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Effects of Transcendental Meditation practice on brain functioning and stress reactivity in college students

Fred Travis [a,*], David A.F. Haaga [b], John Hagelin [c], Melissa Tanner [b], Sanford Nidich [d], Carolyn Gaylord-King [d], Sarina Grosswald [c], Maxwell Rainforth [d], Robert H. Schneider [d]

[a] Center for the Brain, Consciousness and Cognition, Maharishi University of Management, 1000 North 4th Street, Fairfield, IA 52557, United States
[b] Psychology Department, American University, Washington, DC, United States
[c] Institute of Science, Technology and Public Policy, 1000 North 4th Street, Fairfield, IA 52557, United States
[d] Center for Natural Medicine and Prevention, Maharishi University of Management Research Institute, Maharishi Vedic City, IA 52556, United States

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ABSTRACT

This randomized controlled trial investigated effects of Transcendental Meditation (TM) practice on Brain Integration Scale scores (broadband frontal coherence, power ratios, and preparatory brain responses), electrodermal habituation to 85-dB tones, sleepiness, heart rate, respiratory sinus arrhythmia, and P300 latencies in 50 college students. After pretest, students were randomly assigned to learn TM immediately or learn after the 10-week posttest. There were no significant pretest group differences. A MANOVA of students with complete data (N=38) yielded significant group vs treatment interactions for Brain Integration Scale scores, sleepiness, and habituation rates (all $p<.007$). Post hoc analyses revealed significant increases in Brain Integration Scale scores for Immediate-start students but decreases in Delayed-start students; significant reductions in sleepiness in Immediate-start students with no change in Delayed-start students; and no changes in habituation rates in Immediate-start students, but significant increases in Delayed-start students. These data support the value of TM practice for college students.

1. Introduction

Experience-related cortical plasticity was first identified during critical periods of development (von Senden, 1960; Hubel and Weisel, 1977), but now has been reported across the lifespan (Donoghue, 1995; Elbert et al., 1995; Buonomano and Merzenich, 1998; Merzenich, 1998; Maguire et al., 2006). Cortical plasticity explains learning (LeDoux, 2002; Zull, 2002). Synaptic connections are strengthened when students learn new facts, skills, and procedures (Mochizuki-Kawai et al., 2006).

Other experiences in college—high pressure, interrupted sleep, and alcohol and drug use—also leave their mark on brain functioning and behavior (Arnedt et al., 2005; Zeigler et al., 2005). Under high stress, the brain "downshifts" to a stimulus/response mode (Caine and Caine, 1991). Stress results in elevated sympathetic reactivity (Weekes et al., 2006), which can interrupt sleep causing excessive daytime sleepiness (Buboltz et al., 2001; Moo-Estrella et al., 2005) and cognitive deteriorations (Lee et al., 2003). High psychosocial stress causes brain regions involved in memory and emotions, such as the hippocampus, amygdala, and prefrontal cortex, to undergo structural remodeling, with the result that memory is impaired and anxiety and aggression are increased (McEwen, 1998, 2006a,b).

The stress response is a normal response to prepare for emergency situations. However, if the system is not allowed to recover from stressful experiences, then the body becomes sensitized to stress (McEwen, 2004). The stress response may not turn off or it may get triggered by mild experiences (McEwen, 2006a,b).

Transcendental Meditation®[1] practice is reported to decrease effects of previous stressful experiences and to help an individual function better in stressful situations. Transcendental Meditation practice is characterized by 1) lower sympathetic tone (Dillbeck and Orme-Johnson, 1987); 2) higher parasympathetic tone, as reflected in amplitude of the high frequency component of heart rate variability, also called respiratory sinus arrhythmia (Travis, 2001); and 3) higher levels of frontal EEG alpha coherence (8–12 Hz) (Dillbeck and Bronson, 1981; Gaylord et al., 1989; Travis, 2002; Travis et al., 2002) and frontal-parietal phase synchrony (Hebert et al., 2005). Simultaneous recording of EEG and MEG during Transcendental Meditation practice found that higher frontal and central scalp recorded alpha EEG activity is associated with MEG source location in medial frontal and anterior cingulate cortices (Yamamoto et al., 2006).

These physiological changes during Transcendental Meditation practice are associated with improvements in psychological functioning.

* Corresponding author. Tel.: +1 641 472 1209; fax: +1 641 470 1316.
E-mail address: ftravis@mum.edu (F. Travis).

