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IMPROVED FUNCTIONAL ORGANIZATION OF THE BRAIN THROUGH THE MAHARISHI TECHNOLOGY OF THE UNIFIED FIELD AS INDICATED BY CHANGES IN EEG COHERENCE AND ITS COGNITIVE CORRELATES: A PROPOSED MODEL OF HIGHER STATES OF CONSCIOUSNESS

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Research completed September 1981.

The effects of the Transcendental Meditation and TM-Sidhi programme were studied in terms of the functional organization of the brain, as reflected in patterns of EEG coherence and in the correlations of these patterns with measures of cognitive performance and emotional health. Findings indicated that higher levels of coherence in the frontal cortex relative to the occipital area are, in general, correlated with higher levels of cognitive performance and greater emotional stability. Furthermore, results showed increases in both alpha and theta EEG coherence levels as a result of learning the TM-Sidhi programme, with proportionately greater increases taking place in the frontal lobes compared to the occipital lobes. The authors discuss their findings in terms of the development of higher states of consciousness through the Transcendental Meditation and TM-Sidhi programme.—EDITORS

These results were presented in part at the American Psychological Society Annual Convention, Los Angeles, California, U.S.A., September 1981, and at the 15th Annual Winter Conference on Brain Research, Steamboat Springs, Colorado, U.S.A., January 1982.

THE COGNITIVE CORRELATES AND FACTOR ANALYSIS OF EEG COHERENCE—Subjects were 47 male and female undergraduate students of Maharishi International University. At pretest, principled moral reasoning was significantly positively correlated with homolateral left (F3/C3) and right (F4/C4) alpha coherence. Verbal IQ was significantly positively correlated with F4/C4 alpha coherence and tended to be positively correlated with F3/C3 alpha coherence. Psychometrically scaled experiences of cosmic consciousness (the first stable stage of enlightenment) were also significantly correlated with F3/C3 and F4/C4 alpha coherence. Bilateral frontal (F3/F4) alpha coherence was positively correlated with grade point average and wakefulness. Bilateral occipital coherence at all frequencies was inversely correlated with creativity, intelligence, and principled moral reasoning. Neuroticism was inversely correlated with alpha and theta coherence in all derivations.

From this evidence, the different coherence parameters were combined into two composite coherence indices:

1. *bilateral frontal + homolateral left + homolateral right alpha coherence minus bilateral occipital alpha coherence (FLR − O), and*
2. *bilateral frontal + homolateral left + homolateral right alpha coherence divided by bilateral occipital alpha coherence (FLR/O).*

Both indices thus reflect an increase in bilateral and homolateral coherence in the frontal cortex relative to bilateral coherence in the occipital cortex. A stepwise multiple correlation showed that grade point average (beta = .60) and neuroticism (beta = −.36) contained most of the predictive power for the FLR − O coherence index (R = .58, p = .005). For the FLR/O coherence index, the strongest predictors were principled moral reasoning (beta = .27), neuroticism (beta = −.23), and verbal IQ (beta = .47). The multiple R was .63, p = .005.

A factor analysis of the eight alpha and theta variables from the four derivations for all subjects combined from both control and experimental groups at pretest yielded three orthogonal factors similar to those derived from correlations of EEG coherence with the cognitive and affective variables. Second-order factor analysis resulted in a single general coherence factor which was essentially a weighted version of the FLR − O index. The second-order factor computed for each subject was found to be positively correlated with grade point average, verbal IQ, and principled moral reasoning.

CHANGES IN EEG COHERENCE DURING THE TRANSCENDENTAL MEDITATION PROGRAM—General coherence computed according to the second-order factor was found to increase significantly from eyes open to eyes closed ($t(46) = 14.12$, $p < .0001$) and from eyes closed to the Transcendental Meditation period ($t(46) = 3.34$, $p < .002$). Interestingly, the level of general coherence was significantly higher in the eyes-closed period after the practice of TM than during the eyes-closed period prior to TM practice ($t(46) = 11.48$, $p < .0001$), indicating a shift towards improved functional organization of the brain as a result of TM. Drowsiness was found to reduce second-order factor coherence ($t(17) = 3.69$, $p < .002$).

Considering the different EEG derivations separately, alpha EEG coherence was found to increase globally during the TM technique relative to eyes open, with greatest increases in the frontal cortex.

LONGITUDINAL CHANGES IN EEG COHERENCE PRODUCED BY THE TM-SIDHI PROGRAM—After pretesting the experimental group took the TM-Sidhi course, while the control group took their usual summer vacation. At posttest, four months later, findings indicated that compared with controls the TM-Sidhi group increased in alpha and theta coherence measured during the Transcendental Meditation period in the four pairs of EEG leads. The results of the MANOVAs for Group Effect for alpha and theta variables, covarying for percent waking, were $F(4,40) = 2.715$, $p = .043$, and $F(4,40) = 2.818$, $p = .037$, respectively, with a greater longitudinal increase in coherence in the frontal cortex relative to occipital areas.

The TM-Sidhi program also produced a significant increase on the two composite coherence indices, FLR − O and FLR/O, compared to controls ($p = .039$ and $p = .057$, respectively). In addition, the TM-Sidhi course was found to produce a longitudinal increase compared to controls in the degree to which coherence increased during Transcendental Meditation relative to the eyes-open period. This effect was particularly strong for bilateral frontal alpha coherence ($p = .014$) but coherence also changed globally ($p = .06$, trend).

The TM-Sidhi group increased longitudinally on creativity compared to controls (for verbal fluency, $p = .02$; for verbal flexibility, $p = .02$; for figural fluency, $p = .075$, trend; and for figural originality, $p = .08$, trend). Longitudinal change in alpha coherence measured during the TM technique was found to be significantly correlated with longitudinal change in creativity, with correlations as strong as .58, $p = .001$ (between bilateral frontal and verbal fluency).

The present results are consistent with the classical view that the frontal lobes are involved with abstract conscious processes such as comprehension, judgment, planning, and social responsibility. The results of this and other studies suggest that:

1. *Patterns of EEG coherence can describe stages of cognitive and emotional development.*
2. *The nervous system appears to evolve with respect to an anterior-posterior axis.*

3. *Cognitive processing involves simultaneous integration and differentiation, associated with high coherence and desynchronization respectively. Any cortical tissue may perform either of these two roles although integration appears to be particularly associated with the frontal lobes.*
4. *The TM program produces a pattern of coherence indicative of improved psychological functioning.*
5. *The TM-Sidhi program accelerates development of the functional organization of the brain.*

INTRODUCTION

The first experiments on the Transcendental Meditation (TM) technique showed a wide range of physiological changes, including increased alpha EEG power (Wallace, 1970; Wallace et al., 1971 and 1972). In a search for more sensitive physiological measures of the effects of the Maharishi Technology of the Unified Field (which includes both the Transcendental Meditation technique and the TM-Sidhi program) on states of consciousness, our laboratory has studied EEG coherence for a number of years (Dillbeck and Bronson, 1981; Dillbeck, Orme-Johnson, and Wallace, 1981; Farrow and Hebert, 1982; Levine, 1976; Orme-Johnson, 1977; Orme-Johnson, in press; Orme-Johnson and Haynes, 1981). EEG coherence is a measure of correlation between two different EEG leads; analogous to r^2, it ranges from 0 to 1.0 and thus represents the proportion of shared variance between the two EEG signals being compared.

Levine (1976) found that EEG coherence in all frequencies, alpha coherence in particular, decreases markedly among central and frontal leads from waking to sleep onset. He also found alpha and theta coherence increased during the Transcendental Meditation technique.

Frontal EEG coherence has been found to be correlated with verbal creativity (Orme-Johnson and Haynes, 1981) and cognitive flexibility, the ability to solve a concept-learning problem in which the correct concept is reversed during the task (Dillbeck et al., 1981).

High alpha coherence has also been found to be associated with subjective experiences of pure consciousness during Transcendental Meditation (Farrow and Hebert, 1982; Orme-Johnson, 1977; Orme-Johnson and Haynes, 1981).

Dillbeck and Bronson (1981) have found short-term longitudinal increases in alpha coherence but not alpha power in new TM participants compared to controls. Orme-Johnson, Wallace, and Dillbeck (in press) found that an advanced TM course, the TM-Sidhi program, produced longitudinal increases in EEG phase coherence in alpha and theta frequencies using percent stage waking as a covariate.

The present study is an extension of this earlier research and is divided into three parts. In Part 1 we attempt to provide a basis for interpreting EEG coherence by investigating its correlation with a number of measures: percent wakefulness as assessed by standard EEG scoring criteria; scores on standardized psychometric tests of creativity, intelligence, and moral reasoning; scores on a psychological inventory of mental health and experiences of higher states of consciousness; and grade point average.

In order to further elucidate the interpretation of EEG coherence, a factor analysis of eight different coherence variables was conducted, thus providing a quantitative representation of the degree to which different brain areas function together or independently.

In light of the understanding of coherence provided by Part 1 of the experiment, Part 2 then examines the short-term effects of the Transcendental Meditation program on EEG coherence. Part 3 investigates how the pattern of EEG coherence changes longitudinally as a result of the TM-Sidhi program. After these results are considered, a model of the neurophysiological development of higher states of consciousness is proposed.

METHOD

SUBJECTS—The subjects were 47 freshmen and sophomores of Maharishi International University. The experimental group who took the TM-Sidhi course over the three-month summer break consisted of 26 sophomores, 15 males and 11 females, mean age 20.8 years, mean length of TM practice 47.1 months. The control group who took their usual vacation over the summer break consisted of 21 freshmen, 11 males and 10 females, mean age 22.1 years, mean length of TM practice 42.4 months.

