variables

Table 1 presents means and standard errors of breath rate, skin conductance levels, respiratory sinus arrhythmia, and heart period during the session averages and the 1st, 5th, and 10th minutes of both conditions.

Breath rate. The repeated-measures ANOVA with condition as the repeated measure and breath rate over the 10-min sessions as the variate revealed a significant main effect for condition ($F(1, 15) = 4.85, p = .042$), with lower breath rates during TM practice. The repeated-measures ANOVA of condition-change scores was not significant, $F(2, 14) = 1.52$, ns. As seen in Table 1, breath rates dropped during the first minute of TM practice and remained low throughout.

Skin conductance levels. The baseline skin conductance levels were not different at the beginning of each condition, $F(1, 15) = 2.1$, ns. The repeated-measures ANOVA with condition as the repeated measure and skin conductance levels over the 10-min sessions as the variate revealed a significant main effect for condition ($F(1, 15) = 15.37, p = .0017$), with lower skin conductance levels during TM practice. The repeated-measures ANOVA of condition-change scores was not significant, $F(2, 14) = 3.27, p = .092$. As seen in Table 1, skin conductance levels began to drop during the first minute of TM practice and reached and maintained a low level after 5 min.

Respiratory sinus arrhythmia. The repeated-measures ANOVA with condition as the repeated measure and respiratory sinus arrhythmia over the 10-min sessions as the variate revealed a significant main effect for condition ($F(1, 15) = 14.00, p = .0022$), with higher respiratory sinus arrhythmia during TM practice. The repeated-measures ANOVA of condition-change scores was not significant, $F(2, 14) < 1.0$, ns. As presented in Table 1, respiratory sinus arrhythmia increased during the first minute of TM practice and remained high throughout.

[4] Sleep can occur during TM practice, if subjects are tired before that session. For instance, Pagano, Rose, Stivers, and Warrenburg (1976) and Younger, Adriance, and Berger (1975), who reported Stage 1 and 2 sleep during TM practice, observed that those subjects who slept during TM practice also reported being tired when they sat to mediate. See Travis (1994b) for a discussion of sleep during TM practice.

TABLE 1
Means and Standard Errors of Autonomic Variables during Eyes-Closed Rest and during Practice of the Transcendental Meditation Technique

	Eyes closed rest	TM session
	Breath rate (bpm)	
Session average	14.12 (0.81)	12.50 (1.06)
1st minute	13.69 (0.78)	12.59 (1.22)
5th minute	14.15 (0.83)	12.81 (1.00)
10th minute	14.53 (0.94)	12.24 (1.13)
	Skin conductance levels (μS)	
Session average	6.22 (0.56)	5.46 (0.41)
Baseline	6.71 (0.44)	6.60 (0.43)
1st minute	6.60 (0.46)	6.15 (0.45)
5th minute	6.18 (0.56)	5.16 (0.66)
10th minute	5.87 (0.69)	5.08 (0.67)
	Respiratory sinus arrhythmia (bpm)	
Session average	9.36 (0.92)	12.78 (1.50)
1st minute	9.48 (0.94)	12.52 (1.46)
5th minute	9.99 (0.95)	12.06 (1.45)
10th minute	9.26 (1.07)	13.56 (1.78)
	Heart period (ms)	
Session average	782.4 (32.2)	792.9 (26.8)
1st minute	788.0 (35.2)	797.6 (28.3)
5th minute	782.4 (31.4)	796.5 (27.9)
10th minute	776.8 (32.5)	784.7 (25.7)

Note. Entries are means (standard errors).

Heart period. The two repeated-measures ANOVAs with heart period as the variate revealed no significant main effects for condition or for condition-change scores (both $F < 1.0$, ns). Visual inspection of the heart period data revealed that subjects with shorter heart periods during the eyes-closed resting session (corresponding to a heart rate greater than 79 bpm) tended to exhibit a longer heart period during the TM session; those with a medium heart period during the eyes-closed period tended to have a similar heart period during the TM session, and those with a longer heart period during the eyes-closed rest (corresponding to a heart rate less than 70 bpm) tended to exhibit a shorter period during the TM session. These individual differences probably are not due to "regression to the mean." Regression to the mean occurs with repeated measures within the same condition. In the current study, heart period was measured during two different conditions, and the conditions were counterbalanced as to order. In addition, we conducted a post hoc ANOVA with sequence-in-the-counterbalance as the between factor. This ANOVA yielded no significant main effects for sequence, $F(1, 15) < 1.0$, ns. A larger study could test reliability and significance of these patterns of heart rate change.