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A matched longitudinal study reported increases in Cattell Culture Fair IQ scores in college students after two years Transcendental Meditation practice (Cranson et al., 1991), and a random assignment longitudinal study reported increases in multiple measures of intelligence—Cattell Culture Fair IQ, practical intelligence, creativity, field independence and inspection time—after one year Transcendental Meditation practice (So and Orme-Johnson, 2001). A matched design reported greater flexibility in concept learning in college students (Dillbeck, 1982) and faster P300 latency in elderly participants (Goddard, 1989). A meta-analysis of 141 studies reported larger effect sizes for reduction of anxiety through Transcendental Meditation practice compared to other traditional meditation and clinical relaxation responses (Eppley et al., 1989). Another meta-analysis of 101 studies reported larger effect sizes for increases in self-actualization with Transcendental Meditation practice (Alexander et al., 1991).

Transcendental Meditation practice is also reported to result in improved health. A series of randomized controlled trials on the effects Transcendental Meditation practice on prevention and treatment of cardiac heart disease in multi-ethnic groups reported reductions in hypertension, atherosclerosis, left ventricular mass, and CHD morbidity and mortality in high-risk multi-ethnic populations practicing the Transcendental Meditation program, compared to controls (Schneider et al., 1995; Alexander et al., 1996; Castillo-Richmond et al., 2000).

Transcendental Meditation (TM) practice also changes brain patterns during challenging cognitive tasks after the meditation session. Nine brain measures including broadband inter- and intrahemispheric coherence (alpha: 8–12 Hz, beta: 12.5–20 Hz, and gamma: 20.5–50 Hz), broadband absolute and relative power, power ratios (alpha/beta and alpha/gamma), and cortical preparatory responses (contingent negative variation) were derived from EEG recorded during simple and choice reaction time tasks in 17 non-TM, 17 short-term (7.1 yrs TM) and 17 long-term TM participants (24.2 yrs TM). Of these nine brain measures, three measures were entered in a multiple discriminate analysis of group differences: 1) higher broadband frontal (F3–F4) coherence (alpha, beta, and gamma), 2) higher alpha/beta absolute power ratios, and 3) better match between task demands and brain preparatory response (Travis et al., 2000, 2002; Travis, 2002). These empirically identified measures were converted to z-scores and combined to form a scale. This scale was called a "Brain Integration Scale" (Travis et al., 2002).

The Brain Integration Scale derived its name from the long-term TM participants in this research, who reported the permanent integration of deep meditation experiences with waking, sleeping and dreaming states. Also, this name was chosen because EEG frontal coherence, which was the first variable entered in the multiple discriminate analysis, reflects structural and functional connectivity between brain areas (Thatcher et al., 1986). Brain Integration Scale scores in these participants positively correlated with emotional stability, moral reasoning, and inner directedness, and negatively correlated with anxiety (Travis et al., 2004). Also, Brain Integration Scale scores were significantly higher in top-level managers compared to middle-level managers (Travis et al., in press). Thus, the Brain Integration Scale appears to tap brain patterns important for success in life.

Reported effects of Transcendental Meditation practice on psychological and physiological functioning could be beneficial for students and help them manage the stressful experiences of college. The current study uses a random-assignment clinical-trial design with pretest and 10-week posttest to investigate effects of Transcendental Meditation practice on brain functioning, autonomic reactivity, heart rate, sleepiness, and speed of processing. The study hypotheses were that participants randomly assigned to learn the Transcendental Meditation technique, compared to wait-listed controls, would 1) increase in Brain Integration Scale scores; 2) increase in parasympathetic tone as measured by the amplitude of respiratory sinus arrhythmia during paced breathing; 3) decrease in sympathetic reactivity as measured by faster habituation rates to an 85-dB tone; 4) decrease in heart rate; 5) decrease in sleepiness levels as measured by Epworth Sleepiness Scale; and 6) have faster brain response times, as measured by shorter P300 latencies to novel stimuli.

2. Method

2.1. Study design

Pretest data were recorded from 50 students at the beginning of the Spring 2006 term. The students responded to signs advertising the research and came to introductory meetings that explained the study. At these meetings, students volunteered to be part of the EEG section of this study. Following baseline recordings, students were randomly assigned, using computer randomization, to either Immediate-start or Delayed-start in Transcendental Meditation instruction. The posttest occurred 10-weeks before final's week at the end of spring term. This was a time of maximum stress for the students. The IRB approved the study before beginning recruitment for the study.