The experimental and control subjects were randomly selected from a pool of 64 pairs of potential

subjects matched on age, sex, and length of TM practice. Subject eligibility was determined on the basis of three criteria:

1. Availability for testing in both May and September (before and after the three-month recess)
2. No previous participation in the TM-Sidhi program
3. Plans to stay at MIU for at least one year

Pairs of experimental/control subjects were then randomly selected. Pre- and posttesting was successfully completed on 26 experimental and 21 control subjects randomly selected from the subject pool described above.

APPARATUS—Data were acquired via a 17-channel EEG and polygraph with amplifiers set at 0.3 Hz, 0.1 Hz, and 5 μV/mm for EEG and 10 μV/mm for EOG with a 60 Hz notch filter in. The pen filters were set at 90 Hz with the pens' 60 Hz filters out, and the chart speed was 15 mm/sec.

The output from the J6 of each of the Grass amplifiers was digitized on-line to 12 bits at 60 samples per second per channel in a Megatek Laboratory Interface connected to a Data General Nova 3 minicomputer. Records of four seconds (240 samples per channel) were recorded on a nine-track magnetic tape subsystem. All 16 channels were Fourier transformed on-line (sequentially 1 to 16) allowing for the display of the power spectrum along with the actual continuous signal on a CRT display. Coherence was computed for each four-second epoch of data using the average of seven overlapping frames of 128 samples each, incremented with 18 samples between frames. The magnetic tape record number displayed on the Megatek interface and the beginning of each period of the protocol were recorded on the EEG paper chart record by the operator to facilitate *ex post facto* data review. All amplifiers were calibrated at the beginning and end of each session.

PROCEDURE—All subjects were measured on EEG and a battery of psychological tests during May and retested on EEG and creativity in September (see definition of variables below). The mean time between measurements was four months.

EEG measurements were taken at either 10:00 AM or 1:30 PM and each subject was measured at the same time of day on pre- and posttesting. Experimental and control subjects were distributed evenly over AM and PM sessions. Female subjects were not scheduled within three days before or after menstruation. When subjects came in they were shown the laboratory in order to familiarize them with the environment. They then filled out consent forms and background questionnaires. No subject had a recent history of drug use or neurological disorders.

The scalp was measured according to the International 10–20 System, cleaned with alcohol, and Grass EEG 10 mm gold cup electrodes were attached with Grass type EC–2 electrode cream on F3, F4, C3, C4, P3, P4, O1, O2, T3, T4, Cz, and EOG. The right EOG was placed just above the corner of the right eye at E2 and referenced to FP2. The left EOG was placed below the corner of the left eye at E1 and referenced to FP1. P3 data were lost for 21 subjects due to a faulty amplifier. All recordings were monopolar referenced to linked ears. Electrode impedances were usually below 5 kilohms and always below 10 kilohms.

After preparation of electrodes, the subjects were allowed a short walk to refresh themselves and then were seated in a comfortable chair in an electrically shielded, sound-attenuating room. The following protocol was explained to the subjects: 5 minutes eyes open, 5 minutes eyes closed, 30 minutes of the TM technique (eyes closed), 5 minutes eyes closed, and 10 minutes eyes open. The same protocol was used in Session 1 and in Session 2 three to four months later. Instructions signalling the beginning and the end of each period were played over a tape recorder set at a low volume.

THE TM-SIDHI PROGRAM—During the four months between the pre- and posttesting sessions, the experimental group took the TM-Sidhi course and the control group went home on summer vacation. The TM-Sidhi course is a completely standardized course, the essence of which is the process of *samyama* described by Patanjali (e.g., Mukerji, trans., 1977, pp. 281–385). *Samyama* is a process involving three aspects: 1) *dharana,* the ability effortlessly to hold a thought in the focus of attention; 2) *dhyana,* the capacity of thought to refine itself to its subtlest state; and 3) *samadhi,* or pure consciousness. The *Yoga Sutras* of Patanjali specify formulae which, when subject to the process of *samyama,* result in the performance of *sidhis,* which are abilities usually thought to be beyond the range of normal human functioning (see Patanjali, chapter 3).

The purpose of the TM-Sidhi performance is the integration of consciousness. While the actual per-

formance of the TM-Sidhi is being experienced within, and may be expressed in outer behavior (such as refined hearing; Clements and Milstein, 1977), the stability of the state of *samadhi,* or pure consciousness, is simultaneously being challenged and strengthened (Orme-Johnson and Granieri, 1977, p. 715).

DEFINITION OF VARIABLES—*Coherence:* Each four seconds of data was Fourier transformed to a resolution of 0.468 Hz, yielding the power in each 0.468 Hz frequency bin. In order to improve the estimate of power in the short (4 sec) epochs of data, a technique of overlapping windows was used (Levine, 1976). (This was originally done to make fine-grained analysis of the data possible.)

Coherence between two signals x and y at frequency bin j was then computed:

$$\Gamma^2_{xy,j}=\frac{C_{xy,j}}{P_{x,j}P_{y,j}}$$

where $\Gamma^2_{xy,j}$= the coherence between signals x and y at frequency j, $C_{xy,j}$= the cross power (shared power) between x and y at frequency j, and $P_{x,j}$ and $P_{y,j}$ equal the power of x and y, respectively, at frequency j. Thus, coherence equals the power in common between the two signals normalized for total power at a given frequency. It is analogous to r^2, the coefficient of determination, the percent of variance in one variable accounted for by its correlation with a second variable.

Coherence was analyzed for five frequency bands: delta = 1.17 to 4.45 Hz, theta = 4.45 to 8.20 Hz, alpha = 8.20 to 11.95 Hz, beta 1 = 11.95 to 15.7 Hz, beta 2 = 15.7 to 19.92 Hz. Coherence in each band was computed for four pairs of derivations: bilateral frontal (F3/F4), homolateral left (F3/C3), homolateral right (F4/C4), and bilateral occipital (O1/O2) yielding a total of 20 coherence variables (5 frequencies times 4 pairs of EEG leads) for each of the six 5-minute periods of the 30-minute session of the TM technique. The 5-minute blocks of data were further averaged for the 30-minute periods of the TM technique for both Session 1 and Session 2.

In order to reduce the influence of drowsiness, a Best 5 Minutes was also analyzed: the 5-minute period of the 30-minute session with the highest alpha and theta coherence in all four comparisons. The rationale for using the Best 5 Minutes as an index of trait changes was that during that time the subjects were most likely to be fully awake, since coherence decreases with drowsiness (Levine, 1976), thus eliminating *state* effects due to drowsiness. (In fact, the statistical results for the mean of the 30-minute session were essentially the same as for the Best 5 Minutes.)

As a further means to separate state effects of drowsiness from genuine trait changes that might occur in coherence, percent stage waking was used as the covariate in a multivariate analysis of variance (MANOVA). EEG from the C4 lead was scored for sleep stages for each 20 seconds of data using the criteria described by Rechtschaffen and Kales (1968) for waking, stage 1, stage 2, and stages 3 and/or 4 combined into a single score with O2 used to detect the occipital alpha blocking. Each five minutes of data was then assigned a percentage of time in each stage, excluding movement time.

Threshold alpha coherence: In our previous study of coherence and creativity (Orme-Johnson and Haynes, 1981) the coherence variable used was the incidence of coherence over a threshold of 0.95. This was used because it was hypothesized that specific high coherence events might have important behavioral implications. In the present study, threshold coherence was computer generated in the following way: In the 30-minute period of the TM technique, coherence was computed for each of the 450 four-second epochs of data in each of eight 0.468 frequency bins in the alpha band of 8.20 to 11.95 Hz. Thus, there were 450 epochs multiplied by eight frequency bins or 3,600 coherence computations for each pair of derivations. The threshold coherence variable reported in this experiment was the percentage of the 3,600 possible instances in which coherence reached a threshold of 0.95 or greater.

Creativity: Two creativity tests were used—the verbal and figural scales of the Torrance Test of Creative Thinking (Torrance, 1974). The verbal test entails generating verbal ideas in a minimally structured set (e.g., "how many uses can you think of for a brick?"). The figural test requires generating novel ideas in the spatial domain by making drawings.

The creativity tests were given at MIU by one of the authors (O.B.) as part of his doctoral dissertation at the University of Georgia. He was not aware of the subjects' group affiliation and the tests were scored blind at the University of Georgia by professional scorers who had no knowledge of the experiment or groups. The tests were identified by subject numbers only, the numbers being randomly assigned, both groups in one block. The figural and verbal tests were

scored for three standard subscores: fluency, flexibility, and originality. Fluency reflects the number of responses generated in the time allotted by the tests; flexibility reflects the number of conceptually distinct approaches used in creating responses; originality reflects the statistical infrequency or unusualness of the response.

Intelligence: The Wechsler Adult Intelligence Scale (WAIS) was administered according to the standard test protocol (Wechsler, 1955). The intelligence variables used in this experiment were verbal IQ and performance IQ. Verbal IQ is composed of six "left hemisphere" subtests: general information, comprehension of verbal material, arithmetic reasoning, ability to find similarities between two items, ability to remember lists of digits forward and backward, and vocabulary. Performance IQ is composed of five "right hemisphere" subtests: speed of copying novel symbols, finding what is missing in a picture, reproducing spatial designs with patterned blocks, finding a logical story line in a sequence of cartoons, and assembling a puzzle representing an object. The sum of the raw-score points for each test was used in the data analysis.

Grade point average: The subjects' grade point averages (GPA) for their first year at MIU were used. The first-year MIU curriculum is a standard series of 20 one- or two-week core courses covering 20 different academic subjects. Therefore, GPA year 1 reflects global academic ability.

Moral reasoning: Moral reasoning was measured by the Defining Issues Test, DIT (Rest and Kohlberg, 1975). The DIT is an adaptation by Rest of Kohlberg's Moral Judgment Interview in a multiple choice format. The DIT "requires a subject to read a hypothetical moral dilemma and then to select from among 12 statements those that are the most important issues in making a decision about the case. Each issue statement represents a stage characteristic of Kohlberg's stage typology," (Rest, 1975, p. 76). The subject is presented with six stories representing moral dilemmas.

