ADHD, Brain Functioning, and Transcendental Meditation Practice

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ABSTRACT

This random-assignment pilot study investigated effects of Transcendental Meditation (TM) practice on task performance and brain functioning in 18 ADHD students, age 11–14 years. Students were pretested, randomly assigned to TM or delayed-start comparison groups, and posttested at 3- and 6-months. Delayed-start students learned TM after the 3-month posttest. Three months TM practice resulted in significant decreases in theta/beta ratios, increased theta coherence, a trend for increased alpha and beta1 coherence, and increased Letter Fluency. The delayed-start group similarly had decreased theta/beta ratios and increased letter fluency at the 6-month posttest, after they practiced TM for 3 months. Also, all students significantly improved on five ADHD-symptoms over the six months of the study, as reported in the parent's survey. These findings warrant additional research to assess the impact of TM practice as a nondrug treatment of ADHD.

Keywords: ADHD, brain, Transcendental Meditation, coherence, theta/beta ratios, learning disabilities

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Attention-deficit/hyperactivity disorder (ADHD)—characterized by inattentiveness, impulsivity, and hyperactivity—is diagnosed in 8% of children age 4–17 years.[1] Factors associated with increased risk of ADHD include unhealthy maternal lifestyle (drinking and smoking), premature birth and low birth weight, and poor early childhood care.[2–4] Some researchers also theorize that there is a genetic factor associated with ADHD.[5–7] Studies identify imbalances in dopaminergic and noradrenergic systems in ADHD children,[8,9] along with developmental abnormalities in fronto-striatal circuits that lead to maladaptive response to environmental challenge. These abnormalities include (1) lower frontal metabolic rates as measured by PET[10] and by MRI,[11] (2) lower myelination in frontal-striatal circuits,[12] and (3) lower cortical volume in left frontal and temporal areas.[11,13]

The EEG studies report decreased activation in ADHD populations in parietal cross-modal matching areas that weave sensory input into concrete perception,[14] higher density and amplitude of theta activity,[15,16] and lower density and amplitude of alpha and beta activity.[17] Theta/beta power ratios are highly correlated with severity of ADHD symptoms.[18,19] Normal adolescents exhibited theta/beta ratios from 2.5 to 3.5 in one study[20]; and 3.0 to 3.5 in another.[16] The ADHD populations exhibit theta/beta ratios greater than 5.[18,19] In normal adolescents, theta rhythms gradually increase in memory tasks a few seconds before an anticipated response and reach a peak immediately after the response.[21,22] During memory tasks, theta EEG is generated in the hippocampus and is thought to block out irrelevant stimuli during memory processing.[23] In ADHD subjects, greater theta activity may block out relevant as well as irrelevant information.

Another brain marker of ADHD is EEG coherence, a measure that reflects the number and strength of connections between different brain areas.[24] Adults diagnosed with ADHD are reported to have lower alpha coherence,[25,26] and in children diagnosed with ADHD coherence in all frequencies is reported lower.[27,28] The brain processes indexed by alpha coherence have an important role in attention and consciousness. They coordinate the selection and maintenance of neuronal object representations, which are reflected in beta and gamma activity.[29,30] Thus, lower alpha coherence in ADHD populations could document disrupted working memory and attention.

DRUG TREATMENTS OF ADHD

Most drug treatments of ADHD contain methylphenidate or amphetamines that increase dopamine and noradrenalin in the synapse by either increasing the release of neurotransmitters or blocking their reuptake. However, up to 30% of ADHD children either do not respond to, or do not tolerate, treatment with stimulants.[31,32] Even for children who do respond to medication, often the effect is modest.[2] In addition, in some patients drug treatments result in disruptions in sleep and appetite and increases in apathy and depression, which significantly affect physiological, cognitive, and behavioral functioning.[33]

BEHAVIORAL INTERVENTIONS FOR ADHD

Since ADHD may reflect a lag in natural brain development,[11–13] can stalled brain development be jump-started in some way? Brain circuits are highly plastic and are continually sculpted with each experience.[34–37] Thus, behavioral interventions that activate frontal-striatal circuits could potentially facilitate brain development in ADHD populations and so improve executive function and cognitive performance during tasks.