The initial design for this study included only the pretest and 10-week posttest. Subsequently, an additional year of funding was obtained. Following the 14-week summer vacation, the Delay-start participants learned the TM technique, at the beginning of the Fall term, and both Immediate-start and Delayed-start participants meditated throughout the Fall term. A second posttest was conducted at the end of the Fall term. However, only 36% of the Immediate-start participants and 60% of the Delayed-start participants were available for the second posttest at the end of the Fall term. Many study participants missed the second posttest because they were out of the area on college-related internships. Due to the high attrition, it is difficult to make reliable inferences from the second posttest data. Thus, only data from the pretest and first posttest will be reported in this paper.

2.2. Subjects

This EEG research was a sub-study of research investigating effects of the Transcendental Meditation program on brain functioning, cognitive development, and health in 298 college students in the Washington, D.C. area. The inclusion criteria for entering this study were: 1) being an undergraduate or graduate student, 2) being in school through May 2006 (the study began January 2006), and 3) having blood pressure less than 140/90 mm Hg. During the first six weeks of recruitment for the larger study, students were offered the opportunity to participate in this neurophysiological sub-study. Fifty students (13 males and 37 females; average age = 22.4 ± 8.0 years) volunteered to participate in this part of the study. Forty-four were white; five were Asians; and one was Hispanic. These 50 students included 45 students attending American University, and one each attending George Washington University, George Mason University, Walden College, Marymount University, or Johns Hopkins University.

2.3. Procedure

Students came individually for their EEG recording. After completing consent and demographic forms, individuals answered the items on the Epworth Sleepiness Scale, while electrodes were applied. 1) 32 Ag/AgCl sensors were applied in the 10–10 system with sensors on the left and right earlobe for re-referencing offline. While coherence estimates are inflated by an averaged-ears reference (Fein et al., 1988; Travis, 1994), this confound would be the same in both groups and during the three recordings sessions, and so would not mask possible group differences. The average-ear reference will also allow comparison with other TM studies, which used averaged-ear references. 2) A Ag/AgCl sensor was applied on the left wrist to measure heart rate referenced to Cz. And 3) a Ag/AgCl sensor was applied on the palm to measure skin potential responses using the recommended Unibase gel for the palm sensor (Fowles et al., 1981), referenced to a sensor on the forearm after abrading the skin and applied with EC2 crème (Stern et al., 1980).

Physiological variables were recorded at pretest and posttest during 1) 1-min eyes closed, 2) 1-min eyes open, 3) 1-min eyes open paced breathing at 10 bpm to calculate respiratory sinus arrhythmia, 4) 12-min of computer tasks (three different tasks), and 5) a 10-min eyes-closed session. The pretest data were collected at the beginning of the spring term, and the posttest was recorded one week before the finals' week of the spring term. Thus, posttest recordings were during the high pressure and stress of approaching finals' week for the college students.

At pretest, the participants were told to "Close the eyes and sit easily" during the last eyes-closed session. At posttest, participants were told: "Sit with eyes closed for 10 min, or practice the Transcendental Meditation technique for 10 min, if you have been instructed." Since, the researcher recording the data did not know if participants were resting with eyes closed or were practicing the Transcendental Meditation technique during the posttest, he was blind to group membership. Brain patterns during the final eyes-closed/Transcendental Meditation session will be reported elsewhere.

2.4. Intervention: the Transcendental Meditation technique

The Transcendental Meditation technique is a mental technique practiced 15–20 min, twice a day sitting comfortably. Transcendental Meditation practice involves a mantra. However, unlike most mantra meditations, any possible meaning of the mantra is not part of Transcendental Meditation practice. Rather, the individual is trained to appreciate the sound value of the mantra at more "refined levels" (Maharishi Mahesh Yogi, 1969). Also, unlike most mantra meditations, the Transcendental Meditation technique is not a process of concentration. Rather, Transcendental Meditation practice is a process of "effortless transcending"—using the mantra as a vehicle to take attention from the ordinary thinking level to the least excited state of consciousness—consciousness without content, called pure consciousness (Maharishi Mahesh Yogi, 1969; Travis and Pearson, 2000) (see Travis et al., 2002; Cahn and Polich, 2006 for a discussion of the concept of effortless transcending.).