The Kohlberg stages tapped by the DIT range from stage 2, instrumental hedonism, which considers only immediate self-interests, to stages 3, 4, 5A, 5B, and 6. The higher stages represent progressively greater comprehension of the consequences of action for oneself and others culminating in principled moral reasoning, a consideration of abstract principles of action that have broad application.

Factor analytic studies by Cooper (1972) have shown that the three principled stages 5A, 5B, and 6, cluster together and that the DIT can be represented by a single score of the relative contribution of principled moral reasoning in the subject's consideration of the dilemmas. This is the percent principled moral reasoning score used in the present experiment. It includes the social contract and utilitarian law making perspective (5A), higher law and conscience orientation (5B), and universal ethical principle orientation (6).

Neuroticism: Neuroticism was measured by a scale on the State of Consciousness Inventory under development by Charles Alexander, one of the authors (Alexander, Alexander, Boyer, and Jedrczak, in press).

Cosmic consciousness: Cosmic consciousness is a developmental stage characterized by the coexistence of transcendental or pure consciousness with all phases of waking, dreaming, and sleep (Maharishi Mahesh Yogi, 1969). Cosmic consciousness develops through culturing the nervous system to permanently maintain the experience of transcendental consciousness. This is achieved by regularly alternating the experience of transcendental consciousness during the Transcendental Meditation technique with ordinary daily activity. The frequency and extent of experience of cosmic consciousness was assessed by the CC scale[1] of the State of Consciousness Inventory (see above).

RESULTS

Part 1: The Functional Significance of EEG Coherence

In Part 1 we provide a foundation for interpreting EEG coherence in different cortical areas by:

A. presenting their correlations with cognitive and affective variables;
B. reporting two composite coherence indices and their correlations with cognitive and affective variables; and
C. presenting the results of factor analysis of eight alpha and theta coherence parameters in order to indicate how they cluster into a few orthogonal factors.

1. The use of this scale to evaluate experiences of cosmic consciousness must be regarded as preliminary since this part of the Inventory is still undergoing refinement.

A. CORRELATIONS OF EEG COHERENCE WITH COGNITIVE AND AFFECTIVE VARIABLES—Unless indicated otherwise, all correlations are for the mean coherence during the 30-minute period of the TM program for all subjects in Session 1.

Intelligence and principled moral reasoning: Previous studies have shown that principled moral reasoning is positively correlated with comprehension (in the 0.6 range) and intelligence (in the 0.4 range) (Rest, 1975). In the present study, percent principled moral reasoning (Session 1) correlated $r = .46$, $p = .001$ with verbal IQ; $r = .177$, NS with performance IQ; and $r = .50$, $p = .001$ with GPA year 1. Because of the strong interrelationship between verbal intelligence and moral reasoning the results of their correlation with EEG coherence were studied together.

Figure 1 displays the pattern of correlations of verbal IQ, performance IQ, and percent principled moral reasoning with EEG coherence at different frequencies among different derivations. Bilateral frontal coherence at all frequencies is uncorrelated with intelligence and moral reasoning.

The correlations of homolateral left and right coherence variables and principled moral reasoning peak at the alpha frequency, reaching a significant positive correlation. Verbal IQ tends to show a similar pattern to principled moral reasoning.

Bilateral occipital coherence at all frequencies is significantly inversely correlated with principled moral reasoning. Verbal IQ shows a pattern similar to principled moral reasoning. Performance IQ tends to be inversely correlated with occipital coherence but did not reach statistical significance.

Figure 1 also shows that covarying for percent waking did not influence the pattern of correlations of EEG coherence with principled moral reasoning.

In summary, principled moral reasoning and verbal IQ behave quite similarly with respect to these EEG coherence variables. Both are uncorrelated with bilateral frontal coherence, both tend to be positively correlated with homolateral left and right alpha coherence in anterior regions, and both tend to be inversely correlated with bilateral occipital coherence at all frequencies.

Cosmic consciousness: In order to study the hypothesis that the development of cosmic consciousness is associated with increased EEG coherence as a trait, the correlation of the CC scale of the State of Consciousness Inventory with EEG coherence variables was studied. Session 1 correlations (N = 37, due to missing data) of the CC scale with alpha EEG coherence parameters were: F3/C3, $r = .32$, $p = .03$ and F4/C4, $r = .30$, $p = .04$. Correlations with bilateral frontal and bilateral occipital coherence were not significant.

It can be seen that scores on the CC scale were significantly correlated with homolateral alpha coherence in the anterior areas in both cerebral hemispheres. These are also the areas in which alpha coherence was found to be positively correlated with principled moral reasoning and verbal intelligence.

Grade point average: Grade point average was significantly positively correlated with bilateral frontal alpha coherence ($r = .31$, $p = .02$). The correlations with other areas did not reach statistical significance.

Creativity: Bilateral alpha occipital coherence tends to be inversely correlated with creativity. (Verbal creativity: fluency, $r = -.36$, $p = .009$; flexibility, $r = -.37$, $p = .007$; originality, $r = -.26$, $p = .044$. Figural creativity: fluency, $r = -.28$, $p = .035$; flexibility and originality were not significant.)

Neuroticism: Neuroticism was inversely correlated with alpha and theta coherence parameters (Best 5 Minutes) for all pairs of derivations (table 1).

B. COMPOSITE INDICES OF EEG COHERENCE—Two composite indices of coherence (Best 5 Minutes) were computed:

1. A difference score: bilateral frontal + anterior homolateral left + anterior homolateral right *minus* bilateral occipital alpha coherence (FLR-O)
2. A ratio: bilateral frontal + anterior homolateral left + anterior homolateral right *divided by* bilateral occipital alpha coherence (FLR/O)

TABLE 1

CORRELATIONS OF NEUROTICISM WITH COHERENCE PARAMETERS* (SESSION 1, N = 35)

	ALPHA COHERENCE		THETA COHERENCE	
	r	*p*	*r*	*p*
F3/F4	-.26	.07	-.26	.06
F3/C3	-.35	.02	-.31	.03
F4/C4	-.38	.01	-.27	.05
O1/O2	-.36	.02	-.35	.02

* Best 5 Minutes

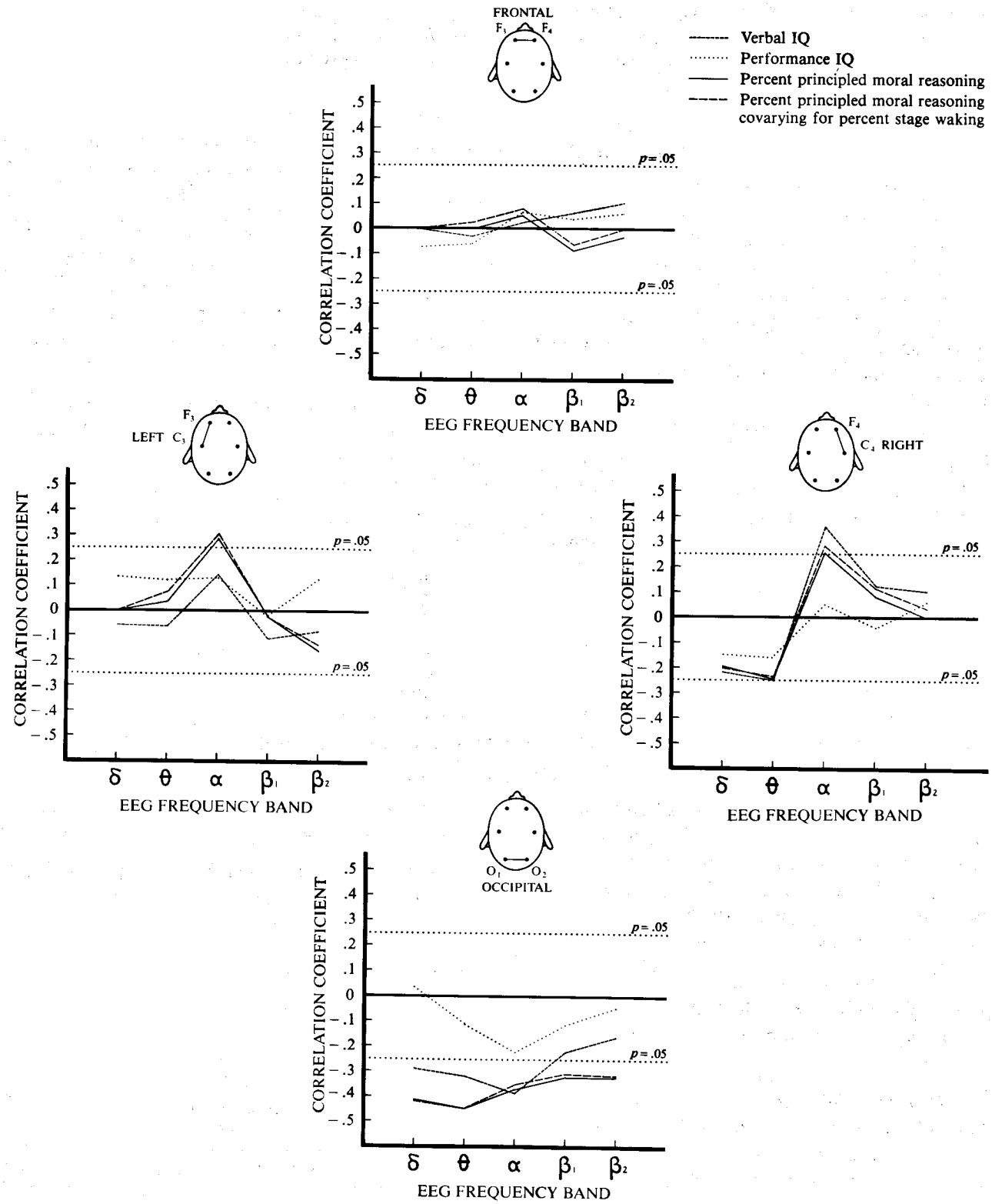


FIG. 1. CORRELOGRAM SHOWING THE PATTERN OF CORRELATIONS OF EEG COHERENCE PARAMETERS WITH PRINCIPLED MORAL REASONING, VERBAL IQ, PERFORMANCE IQ, AND PRINCIPLED MORAL REASONING COVARYING FOR PERCENT STAGE WAKING. The vertical axis represents the strength of the correlation. Homolateral left and right alpha coherence was positively correlated with verbal IQ and principled moral reasoning. Occipital coherence in all frequencies was inversely correlated with verbal IQ and principled moral reasoning while bilateral frontal coherence was uncorrelated with either. Performance IQ was generally uncorrelated with these particular coherence parameters. Covarying for percent stage waking, as a control for state effects of drowsiness, did not change the correlation pattern.