As mentioned, the key brain circuits that are underdeveloped in ADHD populations include frontal areas (major integrative centers), cingulate gyri (attention switching), parietal areas (concrete experience centers), and striatum (motor activation). One class of behavioral interventions exercise the motor node in this circuit. For instance, the Interactive Metronome, which involves matching a computer-generated beat, would exercise motor circuits. This intervention, however, has had limited benefits on reducing ADHD symptoms in clinically controlled studies.[38] Neurofeedback is another nondrug intervention that teaches children to control theta and/or beta brain activity by interacting with a computer game. Although requiring many training sessions—45 sessions lasting 40 minutes each—neurofeedback is reported to reduce ADHD symptoms[39] and reduce amplitude of theta EEG with no effect on beta amplitude.[40]

Meditation as a Behavioral Intervention

Meditation practices activate distinct brain areas, which makes these areas progressively more available during tasks after meditation.[41–43] For instance, Mindfulness Meditation, in comparison with mental math, leads to increased blood flow in prefrontal areas,[44] and to thickening of brain areas involved with attention switching and perception of bodily states.[43] Preliminary research investigated effects of mindfulness training on 24 adults and 8 adolescents diagnosed with ADHD, who received an 8-week mindfulness-training program involving 2.5 hour sessions once/week and 45-min daily meditation sessions at home. Seventy-five percent of these individuals finished the 8-week program. After the mindfulness training, both adults and adolescents exhibited significant decreases in inattention and hyperactivity. Only the adults also showed significant reductions in depression and anxiety.[45]

Another form of meditation, the Transcendental Meditation (TM) technique, is reported to lead to increased cerebral metabolic rate in frontal and parietal attentional areas in a PET study[46]; greater activity in prefrontal executive circuits and anterior cingulate attention circuits in a MEG study[47]; and higher frontal alpha1 power and coherence and higher beta1 power in EEG studies.[48] Preliminary research with a single group design with 10 ADHD children age 11–14 years reported that 3 months of TM practice resulted in significant reductions in anxiety and depression and significant improvements in executive function and behavior regulation.[49]

The current study extends the preliminary findings of the effectiveness of TM practice on reducing ADHD symptoms by using a random-assignment delayed-start design to assess effects of TM practice on performance on standardized measures of executive functioning and on brain wave patterns (EEG) during a computer-administered choice reaction time task. In this study we hypothesized: If TM practice activates and strengthens frontal executive circuits, then ADHD students who practice the TM technique, compared to delayed-start students, should exhibit (1) lower theta/beta power ratios, indicating greater brain activation during tasks; (2) higher frontal, parietal, and anterior/posterior coherence, indicating greater communication between brain areas during a visual-motor task; and (3) improved performance on executive functioning tests.

METHOD

This is a pilot test of effects of TM practice on ADHD symptoms. It tests whether middle school students diagnosed with ADHD can learn and practice the TM technique, and it investigates effects of TM practice on executive functioning and brain functioning in these students.

Subjects

All students attended an independent school for children with language-based learning disabilities in Washington, DC. All students received two clinical diagnoses. First, licensed psychiatrists identified students with ADHD according to the *DSM IV-TR* criteria and recommended that they attend this school. Second, professionals in the school verified the clinical diagnoses and placed them into their school system. The curriculum at the school is designed to help students with ADHD and other learning disabilities.

Twenty-four families responded to an information letter about the study and volunteered to participate. Twenty-three chose to participate in the study; the 24th student learned TM but did not participate in assessments. Four students were not part of the randomized study, because their parents asked that they learn the TM technique immediately. The remaining 18 students were stratified by age, and randomly assigned to learn TM immediately (TM group: 6 boys, 3 girls, average age 12.9 ± 1.3), or learn TM in 3 months (delayed-start group: 7 boys, 2 girls, average age 13.0 ± 1.6).