The Transcendental Meditation technique is learned in a standardized seven-step course, including an introductory and preparatory lecture, personal interview, and four days of instruction—1 h each day (Roth, 1994). The four days of instruction include individual instruction followed by three group meetings. After the initial instruction, students came in individually for verification of correctness of their meditation practice once a month throughout the study. Also, weekly knowledge meetings were available to discuss experiences during meditation practice, application of TM practice to different areas of life, or scientific research on meditation effects.

2.4.1. Regularity of Transcendental Meditation practice

After data recording for the posttest, the meditating participants completed forms that tallied the number of Transcendental Meditation sessions per week since their last EEG recording. They were asked to put their estimate under a "sure" column or "best guess" column for each week since the last EEG recording.

2.5. Psychological measures: description and analysis

2.5.1. Sleepiness

The Epworth Sleepiness Scale is a valid and reliable measure of sleepiness (Olson et al., 1998; Benbadis et al., 1999; Chervin, 2000; Johns, 2000). It asks for the chance of dozing from 0 (never) to 3 (high chance) during eight common events, e.g. sitting and reading, watching TV, etc. The final score is the simple sum of these responses—from 0 to 24. A score of 11 or higher is considered indicative of heavy sleep debt.

2.6. Physiological measures: description and analysis

All physiological signals were digitized online at 256 points/s, with no high or low frequency filters, and stored for later analyses using Brain Vision Analyzer.

2.6.1. Brain Integration Scale

The Brain Integration Scale consists of brain preparatory response (contingent negative variation tasks) during a simple and choice paired reaction-time tasks, and broad band frontal EEG coherence (alpha: 8–12 Hz, beta: 12.5–20 Hz, and gamma: 20.5–50 Hz), and alpha/gamma power ratios during a vigilance task—Conner's Continuous Performance Test.

The simple reaction-time task lasted 2 min and measured attentional vigilance. Students were presented an asterisk (150 ms duration, 1 cm in height) in the center of a computer screen, followed 1.5 s later by S2, a continuous computer-generated tone (1200 Hz, 85 dB), and were asked to press the space bar as soon as they heard the tone. During the trials, participants were asked to focus on the center of the screen, and to rest their eyes after responding to the imperative stimulus. This resulted in very few eye-blinks, as noticed in Fp1 and Fp2, in the beginning 2 s Two-second epochs were extracted from the data stream beginning 100 ms pre-S1 and ending 400 ms post-S2. Any epochs with artifacts were manually marked and eliminated from the average. Before averaging, the data were passed through a .01–6 Hz band pass filter with 48 dB roll off to remove the effects of alpha activity on the averaged waveforms.

The choice reaction-time task lasted 4-min. Students were presented a one- or two-digit number (150 ms duration, 1 cm in height), a 1.5-s blank screen, and then another one- or two-digit number (150 ms duration, 1 cm in height), and were asked to press a left- or right-hand button to indicate which number was larger in value.

The data were analyzed as in the simple trials. Late CNV was measured during both simple and choice trials in microvolts as the average amplitude in the 200 ms window before the second stimulus, relative to the 100 ms baseline. Simple-choice difference-scores were calculated ($CNV_{simple} - CNV_{choice}$) to assess the impact of the additional cognitive load of the choice trials independent of possible group differences in the simple trials.

Connor's Performance Task-Identical Pairs task (CPT-IP) measures frontal executive functioning (Cornblatt et al., 1988). Participants were presented a capital letter (1 cm in height, 300 ms duration) every 0.9 s for 2 min. They were instructed to press a left button every time a letter appeared that was different from the preceding letter; and to press a right button every time the current letter was the same as the preceding letter. This task is highly challenging because the letters came quickly and 80% of the letters require a left-hand button press. Thus, participants develop a response bias for left hand responses. For the rare right-hand responses, the frontal executive system has to inhibit the left-hand response-bias and initiate the correct response.

Data during the CPT-IP task were visually scanned and any epochs with movement, electrode or eye-movement artifacts, as identified in the Fp1 and Fp2 electrodes, were manually marked and not included in the spectral analysis. The artifact-free data were digitally filtered with a 2–50 Hz band pass filter with 48 dB roll off, and fast Fourier transformed in 2-s epochs, using a Hanning window with 20% onset and offset. Absolute power (uV^2/Hz) was calculated from 2–50 Hz at the 32 recording sites in alpha, beta and gamma bands. Coherence was calculated for the 496 possible combination pairs of 32 recording sites in the same three bands. EEG coherence is the absolute value of the cross-correlation function in the frequency domain and reflects the number and strength of connections between spatially distant brain areas (Thatcher et al., 1987).