The rationale for these indices is that:

1. In the present study, bilateral frontal alpha coherence is positively correlated with grade point average and associated with wakefulness (see Part 3, Section A below). Although the Session 1 correlations of frontal coherence with creativity did not reach statistical significance in the present experiment, evidence from previous research indicates that bilateral frontal (F3/F4) alpha coherence is positively correlated with creativity (Orme-Johnson and Haynes, 1981). Furthermore, there were strong positive correlations of longitudinal changes in frontal coherence with creativity (see Part 3, Section E below).
2. Homolateral left and right alpha coherence are positively correlated with verbal IQ, principled moral reasoning, and the CC scale.
3. Bilateral occipital alpha coherence is inversely correlated with verbal IQ, principled moral reasoning, and creativity.

These indices are clearly only a first approximation since the strength of these correlations between EEG coherence and the psychological variables assessed needs to be further established through additional research and since there are many other brain areas to consider which were not measured.

Cognitive and affective correlates of the composite coherence indices: Tables 2A and 2B show the stepwise multiple correlations of psychological variables with the two coherence indices. The psychological variables entered into the equation were GPA, verbal IQ, performance IQ, the CC scale, principled moral reasoning, and neuroticism. For the FLR-O index (table 2A), neuroticism and GPA year 1 were the best predictors. Neuroticism was inversely weighted (beta = −.36) and GPA year 1 was positively weighted (beta = .60). This indicates that an increase by one standard deviation on the index was associated with a decrease of 0.36 standard deviations in neuroticism and an increase of 0.60 standard deviations in GPA. The multiple R was .58, $p = .005$. This result indicates that the FLR-O coherence index was related to two psychological dimensions: a global cognitive performance variable (grade point average from 20 courses) and an emotional health dimension (an inverse weighting with neuroticism). It can be concluded from this that the FLR-O coherence index may be an index of CNS maturation.

TABLE 2A

FLR-O COHERENCE INDEX: MULTIPLE CORRELATION WITH PSYCHOLOGICAL VARIABLES

VARIABLE	BETA	p (BETA)	MULT. R	SIMPLE r	OVER-ALL F	p (R)
Neuroticism	−0.36	0.025	0.41	−0.41	5.63	0.025
GPA	0.60	0.019	0.58	0.30	6.52	0.005

TABLE 2B

FLR/O COHERENCE INDEX: MULTIPLE CORRELATION WITH PSYCHOLOGICAL VARIABLES

VARIABLE	BETA	p (BETA)	MULT. R	SIMPLE r	OVER-ALL F	p (R)
Principled Moral Reasoning	0.27	0.018	0.44	0.44	6.35	0.018
Neuroticism	−0.23	0.070	0.54	−0.43	5.27	0.012
Verbal IQ	0.47	0.044	0.63	0.40	5.49	0.005

The multiple correlation pattern with the FLR/O coherence index was similar (table 2B). The strongest predictors of FLR/O were principled moral reasoning (simple $r = .44$, beta = .27), neuroticism (simple $r = -.43$, beta = −.23), and verbal IQ (simple $r = .40$, beta = .47). The multiple R was .63, $p = .005$. Principled moral reasoning, neuroticism, and verbal IQ each made a separate contribution to predicting FLR/O. Thus, as in the case of the FLR-O index, the pattern of results support the interpretation of the FLR/O index as an index of CNS maturation, as indicated by improved psychological functioning.

C. FACTOR ANALYSIS OF EEG COHERENCE VARIABLES—The correlational pattern of EEG parameters with the psychological variables presented above has provided information on the functional significance of EEG coherence in different cortical areas with respect to intellectual ability, moral judgment, and emotional health. Factor analysis of the various EEG coherence parameters themselves provides another type of information about coherence, i.e., how the different parameters cluster into orthogonal factors. These coherence factors indicate, on the basis of the EEG data itself, which cortical areas tend to function together and which separately.

Factor analysis was performed on eight variables: frontal alpha and theta, left alpha and theta, right alpha and theta, and occipital alpha and theta.[2]

2. The factor analysis was direct Quartimin rotation for simple loadings, with gamma equals zero, tolerance limit for the matrix inverse equals 0.00010, convergence criterion for rotation equals 0.00001 with Kaiser's normalization, Biomedical Data Program 4M, V2.

Theta coherence was included along with alpha because it also changed longitudinally as a result of the TM-Sidhi program (see Part 3, Section A) and because it showed some correlations with cognitive and affective variables.

Five factor analyses were conducted for all subjects from the two groups combined (N = 47) for EEG data from the following five conditions during Session 1: eyes open before the TM program (5 min), eyes closed before the TM program (5 min), the TM program (Best 5 Minutes), the TM program (mean coherence of 30-minute period), and drowsiness (80% or more of the epochs in stage 1 sleep, N = 18).

The factor structure was similar for each state although the level of coherence was higher during the Transcendental Meditation program than during other states (see below). Three factors accounted for 75 – 80% of the total variance:

Factor 1: A homolateral left-right factor which combined four variables, left alpha and theta and right alpha and theta, accounted for approximately 35% of the variance.
Factor 2: A bilateral frontal factor which combined two variables, frontal alpha and theta, accounted for about 25% of the variance.
Factor 3: A bilateral occipital factor which combined two variables, occipital theta and alpha, accounted for another 20% of the variance.

The three factors were quite pure (orthogonal); their intercorrelations were in the range ±0.1.

These three factors derived from the intercorrelations among EEG coherence variables are remarkably similar to the groupings seen in the coherence variables as they correlated with cognitive variables (e.g., fig. 1). Homolateral left coherence and homolateral right coherence were similar to each other in their correlation pattern with intelligence and principled moral reasoning (positive correlation with alpha coherence), providing one factor. Bilateral frontal coherence was uncorrelated with these cognitive variables but positively correlated with grade point average, indicating a second, separate factor. Bilateral occipital coherence at all frequencies was inversely correlated with intelligence and principled moral reasoning, indicating a third factor.

Thus, three coherence factors emerge from two separate considerations: the intercorrelations among coherence variables themselves and the correlations of coherence variables with cognitive performance variables.

Second-order factor analysis of EEG coherence and correlations of second-order factor with cognitive and affective variables: A second-order factor analysis combined these three first-order factors into a single second-order factor which essentially added together the frontal and left-right factors and subtracted the occipital, with appropriate weights:

$$\begin{aligned}\text{SOF} = {} & 0.56\ \text{F theta} + 0.50\ \text{F alpha} + \\ & 0.73\ \text{L theta} + 0.68\ \text{L alpha} + \\ & 0.20\ \text{R theta} + 0.64\ \text{R alpha} - \\ & 0.48\ \text{O theta} - 0.48\ \text{O alpha}\end{aligned}$$

Thus the second-order factor was similar to the FLR-O index reported above.

The second-order coherence factor (SOF) computed for each subject for EEG taken during the TM program when the subject was fully awake (N = 43; missing data is due to subjects who did not have a period of 100% stage waking) was found to be positively correlated with grade point average ($r = .34$, $p < .05$), verbal IQ ($r = .43$, $p < .01$), and principled moral reasoning ($r = .53$, $p < .001$) but was not significantly correlated with neuroticism ($r = -.08$, NS).

Thus the SOF, derived on the basis of the intercorrelation patterns among eight EEG coherence variables, was positively correlated with general cognitive and intellectual ability. This indicates that the higher the EEG coherence in anterior cortical regions relative to the occipital, the greater the ability for abstract thought.

Part 2: The State Effects of the TM Program on EEG Coherence

In Part 2 of the results we present:

A. the effect of changes in the second-order coherence factor that occur during the TM program; and
B. the results of how coherence changes from eyes open to the TM program.

Unless otherwise specified, the results of this part of the study are for all subjects during Session 1 of the experiment.

A. CHANGES IN THE SECOND-ORDER COHERENCE FACTOR BETWEEN EYES OPEN, EYES CLOSED, THE TRANSCENDENTAL MEDITATION TECHNIQUE, AND DROWSINESS—The second-order factor (SOF) represented the eight coherence

variables combined according to the weights derived from factor analysis. Since the factor structure was similar for all states, the same equation was used to compute the SOF for eyes open, eyes closed, and the TM program (N = 47). For a subsample of subjects (N = 18) it was also computed for drowsiness.

The level of the second-order coherence factor was different between eyes open, eyes closed, and the TM program; 0.628, 0.729, and 0.743, respectively. The increases in the SOF factor were highly statistically significant in each case; eyes open to eyes closed, $t(46) = 14.12$, $p < .0001$; eyes closed to the TM program, $t(46) = 3.34$, $p < .002$. These results show that the SOF, which indicates an increase in coherence among frontal and central regions relative to occipital coherence, increases when the eyes are closed and increases even more during the TM program. Interestingly, the level of the SOF was higher in the eyes-closed period after the period of the TM program than for the eyes-closed period prior to the period of the TM program ($t(46) = 11.48$, $p < .0001$).