Table 1 presents the *DSM-IV* clinical diagnoses and medication use for the 18 randomized students. Comorbidities included General Anxiety Disorder (3 subjects), Obsessive Compulsive Disorder (1 subject), and Autism (3 subjects). In each group, five of the nine subjects were on ADHD medication.

As seen in this table, random assignment placed more subjects with comorbidities in the TM group (4) than in the delayed start group (1). Subjects with comorbidities may be more resistant to change. Thus, this was a conservative test of effects of TM practice on brain and executive functioning in an ADHD population.

Written informed consent was obtained from the parents and students before pretesting. The Maharishi University of Management IRB approved the research.

Table 1. DMV-IV Diagnoses and Medication Use for the TM and Delayed Start Groups

	TM Group			Delayed Start Group		
ADHD Type	ADHD Type	Subjects on ADHD Medication	Comorbidity	ADHD Type	Subjects on ADHD Medication	Comorbidity
Inattentive	3	1	1	1	0	0
Hyperactive	2	1	1	2	1	0
Combined	4	3	2	6	4	1
Totals	9	5	4	9	5	1

Procedure

Students were pretested, and then stratified by age and ADHD symptoms and randomly assigned to a group—immediate start TM or delayed-start—using blind drawing of names. Certified teachers of the TM technique went to the school to instruct the students in TM practice—four consecutive days—and then for follow-up meetings once a month. The students were instructed in the standardized format to learn the TM technique, as described below. Four teachers at the school learned the TM technique and meditated with the children morning and afternoon.

Students were given paper-and-pencil tests in the school during class time, and made individual appointments for performance tests and EEG recordings. All students were posttested at 3 months and 6 months. The delayed-start students learned TM after the 3-month posttest.

Psychological Test Measures

Delis-Kaplan Executive Function System (D-KEFS) Verbal Fluency

The D-KEFS tests executive functions such as flexibility of thinking, inhibition, problem solving, planning, impulse control, concept formation, abstract thinking, and creativity in both verbal and spatial modalities.[50] It has been standardized and used in both clinical groups and as a research tool for increasing knowledge of frontal-lobe functions.[51] The Verbal Fluency subscale was considered appropriate because the school specializes in teaching students with language-based learning difficulties. The Verbal Fluency test provides information about the student's word fluency and language-related concept fluency. It also assesses the ability to shift from one concept to another,[52] a difficulty associated with ADHD. The measure also includes an Alternate Form, thus reducing practice effects at posttest.

The analysis of the Verbal Fluency test yields four measures: Letter Fluency, Category Fluency, Category Switching, and Total Switching Accuracy. Letter Fluency is the total number of words the student can think of that start with a specified letter, in three 60-sec trials. Category Fluency is the number of words the student can say that belong to a designated semantic category (eg, animals, fruit) in two 60-sec trials. Category Switching evaluates the student's ability to alternate between saying words from different semantic categories within a 60-sec trial. Total switching accuracy includes the number of responses and number of correct responses in each trial.

Tower of London

The Tower of London measures higher order problem solving. Subjects are shown a configuration of colored balls stacked on pegs. The subject executes a sequence of moves that transforms his or her board to match the displayed configuration with the balls arranged on designated pegs. This analysis yields total correct score, total initiation time, total move score, total execution time, total time score, and total time violation. It has a reliability coefficient of .80 and loads on a principle component analysis with other tests of executive planning/inhibition.[53]

Self-Report Instruments

Two self-report instruments were administered at the end of the study—one to the children and one to their parents. The first one asked the children: ''How much do you like your TM practice?'' on a 7-point Likert Scale—1 (Not At All) to 7 (Very Much). The second scale asked parents how their children had changed on five ADHD-related symptoms. There were asked: ''Compare your child before learning the Transcendental Meditation technique to now. Indicate the degree of change you have observed in the following areas: (a) ability to focus on schoolwork, (b) organizational abilities, (c) ability to work independently, (d) happiness, and (e) quality of sleep.'' Responses were along a 11-point Likert Scale from –5 (Strong Negative Changes) to 5 (Strong Positive Changes).