2.6.2. Brain Integration Scale calculation

Broadband frontal coherence, alpha/beta absolute power ratios, and the CNV difference scores were added to the normative database from our earlier work (Travis et al., 2002), converted to *z*-scores, and summed to yield Brain Integration Scale scores. This database included non-TM, short-term TM and long-term TM participants. Being a *z*-score measure, the non-TM participants scored around −2.3; the short-term TM participants scored around zero; and the long-term participants scored around 2.2. To make the scale intuitively obvious when measuring non-meditating populations, such as university students, we made the non-meditating participants the "zero" level on this scale; otherwise, normal individuals would have "negative" brain integration. While clinical populations could have negative brain integration; it would seem confusing to have normal populations with negative brain integration. To establish the "zero" level, we simply added 2.3 to each score.

2.6.3. P300 latency

Twenty percent of the stimuli in the Continuous Performance Test required a right-hand response. Rare stimuli evoke a P300—a positive component 300 ms after a stimulus that marks categorization processes. P300 latency is a standard measure of cortical speed of processing (Johnson, 1993). Data were binned by rare targets in 1-s windows—200 ms before stimulus onset and 1000 ms after the stimulus. The 39 segments were manually scanned and any segments with artifacts were removed from averaging. The latency of the largest positivity at Pz in a 300–700 ms window after the stimulus was considered the P300.

2.6.4. Heart rate and heart rate variability

Heart rate was recorded during the 2 min of paced breathing. We recorded heart rate during paced breathing (10 bpm), because breath rates below 7 bpm dramatically increase the magnitude of respiratory sinus arrhythmia through baroreflex feedback to the heart—independent of differences in parasympathetic innervation of the heart (Grossman et al., 1991; Grossman and Kollai, 1993). Heart rate and respiratory sinus arrhythmia—the high frequency component of heart rate variability—were calculated during the 2 min of paced breathing at 10 bpm using the moving polynomial algorithm suggested by Porges et al. (1982).

2.6.5. Electrodermal habituation

Skin potential responses were recorded on the non-dominant hand. Participants tapped the space-bar tap by the dominant hand in response to the sixteen 85-dB tones (2 ms rise time, 9 to 11 s ISI) in the first CNV task. Skin potential was measured, rather than skin conductance or skin resistance, because while the BIOSEMI recording-equipment includes DC amplifiers, they do not include GSR amplifiers.

Skin potential responses were counted if they fell in a 1–3 s window following the imperative stimulus. The number of tones before the participants stopped responding to three consecutive tones—the criterion for habituation—was recorded and compared between groups. The participants kept the finger of their dominant hand over the space bar during this task. Thus, there was minimal muscle movement required to press the space bar. EDA was recorded from the non-dominant hand, which was at rest by their side during the task. All subjects habituated to the task by the last trial in both pre- and post tests.

Table 1
Gender patterns, and baseline means (standard deviations) for demographics, Brain Integration Scale scores, sleep, habituation, P300 latency, heart rate variability and heart rate

Variables	Dropouts from the study (N=12)	Immediate-start (N=19)	Delayed-start (N=19)
Gender	Female=5 Male=7	Female=14 Male=5	Female=15 Male=4
Age (years)	20.0 (5.7)	25.6 (11.4)	21.8 (4.9)
Brain Integration Scale	1.5 (1.4)	1.76 (1.1)	1.46 (1.2)
Sleepiness	7.7 (4.2)	9.1 (3.2)	7.6 (3.0)
Habituation (number of trials)	4.2 (2.9)	4.2 (3.3)	4.7 (3.6)
P300 Latency (ms)	491 (76)	466 (80)	457 (60)
HRV (bpm)	7.9 (1.19)	7.9 (0.88)	7.8 (.89)
HR (bpm)	78 (10)	74 (10)	74 (10)

Note: There were no significant initial group differences between groups.