Drowsiness was found to decrease the SOF. During the TM period in Session 1, 18 subjects had at least one five-minute period in which 80% or more of the epochs were in stage waking, and at least one five-minute period in which 80% of the epochs were in stage 1 sleep. The levels of coherence for these subjects for eyes closed, the TM program (awake), and drowsiness were 0.73, 0.74, and 0.70, respectively. The decrease in coherence from the TM program to drowsiness was statistically significant ($t(17) = 3.69$, $p < .002$). The difference between drowsiness and eyes closed was also statistically significant ($t(17) = 2.79$, $p < .01$).

Inspection of the individual data showed that an individual who has a higher level of coherence relative to others in one state will have a relatively higher level of coherence in all states. For example, the subject with the highest coherence in the eyes-open condition is also likely to be the subject with the highest coherence in the eyes-closed condition, as well as during the TM program. This suggests that the level of coherence relative to other individuals is a trait that cuts across state changes.

Since the second-order coherence factor is positively correlated with waking state cognitive ability, the findings 1) that the TM technique increases the second-order coherence factor and 2) that this coherence factor increases in the eyes-closed period following the TM program relative to the eyes-closed period before the TM program together suggest that the TM technique enhances a neurophysiological style of functioning which is conducive to successful cognitive performance.

B. THE TRANSCENDING FACTOR: CHANGES IN COHERENCE FROM EYES OPEN TO THE TM TECHNIQUE—Transcending is defined as the settling down of consciousness from the active phases of waking activity (thought, perception) to the silent, nonactive state of inner wakefulness, transcendental consciousness. It was hypothesized that the change in the level of alpha coherence from the eyes-open awake condition before meditation to the Best 5 Minutes period during the TM program would be a measure of the degree of transcending, the degree to which the active brain had settled to the highly integrated, nonactive state corresponding to transcendental consciousness. In this model, the greater the maximum increase in coherence during the TM program relative to eyes open, the greater the degree of transcendence.

The first step in assessing the effects of the TM program on transcending was a factor analysis of change in alpha coherence, in the four pairs of derivations, from eyes open to the Best 5 Minutes during the TM program.

In contrast to the three factors reported above that resulted from factor analysis of the EEG taken during different states (during eyes open, eyes closed, the TM program, or drowsiness), factor analysis of the change in EEG from eyes open to the TM program resulted in only a single factor. This factor explained 52% of the variance, and the factor loadings were all positive, indicating that the factor represents increased coherence in all derivations.

This single factor resulting from a Quartimin orthogonal rotation had the following factor loadings: F3/F4, 0.692; F3/C3, 0.897; F4/C4, 0.806; O1/O2, 0.405. Increased coherence in all brain areas during transcending is consistent with previous research that has indicated global increase in EEG coherence during transcendental consciousness (e.g., Badawi, Wallace, Orme-Johnson, and Rouzeré, 1984; Orme-Johnson, 1977 and in press; Orme-Johnson and Haynes, 1981).

The mean changes in alpha coherence in the different derivations were: F3/F4, 0.0401; F3/C3, 0.0232; F4/C4, 0.0394; O1/O2, 0.0032. It can be seen that the magnitude of increase in alpha coherence during

TABLE 3

LEVELS OF COHERENCE (SESSION 1)

COHERENCE PARAMETER	ALPHA COHERENCE				THETA COHERENCE			
	TM-SIDHI GROUP (N=26)		CONTROL GROUP (N=21)		TM-SIDHI GROUP (N=26)		CONTROL GROUP (N=21)	
	M	S.D.	M	S.D.	M	S.D.	M	S.D.
Frontal (F3/F4)	0.7087	0.1596	0.7714	0.0742	0.7073	0.1550	0.7413	0.0584
Left (F3/C3)	0.6497	0.1514	0.7114	0.0785	0.7254	0.1567	0.7651	0.0430
Right (F4/C4)	0.6671	0.1549	0.6975	0.0694	0.7382	0.1603	0.7254	0.1570
Occipital (O1/O2)	0.6885	0.1533	0.6782	0.0764	0.7028	0.1554	0.6868	0.0676
	APPROX. *F*	*df* HYPOTH.	*df* ERROR	*p*	APPROX. *F*	*df* HYPOTH.	*df* ERROR	*p*
MANOVA, Group Effect	2.558	4	42	0.052	1.387	4	42	0.254

transcending was largest in the bilateral frontal and homolateral right areas, and that the increase in occipital coherence was one-tenth of that seen in other areas.

Part 3: Longitudinal Changes in EEG Coherence Produced by the TM-Sidhi Program

In Part 3 of the results we present:

A. the longitudinal changes in alpha and theta EEG coherence produced over the four-month period of the TM-Sidhi course;
B. longitudinal changes on the composite coherence indices;[3]
C. longitudinal changes on the change in coherence from eyes open to the TM program, i.e., on the transcending factor;
D. longitudinal changes in creativity; and
E. correlated changes in coherence and creativity variables.

A. LONGITUDINAL CHANGES IN LEVELS OF ALPHA AND THETA COHERENCE—Table 3 shows levels of coherence for Session 1 for experimental and control subjects. There were no initial differences between groups on theta coherence. However, during Session 1 control subjects showed somewhat higher alpha coherence than experimental subjects ($p = .05$).

Although many subjects in both groups showed some periods of coherence as high as 0.9, the means for coherence ranged from 0.67 to 0.77. Since this is well below the ceiling value of coherence of 1.0, it was felt that the differences between groups in mean initial values would not confound possible longitudinal changes by ceiling effects.

Tables 4A and 4B show the statistical results for alpha (table 4A) and theta (table 4B) coherence for the two groups in each of the four comparisons (F3/F4, F3/C3, F4/C4, and O1/O2).

The results of the MANOVA Group Effect (not covarying for percent stage waking) for alpha variables were $F(4,42) = 2.472$, $p = .058$ (table 4A). A second multivariate analysis was conducted which covaried for the effects of percent waking on the EEG coherence variables: the within cells regression for alpha was significant ($F(4,40) = 3.396$, $p = .017$), indicating that change in percent waking was significantly related to the change in the four alpha coherence variables.

In order to assess how degree of wakefulness is correlated with EEG coherence in different parts of the cortex, univariate *F*-tests were conducted for each area. The change in percent waking was correlated $r(46) = .39$, $p = ,004$ with the change in bilateral frontal alpha coherence but was not significantly correlated with change in coherence in any other pair of derivations.

The MANOVA Group Effect for the change in alpha coherence variables taking percent stage waking into account as a covariate (table 4A) was statistically significant ($F(4,40) = 2.715$, $p = .043$). That is, compared to controls there was a significant increase in alpha coherence in the TM-Sidhi group, controlling for the effects of drowsiness.

For theta variables the within cells regression effect was not significant, indicating that percent stage

3. The results of sections A and B were reported in an earlier paper (Orme-Johnson, Wallace, and Dillbeck, in press).

waking was not significantly correlated with theta coherence (table 4B). The MANOVA Group Effect covarying for percent stage waking for theta was $F(4,40) = 2.818$, $p = .037$. Thus the TM-Sidhi course also produced a significant increase in theta coherence compared to controls.

Canonical correlations for the MANOVA Group Effect (with percent waking covariate) for alpha and theta, respectively, were 0.462 and 0.468, indicating that 21.3% and 21.9% of the variance was accounted for by groups (the experimental intervention).

TABLE 4A

CHANGES IN EEG ALPHA COHERENCE (SESSION 2 – SESSION 1)

ALPHA COHERENCE PARAMETER	MEAN CHANGE IN COHERENCE, TM-SIDHI GROUP (N = 26)		MEAN CHANGE IN COHERENCE, CONTROL GROUP (N = 21)	
	M	S.E.	M	S.E.
Frontal (F3/F4)	0.0276	0.0317	−0.0194	0.0105
Left (F3/C3)	0.0432	0.0286	−0.0289	0.0141
Right (F4/C4)	0.0366	0.0315	0.0050	0.0133
Occipital (O1/O2)	0.0145	0.0304	−0.0129	0.0268

MANOVA CHANGE IN MEANS

	APPROX. F	df HYPOTH.	df ERROR	CANONICAL CORREL.	p
Group Effect	2.472	4	42	0.437	0.058
% Waking Covariate					
a) Within Cell Regression Effect	3.396	4	40	0.503	0.017
b) Group Effect	2.715	4	40	0.462	0.043

TABLE 4B

CHANGES IN EEG THETA COHERENCE (SESSION 2 – SESSION 1)

THETA COHERENCE PARAMETER	MEAN CHANGE IN COHERENCE, TM-SIDHI GROUP (N = 26)		MEAN CHANGE IN COHERENCE, CONTROL GROUP (N = 21)	
	M	S.E.	M	S.E.
Frontal (F3/F4)	0.0288	0.0317	−0.0002	0.0091
Left (F3/C3)	0.0383	0.0333	−0.0328	0.0126
Right (F4/C4)	0.0334	0.0335	0.0283	0.0340
Occipital (O1/O2)	0.0038	0.0290	0.0034	0.0157

MANOVA CHANGE IN MEANS

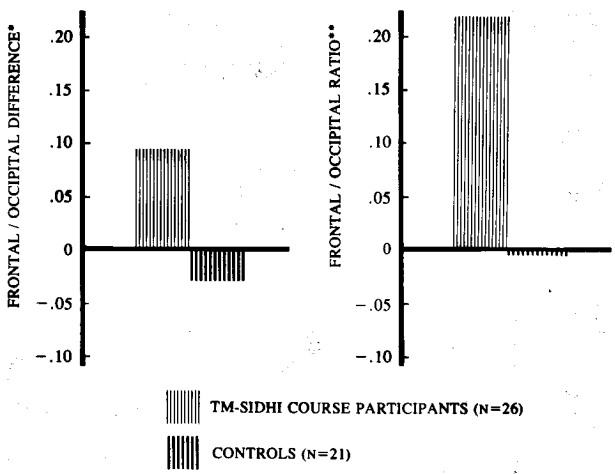
	APPROX. F	df HYPOTH.	df ERROR	CANONICAL CORREL.	p
Group Effect	2.888	4	42	0.464	0.033
% Waking Covariate					
a) Within Cell Regression Effect	0.652	4	40	0.247	0.628
b) Group Effect	2.818	4	40	0.468	0.037

In order to interpret the magnitude of the changes in coherence, the changes were converted into percent change from the initial levels in Session 1. The mean percent change in the alpha variables was 4.6% for the TM-Sidhi group and −1.9% for controls. For theta variables, the mean percent change was 3.6% for the TM-Sidhi group and −0.1% for controls. The tendency to decrease in the control subjects, although not statistically significant, may be due to their being away from the regular daily routine and meditation schedule of Maharishi International University, and from the influence of collective coherence in the MIU community.