Analysis of EEG Variables

There were 36 amplitude estimates—2 hemispheres × 3 bipolar pairs × 3 1-min periods × 2 conditions. To have sufficient degrees of freedom for statistical analyses,

TABLE 2
Means and Standard Errors of EEG Laterality and Alpha Percentage Change-Scores during Eyes-Closed Rest and during Practice of the Transcendental Meditation Technique

	EEG laterality index (%)	
	Eyes closed	TM practice
Session average	5.8 (3.1)	5.6 (3.3)
1st minute	3.7 (2.7)	6.5 (3.8)
5th minute	6.5 (3.5)	4.8 (3.5)
10th minute	7.4 (3.1)	5.5 (2.7)

Alpha percentage change-scores during eyes-closed rest and TM practice (%)

	Bipolar pair		
	Frontal–central	Central–parietal	Frontal–parietal
Session average	8.6 (11.2)	11.9 (17.3)	13.2 (11.0)
1st minute	6.5 (14.1)	8.4 (10.8)	10.9 (13.3)
5th minute	−3.7 (8.2)	1.5 (27.4)	−0.1 (6.5)
10th minute	23.0 (14.1)	25.9 (13.8)	28.8 (13.3)

Note. Entries are means (standard errors).

we reduced the EEG data in two steps. First, EEG laterality values were calculated for frontal-parietal leads [(right − left)/(right + left)]. We reasoned that the frontal–parietal bipolar leads would reflect overall alpha activity within each hemisphere. EEG laterality values were compared between conditions and over time. Next, if there were no significant EEG laterality differences, then estimates for the right and left frontal–central, central–parietal, and frontal–parietal bipolar pairs were averaged together. These averages were then used to calculate alpha percentage change-scores between the TM and the eyes-closed sessions [(TM session-eyes closed)/eyes closed]. Percentage change-scores resulted in the reduction of the number of variates and controlled for the large range in amplitude values—a factor of 25—by yielding relative differences between conditions. In the coherence analysis, we analyzed left and right anterior–posterior coherence (frontal–central/central–parietal bipolar pairs) and frontal bilateral coherence (left and right frontal–central bipolar pairs) in the frequency with peak power.

Table 2 presents the means and standard errors for EEG laterality values and percentage differences during the session averages and during the 1st, 5th, and 10th minutes of both conditions. Table 3 presents the means and standard errors for peak coherence values.

Analyses of laterality and alpha percentage change-scores. The repeated-measure ANOVAs with EEG laterality values over the 10-min sessions as the variate revealed no significant main effects for condition or for condition-change scores, both $F <$ 1.0, ns. Thus, amplitude values for right and left frontal–central and central–parietal pairs were averaged together, and alpha percentage change-scores were calculated. The repeated-measures ANOVAs with alpha percentage change-scores as the variate revealed no significant main effects for condition ($F(1, 15) < 0$, ns). There was a

TABLE 3
Means and Standard Errors of Coherence during Eyes-Closed Rest and during Practice of the Transcendental Meditation Technique

	Eyes closed				TM Session			
Coherence pair	Session average	1st minute	5th minute	10th minute	Session average	1st minute	5th minute	10th minute
F3C3–C3P3	.633 (.049)	.651 (.042)	.639 (.047)	.610 (.058)	.679 (.045)	.668 (.049)	.667 (.042)	.703 (.044)
F4C4–C4P4	.620 (.048)	.561 (.047)	.654 (.047)	.643 (.050)	.668 (.043)	.692 (.038)	.663 (.045)	.649 (.046)
F3C3–F4C4	.576 (.045)	.578 (.042)	.584 (.047)	.568 (.045)	.621 (.039)	.598 (.036)	.614 (.038)	.651 (.044)

Note. Entries are means (standard errors).

trend for significant differences in alpha percentage change-scores for the three 1-min periods ($F(2, 14) = 3.61$, $p = .053$), with 25% higher alpha power during the last minute of the TM session compared to the eyes-closed resting session.