Table 2
Completer analysis: means (standard deviations), and effect sizes for the six variables at pretest and posttest

Variable	Mean (SD) immediate-start (N=19)		Mean (SD) delayed-start (N=19)		Effect size (d)
	Pre	Post	Pre	Post	
Brain Integration Scale	1.76 (1.3)	2.79 (1.2)	1.46 (1.4)	0.9 (1.3)	.99
Sleepiness	9.1 (3.2)	6.5 (3.0)	7.7 (2.9)	7.8 (3.5)	.90
Habituation (number of trials)	4.1 (3.3)	3.7 (3.5)	4.7 (3.4)	7.3 (3.4)	.64
P300 latency (ms)	462 (80)	457 (82)	448 (61)	442 (70)	.01
Heart rate variability (bpm)	7.9 (.7)	7.9 (.9)	7.8 (.9)	7.7 (1.1)	.11
Heart rate (bpm)	74 (10)	75 (9)	75 (10)	77 (14)	.09

Note: The Immediate-start group significantly decreased in sleepiness and habituation rates, and increased in Brain Integration Scale scores.

2.7. Statistical analysis

A MANOVA was used to test pretest group differences in Brain Integration Scale scores, sleepiness, electrodermal habituation, respiratory sinus arrhythmia, heart rate, and P300 latency. In this analysis the 6 subjects in each group, who did not attend the posttest, were included in the analysis (N=50). Another MANOVA compared the six variables in the 12 participants who did not come in for the posttest, the 19 Immediate-start participants, and the 19 Delayed-start participants.

A repeated measure MANOVA tested pretest-posttest differences between the 19 Immediate-start and the 19 Delayed-start participants with complete data. The hypothesis tested was that the Immediate-start group would have higher Brain Integration Scale scores, higher respiratory sinus arrhythmia amplitudes, lower reported sleepiness, lower electrodermal habituation rates, lower heart rate, and lower (faster) P300 latency. Significant group×treatment interactions were tested with post hoc analyses. This analysis tested directional hypotheses. Thus, one-tailed p-values will be reported for those analyses.

The Brain Integration Scale is a composite of three EEG variables. A third analysis compared group differences on the three variables that compose the Brain Integration Scale.

3. Results

3.1. Pretest analyses (N=50)

A MANOVA tested initial group differences. The omnibus F-test of all subjects (N=50) did not yield significant main effects for group (Wilk's Lambda $F(6,43)<1.0$, ns). The F-test of subjects with complete data (N=38) also did not yield significant main effects for group at pretest (Wilk's Lambda $F(6,32)<1.0$, ns). ANOVAs comparing pretest group differences on individual variables also did not yield significant effects—all p values >.19. Table 1 below presents the pretest means and standard deviations for the subjects who did not attend posttests, the Immediate-start and the Delayed-start groups. While there are large mean differences in Brain Integration Report Card and sleepiness between the Immediate-start and the Delayed-start subjects at pretest, these differences did not reach significance due to high variance within groups.

3.2. Repeated measure MANOVA of pretest–posttest scores (N=38)

A repeated measures MANOVA of data from all subjects with complete data resulted in significant three-way measures×group×treatment interactions ($F(5,32)=4.2$, p=.005). Thus, individual repeated

Table 3
Mean (standard deviations), *F*-statistics and *p*-values for the component variables in the Brain Integration Scale at pre- and posttest

Variable	Mean (SD) immediate-start		Mean (SD) delayed-start		Effect size: *d*
	Pre	Post	Pre	Post	
Alpha coherence	.31 (0.13)	.36 (0.10)	.30 (0.14)	.32 (0.11)	.26
Beta coherence	.25 (0.10)	.29 (0.10)	.23 (0.12)	.24 (0.08)	.13
Gamma coherence	.19 (0.09)	.19 (0.12)	.17 (0.09)	.16 (0.10)	.06
Alpha/Beta power ratios	1.42 (0.39)	1.56 (0.29)	1.32 (0.36)	1.44 (0.36)	.15
CNV difference scores (μV)	.69 (2.23)	−.98 (2.6)	1.30 (3.53)	3.45 (2.70)	.85

Note: There was a trend for higher broad band coherence and significant decreases in CNV difference scores for the Immediate-start group. As explained in the discussion, a "negative" CNV difference score means a better match between the timing and magnitude of cortical preparatory response and task demands during the simple and choice reaction-time tasks.

measure ANOVAs were conducted for each variable. There were no significant main effects or interactions for heart rate, respiratory sinus arrhythmia, or P300 latency ($F(1,36)<1.0$, ns). However, there were significant group × treatment interactions for Brain Integration Scale scores ($F(1,36)=17.5$, $p<.0001$), sleepiness ($F(1,36)=10.6$, $p=.001$), and habituation rates ($F(1,36)=6.6$, $p=.007$). Post hoc analyses revealed significant increases in Brain Integration Scale scores for the Immediate-start group ($F(1,18)=14.8$, $p=.001$) and significant decreases in the Delayed-start group ($F(1,18)=4.4$, $p=.05$); significant reductions in sleepiness in the Immediate-start group ($F(1,18)=15.2$, $p=.001$) with no change in the Delayed-start group ($F(1,18)<1.0$); and no changes in habituation rates in the Immediate-start group ($F(1,18)<1.0$), but significant increases in the Delayed-start group ($F(1,18)=5.2$, $p=.035$). Table 2 presents the means, standard deviations and effect sizes for these data.