There was no significant difference between groups in change in coherence in the delta, beta 1, or beta 2 frequencies on similar multivariate testing, nor was there a significant difference between groups on change in sleep scores.

In conclusion, the TM-Sidhi course had an overall effect of increasing alpha and theta coherence compared to controls when state effects due to drowsiness were taken into account. No significant change in coherence between groups was found for delta, beta 1, and beta 2 bands.

B. LONGITUDINAL CHANGES IN THE COMPOSITE COHERENCE INDICES—Figure 2 shows that the



* [Frontal (F3/F4) + Left (F3/C3) + Right (F4/C4)] − Occipital (O1/O2) coherence in the alpha frequency band.
** (Frontal + Left + Right) / Occipital coherence in the alpha frequency band.

FIG. 2. LONGITUDINAL EFFECTS OF THE TM-SIDHI COURSE ON TWO COMPOSITE INDICES OF EEG COHERENCE. On two composite indices of the distribution of coherence (FLR-O, left figure, and FLR/O, right figure) the TM-Sidhi course was found to produce an increase in alpha coherence among frontal regions relative to occipital. The control group showed no appreciable change.

TM-Sidhi course produced a change in the relative distribution of alpha coherence (Best 5 Minutes) with an increase in coherence among frontal and central derivations relative to occipital alpha. The one-tailed *t*-tests for correlated means comparing the change in experimentals with change in controls were significant in the predicted direction (for FLR-O, $p = .039$ and for FLR/O, $p = .057$).

C. LONGITUDINAL CHANGES IN THE TRANSCENDING FACTOR—Longitudinally, there was a trend towards increase on the transcending factor for the TM-Sidhi group compared with the control group from Session 1 to Session 2. The mean change in alpha coherence from eyes open to the Best 5 Minutes of the TM period for the TM-Sidhi group was 0.1722 and the mean change for the control group was 0.0960 ($t(37) = 1.58$, $p = .06$, one-tailed). This indicates that the TM-Sidhi course produced a tendency for the experimental group to transcend more deeply, as indicated by increased EEG coherence from eyes open to the TM program.

Analysis of change from eyes open to the TM program in the individual EEG derivations showed that the TM-Sidhi course produced the greatest change in alpha coherence in the bilateral frontal, as well as a significant trend in anterior homolateral right and a trend in anterior homolateral left: F3/F4, $t(37) = 2.36$, $p = .014$; F4/C4, $t(37) = 1.63$, $p = .055$; F3/C3, $t(37) = 1.42$, $p = .083$; O1/O2, $t(37) = .69$, $p = .246$; one-tailed *t*-tests (fig. 3). None of the theta coherence variables approached statistical significance.

These results indicate that the TM-Sidhi course produced an increase in the degree to which alpha coherence changed from eyes open to the highest point of coherence during the TM program.

To summarize, the data indicate that:

1. The TM-Sidhi course facilitates the depth of transcending.
2. The longitudinal change in the process of transcending produced by the TM-Sidhi program is most closely associated with increased alpha coherence in the frontal cortex, particularly bilateral and homolateral right.

D. LONGITUDINAL CHANGES IN CREATIVITY—For verbal creativity, differences between groups

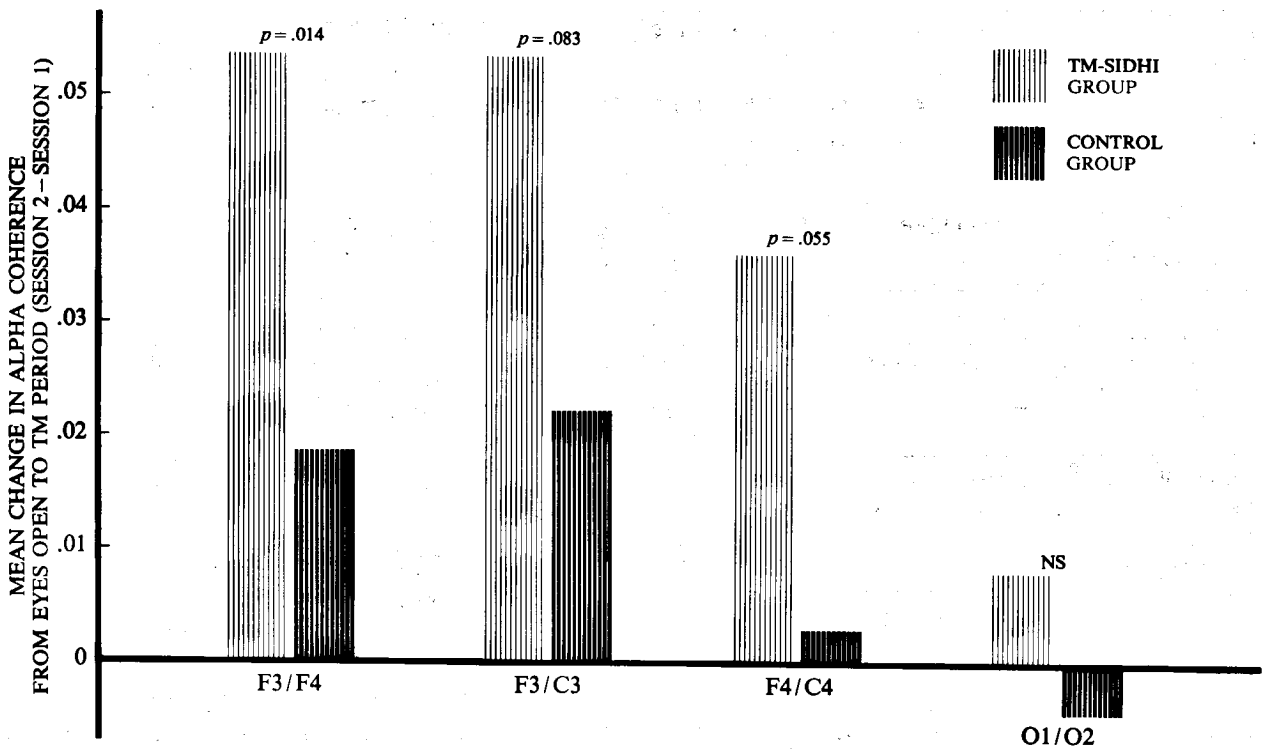


FIG. 3. LONGITUDINAL EFFECTS OF THE TM-SIDHI COURSE ON TRANSCENDING (THE CHANGE IN ALPHA COHERENCE FROM EYES OPEN TO DURING THE TM PROGRAM). The three-month TM-Sidhi course was found to enhance the degree to which alpha EEG coherence increases from the eyes-open period to during the TM program. This figure shows that the largest increase in transcending occurred in bilateral and homolateral alpha coherence in the frontal cortex.

(Session 1 to Session 2) in fluency and flexibility were significant ($F(1,34)=4.41$, $p=.02$ and $F(1,34)=4.33$, $p=.02$) with the experimental group increasing compared to the control group. The experimental group also showed a trend to increase more than the controls in figural creativity: fluency ($F(1,35)=2.14$, $p=.075$) and originality ($F(1,35)=2.01$, $p=.080$). Comparison of changes in verbal originality and figural flexibility were not significant.

E. CORRELATED LONGITUDINAL CHANGES IN EEG ALPHA COHERENCE WITH CHANGES IN CREATIVITY VARIABLES—Because previous research (Orme-Johnson and Haynes, 1981) had shown positive correlations between creativity and several alpha coherence variables among frontal and central regions, correlations of change in creativity and change in all alpha variables were studied (tables 5A and 5B).

Change in bilateral frontal alpha coherence was significantly positively correlated with all creativity variables (fluency, flexibility, and originality) for both the Torrance Verbal and Figural Tests of Creative Thinking (largest $r=.58$, $p=.001$).

Change in bilateral occipital alpha coherence and change in creativity tended to be inversely correlated (largest absolute magnitude $r=-.48$, $p=.002$).

Change in anterior homolateral left alpha coherence tended to be positively correlated with figural creativity (largest $r=.44$, $p=.003$) and change in anterior homolateral right alpha coherence tended to be positively correlated with verbal creativity (largest $r=.37$, $p=.013$).