Other Psychological Tests

Four other tests were administered. However, because there were incomplete data for these four measures, these data are not interpretable. Thus, they will not be reported. The test and the corresponding number of completed forms were: Spielberger's State and Trait Anxiety scale (TM = 4, Delayed = 6), SNAP IV (TM = 5, Delayed = 5), the Teacher BRIEF (TM = 3, Delayed = 5), and the Youth Self-Report (TM = 7, Delayed = 5).

EEG Recording Protocol

The EEG was recorded during a computer-administered paired choice reaction-time task to calculate theta/beta ratios (Cz) and patterns of EEG coherence. The task began with a one- or two-digit number (300 ms duration), a 1200 ms blank screen, and another one- or two-digit number (300 ms duration). Subjects were asked to press a left- or right-hand button to indicate which number was larger in value. This task was chosen because performance on this task discriminated meditating and nonmeditating college students.[54]

The BIOSEMI ActiveTwo system was used to record EEG from 32 locations over the scalp, following the 10-10 system. Signals from the left and right ear lobes were recorded for later re-referencing as a linked-ears reference. All signals were digitized on line at 256 points/sec, with no high or low frequency filters, and stored for later analyses using the Brain Vision Analyzer.

The data during the task were visually scanned and any epochs with movement, electrode, or eye-movement artifacts 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 and fast Fourier transformed in 2-sec epochs, using nonoverlapping Hanning windows with a 10% onset and offset.

Power (uV^2/Hz) was calculated from 2 to 50 Hz at the 32 recording sites. To investigate theta/beta ratios, power at Cz during the task was averaged into theta (4–7.5 Hz) and beta (13–20) bins and theta/beta ratios were calculated.[19]

Coherence patterns during the computer task were averaged into 11 intra- and interhemispheric frontal coherence pairs, 11 intra- and interhemispheric parietal coherence pairs, and five anterior/posterior coherence pairs. The 11 frontal pairs included: AF3-AF4, F3-F4, FC1-FC2, F7-F3, AF3-F3, AF3-FC1, F3-FC1, F8-F4, AF4-F4, AF4-FC2, F4-FC2; the 11 parietal pairs included: CP1-CP2, P3-P4, PO3-PO4, P7-P3, CP1-P3, CP1-PO3, P3-PO3, P8-P4, CP2-P4, CP2-PO4, PO4-P4; and the five anterior/posterior pairs included: F3-P3, FzPz, F4-P4, AF3-PO3, AF4-PO4. Averaged coherence was analyzed in theta (4–7.5 Hz), alpha (8–12 Hz), beta1 (12.5–20 Hz), and gamma bands (20.5–50 Hz).

Intervention: The Transcendental Meditation Program

The Transcendental Meditation (TM) technique is a mental technique practiced for 10 min (for these students) sitting in a chair with eyes closed. During TM instruction, the student learns how to let the mind move from active focused levels of thinking to silent, expanded levels of wakefulness underlying thoughts.[55,56] Certified teachers taught these students the TM technique using the standardized teaching format of four 1-hour meetings over 4 days, followed by knowledge and experience meetings every other week for the first few months to assure correct practice. (See Travis & Shear[57] for a more detailed description of the TM technique.)

After personal instruction, students meditated in a group at school at the beginning and at the end of the day with a school teacher, who was trained to lead the meditation. A certified TM teacher met with students as needed to discuss experiences, verify correct practice, and answer questions about their TM practice. The group practice allowed easy logging of compliance—as long as students were not absent, they practiced TM.

Statistical Analysis

The primary analysis was a between comparison of differences from baseline to the 3-month posttest between groups. The TM group had been practicing the TM technique for 3 months along with the curriculum at the school; the delayed-start comparison group had only been receiving the curriculum at the school. This analysis is the strongest test of the hypothesis. In this analysis, two repeated measures MANOVAs were conducted—psychological and performance variables in one and coherence in the other. An ANCOVA of theta/beta ratio difference scores, covarying for pretest scores, was also conducted.