3.2.1. Statistical test of the three components of the Brain Integration Scale

The Brain Integration Scale is a composite of three measures: 1) frontal coherence in alpha, beta, and gamma bands, 2) alpha/beta absolute power ratios, and 3) timing and magnitude of brain preparatory responses as reflected in the CNV difference scores. A MANOVA testing group differences in these three measures also resulted in a three-way measures × group × treatment interaction ($F(2,35)=5.2$, $p=.01$). Individual ANOVAs revealed 1) a trend for higher frontal broadband coherence for the Immediate-start group ($F(1,35)=2.3$, $p=.07$); 2) no significant main effects for power ratios ($F(1,35)=1.1$, $p=.15$); and 3) significant group × treatment interactions in CNV difference scores ($F(1,35)=8.1$, $p=.008$). Post hoc analyses revealed significant decreases in CNV difference-scores in the Immediate-start group ($F(1,18)=5.2$, $p=.035$), and significant increases in the Delayed-start group ($F(1,18)=4.3$, $p=.05$). A negative CNV difference-score is argued to reflect a better match between task demands and brain functioning, as detailed in Discussion.

Table 3 presents the means, standard deviations and effects sizes for the three components of the Brain Integration Scale. In this table, means and effect sizes of frontal coherence are presented in the three bands analyzed, even though they were combined into a single variable to calculate the Brain Integration Scale. The means are presented for each band to allow the reader to see the effect of Transcendental Meditation practice on coherence in each band.

3.2.2. Correlations between significantly different variables

Scores on the Brain Integration Scale negatively correlated with sleepiness ($r(37)=-.56$) and with habituation rates ($r(37)=-.38$).

4. Discussion

Significant differences in Brain Integration Scale scores, sleepiness, and habituation rates were seen after 10 weeks of Transcendental Meditation practice. Lower sleepiness and faster habituation rates were negatively correlated with higher scores on the Brain Integration Scale. This study reports effects of Transcendental Meditation practice compared to wait-listed controls. Future research could compare effects of Transcendental Meditation practice to other programs of stress reduction in college populations. For instance, practice of mindfulness-based stress reduction has been reported to increase self-reported well-being and decrease self-reported stress (Oman et al., 2008; Shapiro et al., 2008).

4.1. Consideration of significant findings

This study is the first random assignment study of effects of Transcendental Meditation practice on brain and physiological functioning in college students. These results replicate increases in Brain Integration Scale scores reported in a one-year longitudinal study using participants as their own controls (Travis and Arenander, 2006), and in a six-month longitudinal study comparing students practicing the Transcendental Meditation technique to matched controls (Travis, 2002). These two earlier studies tested students at Maharishi University of Management, where twice-daily meditation practice is part of the curriculum. The current random-assignment study extends these findings to include effects of Transcendental Meditation practice in meditating students following a more typical college curriculum.

The variables that changed significantly are functionally related. The Brain Integration Scale includes broadband frontal coherence. Prefrontal executive areas control electrodermal habituation (Hugdahl, 1998; Critchley et al., 2000). The efficient physiology responds initially to any novel stimulus, but then stops responding, once the stimulus has been recognized as being non-threatening. The posttest was recorded one week before the end of the term. It was a time of high pressure and stress for the students. While the Delayed-start participants showed the expected increased in sympathetic reactivity under high stress, the sympathetic reactivity of the meditating students remained low. Transcendental Meditation practice seemed to buffer effects of the high stress of finals' week. This replicates findings of faster habituation rates and also faster recovery from stressful stimuli in TM participants (Orme-Johnson, 1973), and fMRI findings of lower thalamic and lower total brain activation during a temperature stress in long-term TM participants (Orme-Johnson et al., 2006).

Prefrontal cortices also guide timing and magnitude of brain preparatory responses (Gomez et al., 2007). Higher preparatory responses during simple trials reflect efficient use of resources—participants knew the correct response after the first stimulus, and so could begin preparatory processes. In contrast, during the choice trials, participants did not know the correct response after the first stimulus and so should remain balanced. The control group had higher preparatory responses during the choice trials, which did not indicate efficient use of brain resources.