DISCUSSION

The overall trend of the data showed that the Transcendental Meditation and TM-Sidhi program changed the pattern of EEG coherence in a way which can be interpreted as beneficial. In this discussion we first

TABLE 5A

PEARSON CORRELATION COEFFICIENTS BETWEEN CHANGE IN EEG ALPHA COHERENCE WITH CHANGE IN VERBAL CREATIVITY OVER A FOUR-MONTH PERIOD (N = 36)

VERBAL CREATIVITY		THRESHOLD ALPHA*				MEAN ALPHA			
		Frontal	Left	Right	Occipital	Frontal	Left	Right	Occipital
Fluency	*r*	0.457	0.022	0.242	−0.075	0.584	0.082	0.372	−0.303
	p	0.003	0.449	0.078	0.332	0.001	0.318	0.013	0.036
Flexibility	*r*	0.580	0.225	0.248	−0.179	0.554	−0.095	0.100	−0.477
	p	0.001	0.094	0.072	0.148	0.001	0.290	0.282	0.002
Originality	*r*	0.285	0.010	0.138	−0.062	0.488	0.030	0.336	−0.385
	p	0.046	0.478	0.211	0.360	0.001	0.432	0.023	0.010

* Threshold coherence is the percent of epochs in which coherence was over a threshold of 0.95 (1.0 = perfect coherence).

TABLE 5B

PEARSON CORRELATION COEFFICIENTS BETWEEN CHANGE IN EEG ALPHA COHERENCE WITH CHANGE IN FIGURAL CREATIVITY OVER A FOUR-MONTH PERIOD (N = 37)

FIGURAL CREATIVITY		THRESHOLD ALPHA*				MEAN ALPHA			
		Frontal	Left	Right	Occipital	Frontal	Left	Right	Occipital
Fluency	*r*	0.309	0.437	0.209	−0.115	0.296	−0.182	0.052	−0.118
	p	0.032	0.003	0.112	0.249	0.038	0.140	0.380	0.243
Flexibility	*r*	0.312	0.344	0.167	−0.142	0.267	0.126	−0.015	−0.228
	p	0.030	0.019	0.161	0.201	0.055	0.228	0.465	0.087
Originality	*r*	0.253	0.063	0.023	0.083	0.041	−0.162	−0.179	−0.179
	p	0.065	0.350	0.450	0.320	0.400	0.159	0.149	0.338

* Threshold coherence is the percent of epochs in which coherence was over a threshold of 0.95 (1.0 = perfect coherence).

examine the significance of different patterns of EEG coherence in terms of their correlations with measures of cognitive and affective functioning. Then the changes in coherence resulting from the Transcendental Meditation and TM-Sidhi program are discussed in light of these patterns. Finally, the role of EEG coherence in information processing is discussed.

Patterns of EEG Coherence and the Transcendental Meditation and TM-Sidhi Program

The pattern of correlation of coherence variables with psychological variables suggests three distinct functional systems of the cerebral cortex with respect to the specific areas measured. Bilateral frontal alpha coherence was positively correlated with wakefulness, i.e., it was most sensitive to the effects of drowsiness. It was also positively correlated with creativity (longitudinally), overall grade point average, and emotional stability (i.e., inversely correlated with neuroticism). Thus, coordination between the left and right hemispheres of the frontal lobes appears to be important in modulating the degree of alertness to the immediate environment, as wakefulness, creativity, and GPA imply.

Homolateral left and right alpha coherence in the frontal cortex was positively correlated with verbal intelligence and principled moral reasoning. This indicates that coherence within each of the two frontal lobes is associated with learned abstract principles and strategies stabilized in memory, the essence of "book learning." This suggests a distinction between the functional significance of coherence in the bilateral and homolateral frontal systems which is similar to Cattell's distinction between general fluid intelligence and general crystallized intelligence; the function of bilateral frontal alpha coherence appears to be associated with general fluid intelligence whereas homolateral frontal coherence is associated with general crystallized intelligence.

Homolateral left and right frontal coherence was also inversely correlated with neuroticism and positively correlated with a measure of experiences of cosmic consciousness (pure consciousness stabilized throughout waking, dreaming, and sleep). These results clearly indicate that homolateral frontal coherence is functionally distinct from bilateral frontal coherence in terms of its cognitive and affective correlates.

Bilateral occipital alpha coherence, the third system, was found to be inversely correlated with verbal intelligence, principled moral reasoning, and creativity, but to be uncorrelated with grade point average and positively correlated with emotional stability. This apparent contradiction between an inverse correlation with cognitive ability and a positive correlation with emotional stability can be resolved if one considers that the correlations were moderate, and therefore there is room for many exceptions to the relationships implied by the correlations. For example, some subjects may have high occipital coherence and also have high verbal IQ.

This proposition is supported by the finding that the three coherence factors to emerge from the factor analysis were orthogonal indicating that there can exist different combinations of these factors in different individuals. For example, one person may be high on the bilateral frontal, high on the homolateral frontal, and low on the occipital factor, while another may be high on all three factors. Whereas higher coherence in frontal areas relative to posterior appears to be favorable for cognitive ability, high coherence in all areas reflects mental health. Therefore, it seems that the optimal pattern of *change* in coherence would be increased coherence in all areas, with a relatively greater increase in frontal areas, implying enhanced cognitive ability as well as increased emotional stability.

This is just the pattern of change that both the Transcendental Meditation program and the TM-Sidhi program produced. Coherence increased in all cortical areas during the TM program and longitudinally due to the TM-Sidhi program, with the largest increase in frontal areas. The experience of the TM and TM-Sidhi program thus appears to culture global improvements in CNS functional organization.

This conclusion is further supported by other experiments which have shown that the TM and TM-Sidhi program produces longitudinal changes in intelligence over a span of a year or more (Aron, Orme-Johnson, and Brubaker, 1981; Shecter, 1975; Tjoa, 1977). Further, a cross-sectional study has shown higher levels of moral reasoning in TM participants relative to controls (Nidich, 1977), and another experiment has indicated positive correlation of moral reasoning with frontal EEG coherence (Nidich, Ryncarz, Abrams, Orme-Johnson, and Wallace, 1983).

In addition, previous research has also found lon-

gitudinal increases in creativity (Orme-Johnson and Granieri, 1977; Travis, 1979). The strong correlation between change in creativity from Session 1 to Session 2 with change in coherence supports the conclusions of a previous study that alpha coherence among frontal and central regions is positively correlated with creativity (Orme-Johnson and Haynes, 1981).

With regard to EEG frequency, virtually all the correlations with psychological variables and all the changes produced by the TM and TM-Sidhi program found in this study were in the alpha frequency, with some theta involvement. No reliable effects were found for delta, beta 1, or beta 2, with the exception of inverse correlation of occipital coherence at all frequencies with verbal intelligence and principled moral reasoning.

THE ANTERIOR-POSTERIOR AXIS—The data of the present experiment indicate that EEG coherence in the frontal and occipital regions of the cortex are quite different from each other with respect to their cognitive correlates. In order to interpret this finding we will now consider the possible neurophysiological role of EEG coherence in the light of the literature on the functional significance of anterior and posterior cortical regions.

High EEG coherence indicates that the cell populations in the regions of the electrodes being compared are operating together as a single unit with respect to the brain macropotentials being measured. For the parameters of sampling rate, epoch length, etc., used in the present experiment, coherence of 0.95 indicates that the frequency difference between the two EEG signals being compared is less than 0.05 Hz (Levine, 1976).

Frontal coherence: Since the central EEG leads (C3 and C4) are near the posterior regions of the frontal lobes, frontal and central leads measure intrahemispheric or homolateral coherence within the frontal lobes; F3/C3 reflects coherence on the left side of the frontal lobe whereas F4/C4 measures coherence on the right side of the frontal lobe.

Thus, considering that EEG coherence is a measure of the degree of integration of large masses of cortical tissue, the present data indicate that it is advantageous for the frontal lobes to function together in a highly coherent state. The frontal lobes are known to be involved with abstract conscious processes such as comprehension, judgment, planning, and social responsibility (Pribram and Luria, 1973). The findings of the present study are consistent with this classical view, and indicate that coherent functioning is associated with high performance in these areas.

The finding that the TM and TM-Sidhi program produces increased coherence in the more anterior and more recently evolved areas of the cortex, as well as producing increased efficiency in tasks mediated by these areas, must be perceived in the light of current knowledge of the functional organization of the brain. The frontal lobes appear to be an integral part of sensory systems, responding to specific stimuli, and performing the function of selection and storage of information involved with attention (Pribram and Luria, 1973). The role of attention is to integrate current information processing with the existing organization of knowledge structures and the frontal lobes appear to be intimately involved in this process. For example, the N100 component of the auditory evoked response, which is associated with attention, is more developed in the frontal-central areas (Picton, Campbell, Baribeau-Braun, and Ptoulx, 1978).

Unit studies have also concluded that the frontal units may be involved with attention, specifically with species-specific sounds which may be interpreted as the integration of stimulus events with their genetically transmitted sense of relevance to the species (Newman and Lindsley, 1976). This indicates the importance of the frontal lobes for integrating the organism with those aspects of the environment that are most important for its survival and well-being.

Studies of synchronized "focal" rhythms in frontal thalamo-cortical columnar channels have shown that synchronized oscillations replace desynchronized activity during attention. Different frequencies of rhythms correspond to different degrees of attention; high vigilance is associated with fast rhythms, "diffuse" attention or broad comprehension with middle range frequencies, and drowsiness with slow frequencies (Brown, 1970; Buser, 1980; Rougeul-Buser, Bouyer, and Buser, 1978).

Attentional processes during mental arithmetic have been shown to increase the correlation of theta and alpha EEG (3 – 12 Hz band) within frontal and central cortical areas (Livanov, Gavrilova, and Aslanov, 1974). Mental problem solving requires the coordination of algorithms of arithmetic operations, short-term memory, and focused attention on the ongoing mental processing. It appears that an extended, correlated structure of the frontal cortex provides an

organizing context (ground) for guiding the temporal evolution of ongoing cognitive processing (figures). The present finding of a positive correlation of change in frontal cortex EEG coherence with change in creativity provides further support for this view. These creativity tests measure the ability to make broad and original associations, requiring the successful integration of the "problems" set forth by the tests with the widest possible organization of previous knowledge structures.