Coherence. A repeated-measures MANOVA with condition as the repeated measure and left and right anterior–posterior and bilateral frontal coherence over the 10-min sessions as the variates revealed a significant main effect for condition ($F(1, 15) = 14.3$, $p = .002$), with higher coherence values during TM practice. There were no significant main effects for condition-change scores ($F(2, 14) < 1.0$, ns). Post hoc comparisons were also calculated for the 1st and 5th minutes vs the 10th minute. This was done to assess whether the large increase in percentage alpha amplitude seen in the 10th minute led to a corresponding large increase in coherence. This comparison was not significant, $F(1, 15) < 1.0$, ns.

DISCUSSION

In this true experiment, physiological patterns during equal-length, counterbalanced eyes-closed and TM periods were significantly different. TM sessions were characterized by significantly lower breath rates and skin conductance levels, significantly higher respiratory sinus arrhythmia levels, and significantly higher anterior–posterior and frontal alpha coherence. Alpha power estimates were not significantly different between conditions. These results were seen in the first minute and were maintained throughout the 10-min sessions. These findings suggest that (1) TM practice leads to a state fundamentally different than eyes-closed rest; (2) TM practice results in a cascade of events in the central and autonomic nervous systems, leading to a rapid change in state—initiated within the first minute—that is maintained throughout the meditation session; and (3) TM practice may be best distinguished from other conditions through autonomic and EEG coherence patterns, rather than EEG power.

Consideration of Nonsignificant Findings

Heart rate, EEG laterality, and EEG percentage change-scores were not significantly different between conditions. While initial studies reported significantly lower heart rates during TM practice (Wallace, 1970), a meta-analysis of 31 studies concluded that heart rate did not significantly decrease during a TM session compared to eyes-closed rest (Dillbeck & Orme-Johnson, 1987). Resting and meditation both involve sitting with eyes closed. It appears that any differences in mental activity between those two eyes-closed conditions do not appreciably affect heart rate. Another possible explanation for the lack of heart rate difference was the new observation of different patterns of heart-rate change from eyes-closed to TM practice—subjects with either higher or lower heart rates during the eyes-closed session tended to come to a middle level during TM practice. This observation needs to be tested with a larger group with order-balanced eyes-closed and TM sessions, as in this study, to control for simple regression to the mean.

The lack of differences in EEG laterality and alpha percentage change-scores was unexpected. It could be due to the subject population used, who were all experienced TM subjects. Research reports that alpha power increases outside of TM practice the longer one practices the technique (1 year vs 8 years) (Travis, 1991; Travis & Mason, in press). Since these subjects had practiced the TM technique for an average of 9.9 years, it is possible that these subjects had higher alpha amplitude during the eyes-closed period than a nonmeditating group, which decreased the effect sizes in the amplitude analyses.

Even though amplitude estimates were not significantly different between conditions, the coherence estimates were. Coherence may be more sensitive than amplitude to distinguish TM sessions from other conditions. Other authors have also reported a dissociation between alpha power and coherence during TM practice (Dillbeck & Bronson, 1981), during cognitive tasks (Petsche, Kaplan, von Stein, & Filz, 1997), during normal aging (Koyama et al., 1997), and during sleep (Achermann & Borbely, 1998).

Consideration of Coherence Differences

EEG coherence is understood as a measure of cortical connectivity (Florian, Andrew, & Pfurtscheller, 1998). Lower values of coherence are associated with white matter lesions and decreased cerebral blood flow (Leuchter, Cook, Uijtdeharge, Dunkin, Lufkin, Anderson-Hanley, Abrams, Rosenberg-Thompson, O'Hara, Simon, Osato, & Babaie, 1997), schizophrenia (Wada, Nanbu, Kikuchi, Koshino, Hashimoto, & Yamaguchi, 1998), depression (Leuchter et al., 1997), and normal aging (Koyama, Hirasawa, Okubo, & Karasawa, 1997). Higher values of coherence have been interpreted as evidence for functional coupling (Thatcher, Krause, & Hrybyk, 1986), information exchange (Petsche et al., 1988), or functional coordination (Gevins, Bessler, Morgan, Cutillo, White, Greer, & Illes, 1989) between brain regions. Higher beta coherence correlates with inhibition processes in Go/No Go tasks (Shibata et al., 1997) and in self-paced finger movements (Leocani, Toro, Manganotti, Zhuang, & Hallett, 1997). Higher $alpha_1$ coherence (8–10 Hz) has been correlated with increased alertness during TM practice (Orme-Johnson & Haynes, 1981). In general, $alpha_1$ coherence is sensitive to changes in alertness, while $alpha_2$ coherence (10–12 Hz) is sensitive to task processing (Klimesch, Pfurtscheller, & Schenke, 1992; Petsche et al., 1997). The quality of alertness indexed by high $alpha_1$ coherence seen during TM practice has been called "restful alertness" (Maharishi Mahesh Yogi, 1969)—mental quiescence with full inner wakefulness.