There was a trend for higher frontal (F3–F4) broadband coherence at posttest in the Immediate-start group. EEG coherence indexes functional connectivity between brain areas. The electrode sites F3 and F4 are over medial frontal and anterior cingulate cortices, which were identified as sources of EEG alpha activity during Transcendental Meditation practice in a MEG study (Yamamoto et al., 2006). The anterior cingulate is important in conflict detection (Carter and van Veen, 2007) and works with the medial prefrontal cortices to control mental flexibility, self-regulation, processing speed, and memory (Pardo et al., 2007). Frontal coherence may support enhanced flexibility and self-regulation, which were not directly measured in this study but have been reported in TM studies of cognitive functioning (Dillbeck, 1982; Alexander et al., 1991).

Last, the Delayed-start group's "chance of dozing" in eight common events did not change from pretest to posttest, while there were significant reductions in sleepiness in the Immediate-start group. This finding could reflect the impact of the restfully alert state gained during Transcendental Meditation practice on mind and body after meditation. Also, we could speculate that frontal areas responsible for planning and guiding behavior, which are activated during Transcendental Meditation practice, may lead to better decision-making and lifestyle choices after meditation.

4.2. Consideration of non-significant findings

4.2.1. Respiratory sinus arrhythmia—high frequency component of heart rate variability

Changes in respiratory sinus arrhythmia, a measure of parasympathetic tone, were similar in both groups over the three testing periods. In this study, respiratory sinus arrhythmia was calculated from EKG recorded during an eyes-open paced-breathing period, which controls for the effect of slow breath rate on the amplitude of respiratory sinus arrhythmia (Grossman et al., 1991).

A previous randomized controlled trial reported a trend ($p = .07$) for greater respiratory sinus arrhythmia after 16 weeks of Transcendental Meditation practice in an older population with cardiovascular disease (Paul-Labrador et al., 2006). Respiratory sinus arrhythmia calculated over 24 h has been shown to differentiate participants with hypertension, diabetes, and coronary artery disease, and those with myocardial infarction and heart failure (Sztajzel, 2004; Madsen et al., 2007). The lack of replication of these findings could be due to three factors. First, the subject populations differed. The previous study investigated an older clinical population with coronary heart disease, ranging in age from 50–80 years, compared to healthy college age participants measured in the current study. Second, EKG was recorded over different periods. The previous study calculated respiratory sinus arrhythmia over 24 h, which includes effects of lifestyle on the calculated heart rate variability. The current study recorded EKG during paced breathing session that controls for these factors (Grossman et al., 2004). The last factor—how respiratory sinus arrhythmia was calculated—probably did not affect the outcome. Spectral power methods, used to calculate heart rate variability in the previous study, yield results similar to those from the polynomial algorithm used in the current study (Berntson et al., 1997). Future research is needed to further evaluate effects of Transcendental Meditation practice on parasympathetic tone.

4.2.2. Heart rate

Heart rate during the paced breathing session also did not change during the study period. The participants were sitting comfortably and not under challenge during the paced-breathing recording session. Thus, metabolic needs were similar during the two recordings.

4.2.3. P300 latency

P300 latencies also did not change during the study period. P300 latency is a brain measure of cognitive functioning—how quickly one categorizes stimuli. Elderly participants practicing the Transcendental Meditation technique for an average of 15 years do not show age-related declines in P300 latency (Goddard, 1989). Additional research is needed to investigate possible effects of Transcendental Meditation practice on P300 latency.

4.3. Implication of these findings for education

College is a time of great challenge for the student. Most students are making major lifestyle decisions for the first time. At the same time, the academic, financial, and social demands of the college experience can be highly stressful (Arnedt et al., 2005; Zeigler et al., 2005). These factors add up. In these data, the decrease in Brain Integration Scale scores and the increase in sympathetic reactivity and sleepiness in the Delayed-start group from the beginning of the term (pretest) to just before finals' week (posttest) suggest the substantial effect of the college experience on students. In contrast, Transcendental Meditation practice appeared to buffer effects of the high stress of finals' week—Brain Integration Scale scores increased; sleepiness decreased—students were less tired, sympathetic reactivity did not change from pretest to posttest. These data support the value of practicing the Transcendental Meditation technique during college.

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