Other evidence also supports this interpretation that the frontal lobes are involved in providing the conceptual context within which the content of information is processed. For example, frontal theta and alpha coherence is positively correlated with flexibility and efficiency of concept-learning (Dillbeck et al., 1981). In general, the frontal lobes are important for the flexible application of behavior (Berg, 1948; Luria and Homskaya, 1964; Milner, 1964; Gabriel, Freer, and Finger, 1979; Becker and Olton, 1980). Flexibility and efficiency in deploying cognitive and behavioral sequences implies their coordination by a meta-plan which appears to involve long-range spatial organization of the frontal cortex of the type that is generated by the TM and TM-Sidhi program.

The fact that the TM and TM-Sidhi program involves attentional processes with respect to the mental experience of a sensory (auditory) modality may well account for the predominantly frontal influence of coherence produced by these practices.

The neurophysiological state of waking is a precondition for attention. The transition from waking to sleep is characterized by the withdrawal of attention from the external environment and the diminution of wakefulness, associated with decreased bilateral frontal alpha coherence. The transition from waking to transcendental consciousness is characterized by the withdrawal of attention from the external environment and the enhancement of inner wakefulness, primarily associated with increased bilateral frontal alpha coherence.

Sleep revitalizes the attentional abilities of the waking state. The experience of transcendental consciousness during the Transcendental Meditation and TM-Sidhi program not only leads to an immediate enhancement of attentional abilities but has also been shown to result in cumulative improvements in these abilities, as reflected in enhanced cognitive performance and increased frontal alpha coherence.

Occipital coherence: Whereas the frontal lobes appear to be involved with connecting concrete information with abstract plans and schemata, the occipital area appears to be concerned with more concrete processes. Specifically it contains the primary projection area and secondary and tertiary processing areas for vision. Various stages of feature analysis are believed to occur in the occipital cortex which build up the perceptual boundaries giving visual forms their concrete definition. Frontal functions may thus be considered as concerned with action and control of future events, while posterior cortical areas, being concerned with perception, have to do with interpretation of the immediate past.

A Model of the Role of EEG Coherence in Information Processing

Three principles of neurophysiological organization with respect to the EEG appear to explain much of the data:

1. An anterior-posterior axis represents an abstract-concrete dimension.
2. High EEG coherence in the alpha and theta frequencies represents the neurophysiological correlate of the more generalized, abstract, synthetic, holistic, integrative functions of the brain (Campeau et al., 1971; Cazard, 1973; Gionnitropani, 1973; Beaumont, Mayes, and Rugg, 1978; Beaumont and Rugg, 1979); while low coherence, desynchronization, and high frequencies are correlates of more concrete, specialized functions of particular cortical areas, such as perceptual and motor functions.
3. Any cortical area can perform general or specialized functions; cortical tissue can perform its regional, specialized function, associated with a desyncronized, low coherence state, or can join other tissues via high coherence to perform a general, integrative function.

We propose that when a cortical area is involved in a generalized, integrative function that coherence is high in that area whereas when the area is performing its specialized motor or perceptual function that coherence will be low. For example, it has been found during the concrete, specialized functions of the occipital cortex such as foveal stimulation, visual problem solving, and eye movements, that bilateral occipital coherence decreases (Nathan and Hanley, 1975). However, during attention to acoustical stimuli, occipital coherence increases (Martinius and

Hoovey, 1972), which suggests that when the specialized visual functions of the occipital lobe are not being used, it joins other tissue as reflected in EEG coherence to perform a generalized integrative function.

Whereas any cortical area is viewed as possessing the property of an integrative function, we propose that this is primarily the function of the frontal cortex. For example, the increased correlations among many frontal areas seen during problem solving (Livanov et al., 1974) may reflect the onset of a generalized integrative function of the frontal lobes supportive of more concrete aspects of information processing taking place in other brain areas. According to this model, during any task coherence may be high in some areas and low in others, reflecting the complementary role of integration and differentiation, respectively.

INTERPRETATION OF THE PRESENT RESULTS IN TERMS OF THE MODEL—In the present experiment it was found that verbal creativity and verbal intelligence were both strongly positively correlated with homolateral right hemisphere alpha coherence, while figural (spatial) creativity was more strongly correlated with homolateral left hemisphere alpha coherence than with right alpha coherence. It is also generally believed that verbal, temporal processing desynchronizes the left hemisphere while nonverbal, spatial processing desynchronizes the right. Applying the third principle described above, this finding is interpreted as an example of the way in which the contralateral hemisphere may provide a supportive, integrative function for the active, desynchronized hemisphere, rather than merely passively resting.

For example, active processing of information specific to the left hemisphere (e.g., verbal) will cause the left hemisphere to be desynchronized, while the synchronized, coherent right hemisphere will assist the left by providing an integrating context. On the other hand, desynchronized, specialized spatial processing in the desynchronized right hemisphere will be assisted by coherence and integration from the left. In this view, the hemisphere contralateral to the hemisphere involved in active processing does not merely "rest" and is not "nonactive" but rather is intimately engaged in the processing; its role is to provide a "ground" for the "figure" in the other hemisphere.

In this context, it is of interest that TM participants have been found to show greater lateral EEG asymmetry during both left and right hemisphere tasks compared to controls (Bennett and Trinder, 1977). This shows relatively greater alpha power in whichever hemisphere is "nonactive" and synchronized, and lower power in whichever hemisphere is active and desynchronized. This result supports the present hypothesis if it is assumed that synchronization reflects increased efficiency of integration, and that desynchronization indicates more efficient differentiation.

This model may provide a neurophysiological explanation for the dual process of maintaining pure consciousness together with focused waking activity that Maharishi Mahesh Yogi has described as characteristic of the first stage of enlightenment, cosmic consciousness (Maharishi Mahesh Yogi, 1969). In this view, the contralateral hemisphere is the "witness"; in its coherent state, it is silent and does not contribute to detailed information processing, but it is the real source of organizing power for integrating the data being processed by the working hemisphere. In other situations, in which the division of cerebral work is antero-posterior rather than left-right, the same duality of functioning between integrative and focal activities is hypothesized to exist, the active part of the cortex playing the focal, desynchronized role, and the remainder of the brain representing the holistic or unified element (see point 3 above).

The results of the present experiment showed that a measure of experiences of cosmic consciousness was correlated with homolateral coherence in both the left and right frontal cortex. This result supports the hypothesis that either hemisphere may play the role of integrating the activity in the contralateral hemisphere. This is different from other views about the importance of the left for verbal functions and the right for creative or nonverbal functions, and suggests that the two hemispheres complement each other during both types of processing. Certainly it should give medicine and surgery cause for much greater caution in making decisions about "silent areas of the brain."

Finally, it suggests that the key to human intelligence may be found not in mere computing power but rather in the relationship of the concrete, analytic, "point" value of consciousness, the specific content of conscious awareness, to the abstract, synthetic, "infinite" value of consciousness, which provides the context or field within which the specific content is interpreted and given meaning. Table 6

outlines this relationship in terms of the different elements of cognitive functioning involved in the TM-Sidhi program and their possible EEG correlates.

Although the elements of cognition described in table 6 specifically pertain to the TM-Sidhi program, these three general cognitive functions are considered to be at the basis of all cognitive processes. According to this view, cognitive development entails the development of all three elements: 1) the development of increasingly greater ability to focus attention (differentiation); 2) the development of an increasingly broader, more complete integrating context of interpretations (integration); and 3) the development of the ability to effectively place content in a context, i.e., to connect the part with the whole.

The practice of the TM-Sidhi program employs the process of *samyama* which integrates the three basic elements of cognition, *dharana, dhyana,* and *samadhi* (see table 6 and Method section). The purpose of this process is to spontaneously enhance the balanced development of all three aspects of consciousness to their ultimate level, the "point" value of consciousness smoothly connected to the "infinity" value of consciousness, *samadhi,* transcendental consciousness.

In the process of *samyama,* the focus or "point" value of consciousness (*dharana*) is refined to finer and finer levels (*dhyana*) until, having reached the very subtlest point value, consciousness transcends to its unbounded state, transcendental consciousness (*samadhi*). Transcendental consciousness is posited to be the direct experience of the most abstract level of nature, the unified field of natural law recently glimpsed by modern quantum field theory (Hagelin, 1984; Orme-Johnson, Dillbeck, Alexander, Van den Berg, and Dillbeck, in press). During transcendental consciousness, coherence increases globally in all areas of the brain, frontal, occipital, left, and right (Badawi et al., 1984) as was found using the transcending measure (eyes open to the TM period) in the present experiment. This is interpreted as a state in which all cortical areas participate in the generalized, integrative function to produce the experience of pure consciousness, pure knowledge, the experience of the Self, the knower.

TABLE 6

MODEL OF COGNITIVE FUNCTIONS AND NEUROPHYSIOLOGICAL CORRELATES

ELEMENTS OF COGNITION*	FUNCTION	EEG CORRELATE
Dharana: focus of attention, "point"	known, content of knowledge	low coherence in areas specializing in focusing process
Dhyana: process of transcending from focused awareness to unbounded awareness	process of gaining knowledge, process of connecting content to context	transition from low coherence to high coherence
Samadhi: unbounded awareness, "infinity"	knower, context of knowledge	high global coherence

* *Dharana, dhyana,* and *samadhi* are three elements of the process of *samyama* which is employed in the TM-Sidhi program.

The longitudinal results of the transcending measure (eyes open to the TM program) indicate that the TM-Sidhi program enhances the ability to transcend to *samadhi.* This is seen as the direct result of exercising the capacity of thought to refine itself to its subtlest state during the TM-Sidhi program. In the light of the pattern of correlations of EEG coherence with the cognitive and affective variables, it appears that the TM-Sidhi program cultivates the ability to refine thought to a more profound, universal level.

In conclusion, the present data indicate that the TM and TM-Sidhi program improves the functional organization of the brain and suggest general principles for modeling higher states of consciousness.

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