A Proposed Physiological Model of TM Practice

These data suggest two complementary neural networks that may underlie practice of the Transcendental Meditation technique. One network, analogous to a "neural switch," may mediate the rapid shift of physiological and cortical processing to a more restfully alert state at the onset of TM practice (phasic control). The other network, analogous to a homeostatic, threshold regulation mechanism, may mediate the maintenance of this restful state for the duration of the TM session in a relatively automatic manner (tonic control).

The neural network underlying phasic control would need to (1) innervate nearly every brain structure to account for the constellation of changes in central and autonomic nervous system functioning, (2) have an inhibitory effect, and (3) be under conscious control—the beginning of TM practice is an intentional act. The prefrontal cortex fits these three requirements. (1) The frontal lobes receive afferents from all brain areas and send efferents to the same structures in well-defined feedback loops, i.e., cortico-striatal, cortico-thalamic, and cortico-pontine circuits (Goldman-Rakic, 1987; Fuster, 1980). (2) The frontal lobes have an inhibitory effect. Lesions in the frontal areas lead to disruption of performance during Go/No Go tasks (Leimkuhler & Mesulam, 1985) and during Stroop tasks and the Wisconsin Card Sorting task (Kimberg & Farah, 1993). (3) The frontal areas are involved in prospective memory—remembering to act in the future (Okuda, Fujii, Yamadori, Kawashima, Tsukiura, Fukatsu, Suzuki, Ito, & Fukuda, 1998)—and in temporal (Daum & Ackermann, 1994; Kesner, Hopkins, & Fineman, 1994) and hierarchical sequencing of information (Klouda & Cooper, 1990).

TM practice begins with innocently thinking a mantra—a sound without meaning. This is an intentional act that sets up the rest of the TM session. This process could involve prefrontal cortices activating the nucleus reticularis thalami, inhibiting specific and nonspecific activity in thalamocortical circuits (Skinner & Yingling, 1976; Steriade, Datta, Pare, Oakson, & Dossi, 1993). This may lead to the cascade of physiological changes seen in the first minute of TM practice.

After initial changes in state, possibly mediated by prefrontal cortices, a restfully alert state was maintained for a relatively long period—10 min in these data. This would seem to require neural feedback mechanisms to maintain a lower level of cortical excitability. In addition, the data in the current study suggest that these feedback circuits operate without focused attention to the details of the process. Focused conscious processing is marked by alpha desynchronization (Siddle, 1983), heightened skin conductance levels (Dawson et al., 1990), and reduced respiratory sinus arrhythmia (Porges, 1992). As we saw, the TM session was characterized by a completely opposite pattern of physiology—increased alpha coherence, lower skin conductance levels, and heightened respiratory sinus arrhythmia.

Tonic control would seem to involve *subcortical structures,* which are known to affect state of consciousness, rather than *cortical structures,* which are involved in the contents of consciousness (Baars, 1995). The frontal lobes, while initiating TM practice, may not be involved in maintaining the practice. Alexander, DeLong, and Strick (1986) have delineated basal ganglia–thalamocortical feedback loops that may serve this maintenance function. Specifically, the authors cite anterograde transport data showing distinct basal ganglia–thalamocortical circuits funneling diverse cortical inputs through this circuit back to the cortex via a single output (Delong & Georgopoulos, 1981). These circuits involve projections from the prefrontal, temporal, and parietal cortices terminating in the caudate. These efferents feed forward to the globus pallidus and then to the mesencephalic reticular formation, responsible for maintaining tone in thalamocortical circuits, and to the medial dorsal parvocellular nuclei of the thalamus. These inputs are funneled through the thalamus back up to the cortex, completing the circuit.