An alpha level of .05 was used for these three initial tests. If significant interactions were found, then further F-tests were used for subanalyses. An alpha level of $<.025$ was used for further tests. Partial eta squared ($\eta 2$), the power statistic reported for F-tests by SPSS, is reported for all analyses. Partial eta squared is the variance accounted for, similar to r^2.

A secondary within analysis assessed changes in the delayed-start students comparing differences from baseline to the 3-month posttest, when these subjects were not yet meditating, to differences from the 3-month to the 6-month, when these subjects were meditating. This analysis is an exploratory analysis, since it is a single group design. However, we expect to see a similar pattern of change as in the primary analyses.

RESULTS

Feasibility of the Intervention

All students in the TM group and, later, all students in the delayed-start group were able to learn the TM technique and practice it successively. This was evidenced in their daily group TM practice, which was done in the morning and afternoon in groups at the school. Also, a questionnaire was administered at posttest to assess how the students felt about their TM practice. This questionnaire used a 7-point Likert scale—1 Not-At-All to 7 Very-Much—to quantify the response. Students reported that the TM technique was enjoyable and easy to do (average $= 5.3 \pm .9$). They may have been able to learn and practice this meditation technique, because TM does not involve concentration or control of the mind—a challenge for anyone with ADHD. (For a detailed discussion of mechanics during TM practice see Travis & Shear[57]).

Changes in Brain Functioning

Theta/Beta Ratios

The ANCOVA of theta/beta difference scores, covarying for pretest scores yielded significant decreases in theta/beta ratios of EEG recorded at Cz in the TM group ($F(1, 17) = 4.7$, $p = .05$, $\eta 2 = .24$). **Figure 1** presents the means and standard errors for the theta/beta ratios at pretest and the two posttests. At pretest, both groups were well above the average for theta/beta ratios in normal populations. At the 3-month posttest, theta/beta ratios increased slightly in the delayed-start group (dotted

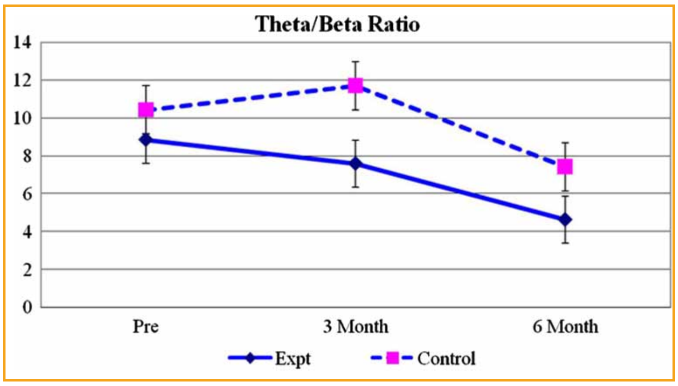

Figure 1. Theta/beta power ratios during computer tasks in the TM group decreased compared to the delayed-start group after 3 months of TM practice and continued to decrease at the 6-month posttest in these subjects. In the delayed-start group theta/beta power ratios increased slightly from baseline to the 3-month posttest and then decreased sharply after they learned TM (3- to 6-month posttest).

line with square markers), while the TM subjects (solid line diamond markers) decreased—moved closer to normal values. At the 6-month posttest after both groups were practicing the TM technique, theta/beta ratios decreased in both groups.

Coherence Patterns: Quantitative Results

A repeated measures (pretest/3-month posttest) MANOVA of coherence during tasks with 12 variates—coherence in theta, alpha, beta, and gamma frequency bands averaged into frontal, parietal, and anterior/parietal brain areas—yielded significant frequency $\times$ group interactions (Wilks' Lambda $F(3, 14) = 4.70$, $p = .018$ $\eta 2 = .50$). Thus, analyses were conducted within each frequency. Significant group $\times$ pre/posttest interactions were seen in the theta band (Wilks' Lambda ($F(1, 16) = 5.60$, $p = .031$, $\eta 2 = .26$), a trend for significant increases in the alpha band ($F(1, 16) = 3.3$, $p = .09$, $\eta 2 = .17$), and in the beta band ($F(1, 16) = 5.50$, $p = .08$, $\eta 2 = .18$) across all brain areas in the TM group.

Coherence Patterns: Visual Results

As this is a pilot test of effects of TM practice on ADHD brain patterns, we explored differences in coherence across the three periods. Coherence-difference maps were created by subtracting coherence calculated at pretest from coherence at the 3-month posttest within each group. Also, in the delayed start group, we subtracted coherence from the two posttests—after they had been meditating for 3 months. These coherence-difference maps in theta (5.0–7.5 Hz), alpha (8.0–12 Hz), beta1 (13–20 Hz), and gamma bands (20.5–50 Hz) are displayed in **Figure 2**. A .2 cutoff was used to display coherence differences. Coherence averaged around .6. Thus, a difference of .1–.2 in coherence between groups represents a 30% difference in coherence.

Figure 2 presents the coherence-difference maps. As seen here, there were few sensors with higher coherence in the delayed-start group at the 3-month posttest compared to their pretest values (top row); there were many frontal and parietal areas with higher coherence in the TM group at 3-month posttest compared to pretest values (middle row); and there were many frontal and parietal areas with higher coherence in the delayed-start group at the 6-month posttest compared to the 3-month posttest values (bottom row).

Changes in Performance on the D-KEFS and the Tower of London

Baseline Differences

There were no significant group differences at baseline for the four measures from the D-KEFS and six measures from the Tower of London (all Wilk's Lambda $F(12, 5) < 1.0$).

Primary Analyses

The omnibus repeated-measures MANOVA with 10 variates—four measures from the D-KEFS and six from the Tower of London—yielded significant measure $\times$ group interactions, Wilk's Lambda $F(10, 7) = 3.7$, $p = .041$, $\eta 2 = .84$. Thus, individual repeated-measure MANOVAs were conducted for each psychological measures.

Tower of London

The repeated measures MANOVA with the six Tower of London measures as variates yielded significant pre/posttest differences for all variables (Wilk's Lambda $F(1, 16) = 17.7$, $p = .001$, $\eta 2 = .52$), but no significant group $\times$ pre/posttest interactions ($F(1, 16) < 1.0$). There appears to have been significant learning effects in subjects in both groups on this test.

D-KEFS Verbal Fluency

The repeated measures MANOVA with the four DKEF measures as variates yielded significant measure $\times$ prepost interactions (Wilks' Lambda $F(3, 14) = 4.2$, $p = .025$, $\eta 2 = .48$). Therefore, separate ANCOVAs of difference scores covarying for pretest values were conducted for each subscale. There were significant increases from pretest to 3-month posttest in Letter Fluency for the TM group ($F(1, 15) = 7.7$, $p = .017$, $\eta 2 = .34$), and no significant group differences on other components of the Verbal Fluency test. **Table 2** presents the mean scores on the D-KEFS Verbal Fluency test for pretest, 3-month, and 6-month posttest for the two groups.

Parent's Self-Report Questionnaire

At the end of the research, the parents completed an 11-point Likert scale questionnaire (–5 Strong Negative Changes to 5 Strong Positive Changes) to assess their perceptions of changes in five ADHD-related symptoms in the their children from the beginning to the end of the study. On this instrument, there were positive and statistically significant improvements in the five areas measured: (a) ability to focus on schoolwork, (b) organizational abilities, (c) ability to work independently, (d) happiness, and (e) quality of sleep. **Table 3**