Basal ganglia–thalamocortical circuits are reported to underlie the generation, maintenance, switching, and blending of a wide range of motor, mental, and emotional behaviors (Elsinger & Grattan, 1993; St. Cyr, Tayler, & Nicholson, 1995) and underlie the integration of past experiences, present conditions, and future behaviors (Nader, 1994). Elbert and Rockstroh (1987) suggested that basal ganglia–thalamocor-

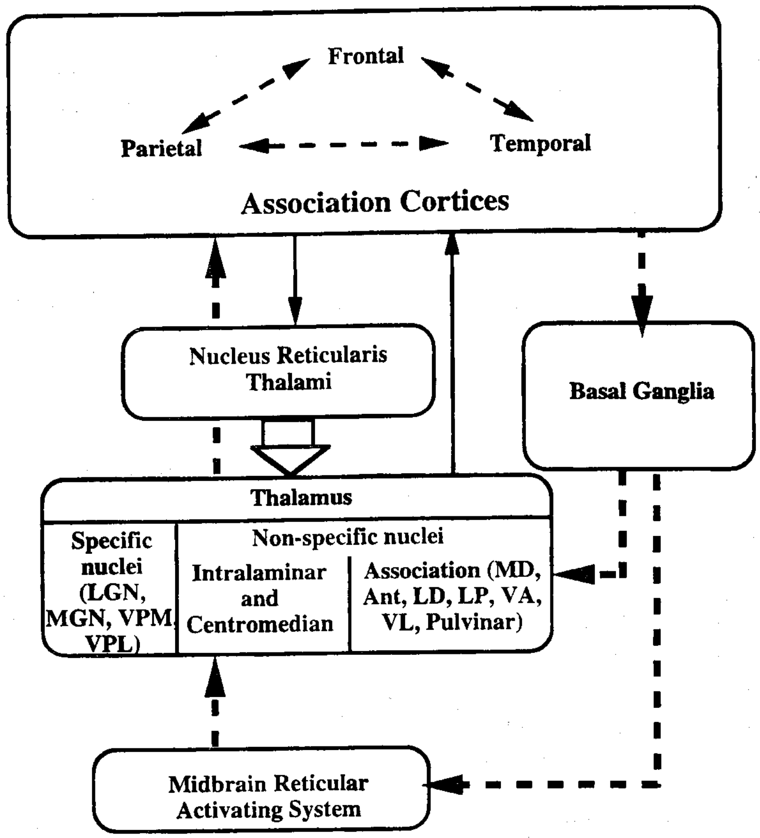

FIG. 1. The proposed neural circuits underlying TM practice. The solid line between association cortices and the nucleus reticularis thalami represents the inhibitory effects of frontal areas on thalamic activity through the GABA-rich nuclei of the nucleus reticularis thalami. The dashed lines represent the proposed threshold-regulation loop involving cortex, basal ganglia, and thalamic areas.

tical circuits constantly sample ongoing cortical activation and dampen or open up the system to maintain an optimal level of cortical excitability. Such a threshold regulation system, largely driven by subcortical structures, may be operating in a fairly automatic manner to maintain the restfully alert state achieved within the first minutes of TM practice.

Figure 1 presents a schematic of the proposed neural circuits. In this figure, the cortical areas are at the top, subcortical areas are in the middle, and brain stem areas are at the bottom. During TM practice, sensory inputs and motor outputs are minimized—the individual sits in a quiet room with eyes closed. The primary inputs are therefore internal. The solid line between association cortices and the nucleus reticularis thalami represents the inhibitory effects of frontal areas on thalamic activity through the GABA-rich nuclei of the nucleus reticularis thalami. The dotted lines represent the proposed threshold-regulation loop involving cortex, basal ganglia, and thalamic areas.

While there are no neural imaging data of subjects practicing the TM technique, recent positron emission tomography data support this proposed neural model. Increased activity in the caudate and medial dorsal nuclei of the thalamus modulates levels of tonic alertness (Alkire et al., 1996). Also, significant decreases in basal ganglia metabolic activity are observed in clinical populations (schizophrenia and depression) who exhibit disruptions in attention (Posner & Raichle, 1994).

Neural imaging could test these proposed neural networks underlying TM practice. If these circuits are supported by neural imaging, they may define a new model of attention involving shifts of *inner* attention, rather than shifts of *outer* attention to objects in the environment.

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