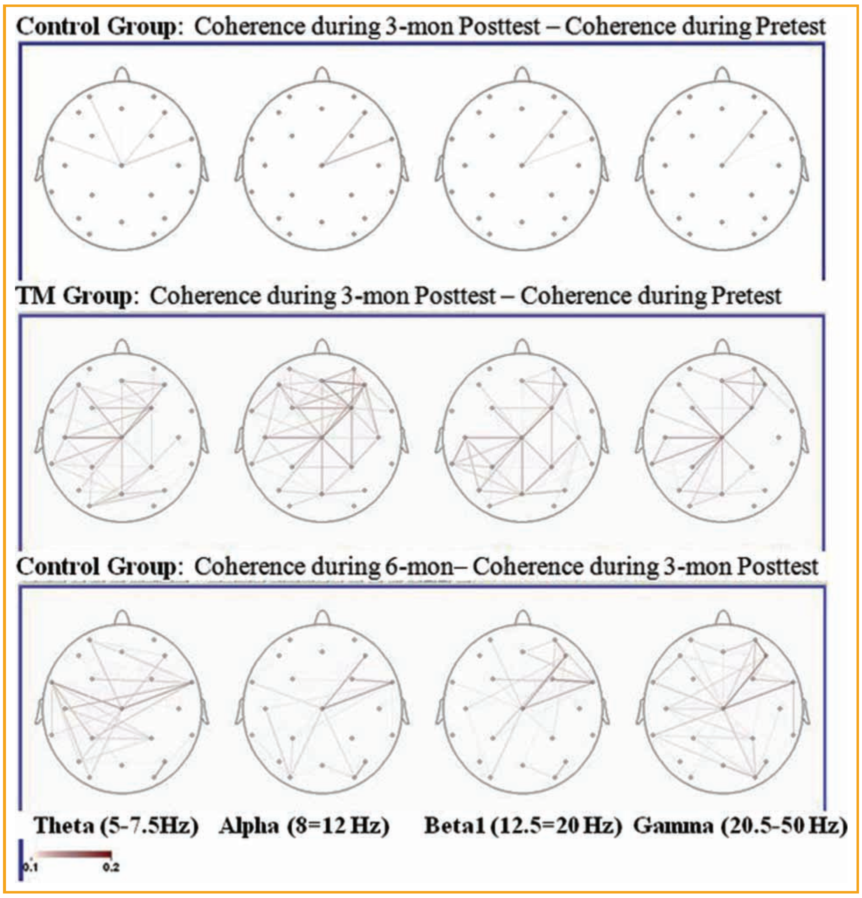

Figure 2. Three coherence-difference maps are presented in this figure. In the top row is coherence during the 3-month posttest minus baseline coherence for the delayed-start subjects who did not meditate over this time. In the middle row is coherence during the 3-month posttest minus baseline coherence for the TM subjects. In the bottom row is coherence during the 6-month posttest minus 3-month posttest coherence for the delayed-start subject, who had been meditating over this time. As seen in this figure, there are few recording pairs with higher coherence in the control group (3-month posttest minus pretest), and many areas of increased coherence pairs after 3 months of TM practice in the TM and delayed-start groups.

presents the means, standard error, *t*-test statistics, and significance for these variables.

Secondary Analysis

Repeated measure MANOVAs reported significant increases in D-KEFS in the delayed-start group after they learned TM compared to the time from baseline to the 3-month posttest ($F(1, 8) = 7.8$, $p = .024$, $\eta 2 = .49$). Theta/beta ratios also significantly decreased from the 3-month to 6-month posttest (–4.3) in this group when compared to baseline to 3-month posttest (1.3) ($F(1, 8) = 5.1$, $p = .053$, $\eta 2 = .39$). There were no within group differences in the delayed-start group on other measures.

DISCUSSION

In this random assignment pilot test, 3-months practice of the TM technique resulted in significant decreases in theta/beta ratios, significant increases in theta coherence, and trends for increases in alpha and beta coherence during tasks. These brain measures were supported by significant increases in Letter Fluency and significant increases in positive behavior reported by the parents. The single-group within analysis of the delayed-start group yielded similar decreases in theta/beta ratios and increases in Letter Fluency after the delayed-start group learned TM.

Table 2. Mean Scores (Standard Error) for the Pretest, 3-Month, and 6-Month Posttests for the D-KEFS Verbal Fluency Scores

	TM Group			Delayed Start Group		
Variable	Pretest	3-Month Posttest	6-Month Posttest	Pretest	3-Month Posttest	6-Month Posttest
Letter fluency	**20.3 (3.5)**	**27.1 (3.5)**	30.0 (4.1)	22.6 (1.9)	**23.1 (2.7)**	**31.8 (2.9)**
Category fluency	27.2 (3.0)	25.3 (3.7)	29.8 (2.3)	29.3 (3.2)	26.3 (2.3)	31.1 (2.7)
Category switching	8.8 (.9)	8.7 (.8)	9.0 (1.0)	10.6 (.6)	10.2 (.7)	11.5 (.5)
Total switching accuracy	6.8 (.8)	9.3 (.8)	10.7 (1.0)	7.3 (.7)	8.7 (1.1)	9.5 (.4)

Note: There were significant increases in Letter Fluency in the TM group from pretest to 3-month posttest, and in the delayed-start group from the 3-month posttest to 6-month posttest. Significant differences are bolded for easy identification.

Table 3. Mean, Standard Error, *t*-Test and *p*-values for Likert Scale of Parent's Observations

	Mean	Standard Error Mean	t-Test (17)	p (Two-Tailed)
Ability to focus on work	1.83	.36	5.16	.000
Organizational abilities	1.67	.43	3.89	.002
Ability to work independently	2.08	.33	6.33	.000
Happiness	1.42	.37	3.87	.002
Quality of Sleep	1.50	.40	3.75	.003

Note: There were significant improvements in these given areas after the children had practiced TM for 3–6 months.

Proposed Mechanism: Experience Related Cortical Plasticity

The brain is a self-organizing system—repeated experience enhances brain circuits involved in that experience.[34] During TM practice, one experiences a mantra as a thought, and then experiences that thought at more subtle levels—less clear, less distinct. This results in a style of attending characterized by low arousal with high attention. This is a new style of directing attention called "restful alertness."[55,56] Typically high arousal goes with high attention and low arousal goes with low attention.[58] This state of restful alertness corresponds to higher frontal and parietal cerebral metabolic rate—part of the attentional system—and lower thalamic metabolic rate,[46] and to higher activity in the default mode network.[48] Activity in the default mode network is higher during self-directed tasks and lower when attention is engaged with objects of attention.[59,60]

Repeated experiences of restful alertness during TM practice may change attentional processes during tasks. Heightened attention could lead to higher beta EEG leading to decreased theta/beta ratios. The percentage decrease in theta/beta ratios over the 6 months of this study was 48%—from 8.8 to 4.6 in the TM group and from 11.7 to 7.4 in the delayed-start group after they learned TM. This percentage decrease is more than that reported from use of methylphenidate, less than 3%,[61] and more than that reported from neurofeedback—an average of 33% in three studies.[40,62,63]

Frontal executive circuits activate and sequence other brain areas. Subjects with greater success in a visuomotor tasks exhibit higher coherence across all frequency bands.[64] With 3-month TM practice, frontal, parietal, and anterior/posterior theta, alpha, and beta1 coherence increased. These coherence changes were observed during a demanding computer task. Higher coherence could also explain previous findings of improved ability to concentrate and better emotion control in ADHD children with 3 months of TM practice.[49]

Phenomenologically, higher alpha and beta coherence are associated with a stable experience of inner self-awareness, posited to underlie thinking.[56] With regular TM practice, this experience of inner self-awareness could begin to form a stable background for processing experiences.[42] In ADHD children, this could provide a new foundation to organize experiences resulting in better behavior regulation and improved mental performance.

Ability of D-KEFS to Discriminate ADHD Groups

After the study was conducted, Wodka and colleagues investigated D-KEFS's ability to classifying ADHD (N = 54) and normal control subjects (N = 69).[65] They reported that DKEF discriminated groups at a trend level ($p = .09$). Their finding could reflect the fact that they used high functioning subjects. Future research could explore the relation of D-KEFS scores, brain scores, and behavioral measures in ADHD populations.

FUTURE RESEARCH

This random assignment study of brain and psychological measures supports the efficacy of TM practice as treatment for ADHD, replicating an earlier study using a single-group design. Future research is needed to replicate these findings in a larger subject population, to use other measures of executive functioning, and to compare effects of different meditation practices on enhancing brain functioning and promoting positive psychological and emotional well-being in ADHD populations.

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