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Patterns of EEG coherence, power, and contingent negative variation characterize the integration of transcendental and waking states

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Abstract

Long-term meditating subjects report that transcendental experiences (TE), which first occurred during their Transcendental Meditation (TM) practice, now subjectively co-exist with waking and sleeping states. To investigate neurophysiological correlates of this integrated state, we recorded EEG in these subjects and in two comparison groups during simple and choice contingent negative variation (CNV) tasks. In individuals reporting the integration of the transcendent with waking and sleeping, CNV was higher in simple but lower in choice trials, and 6–12 Hz EEG amplitude and broadband frontal EEG coherence were higher during choice trials. Increased EEG amplitude and coherence, characteristic of TM practice, appeared to become a stable EEG trait during CNV tasks in these subjects. These significant EEG differences may underlie the inverse patterns in CNV amplitude seen between groups. An 'Integration Scale,' constructed from these cortical measures, may characterize the transformation in brain dynamics corresponding to increasing integration of the transcendent with waking and sleeping.

Keywords: CNV; Meditation; EEG; Coherence; TM; Enlightenment; Transcendental experiences

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1. Introduction

In western cultures, transcendental experiences (TE) are generally considered either momentary, ephemeral (James, 1961; Maslow, 1972), or as epiphenomena of limited importance (Persinger, 1984, 1993). Eastern traditions, however, include meditation practices that elicit frequent TE with the purpose of enhancing human development (Maharishi Mahesh Yogi, 1967; Travis et al., 2000; Walsh, 1982).

Various physiological markers have been reported during TE in subjects practicing different meditation techniques. For instance, during practice of Tibetan Buddhism, experiences characterized by the 'loss of the usual sense of space and time' were associated with increased frontal regional cerebral blood flow (rCBF), and significant correlation between left dorsolateral frontal rCBF increases and left parietal rCBF decreases (Newberg et al., 2001). During practice of Diamond Way Buddhism, experiences of the 'dissolution of the self into a boundless emptiness' were associated with right fronto-temporal 40-Hz amplitude increases (Lehmann et al., 2001). During Transcendental Meditation (TM) practice[1], experiences of 'unboundedness' and the 'loss of time, space and body sense' (Travis and Pearson, 2000) were associated with spontaneous breath quiescence (breath periods from 10 to 40 s) (Badawi et al., 1984; Farrow and Hebert, 1982), with autonomic orienting at the onset of breath changes (Travis and Wallace, 1997). These breath changes occurred on the background of high EEG coherence, which rises to high levels in the first minute of TM practice (Travis and Wallace, 1999).

These reports indicate a growing body of physiological research investigating experiences marked by the absence of time, space and body sense during meditation practice. Time and space are the framework for organizing waking experiences into coherent perceptual wholes, and body-sense helps provide the boundary between inner and outer phenomena. This framework, which gives structure to waking experiences, appears to be absent during TE. Thus, subjectively and physiologically, TE appears to be fundamentally different than waking experiences.

Eastern traditions encourage TE for the larger purpose of culturing a new style of mental and physiological functioning in which the transcendental state is integrated with waking and sleeping states (Maharishi Mahesh Yogi, 1963; Mason et al., 1997; Shearer and Russell, 1978). The current study investigated TM subjects reporting this integrated experience. TM subjects were tested because: (1) a body of physiological research exists that delineates different substates during TM practice to help guide this research (Farrow and Hebert, 1982; Travis, 2001; Travis and Wallace, 1997); and (2) many TM subjects are available who report the continuous integration of the transcendent with waking and sleeping states for 1 year or longer.

An individual who practices the TM technique describes this integrated experience in this way.

[1] Transcendental Meditation® is registered in the US Patent and Trademark Office as a service mark of Maharishi Foundation, Ltd., and is used under license by Maharishi University of Management.

"The flurry of waking activity comes and goes; the inertia of sleep comes and goes. Yet, throughout these changing values of waking and sleeping, there is a silent, unbounded continuum of awareness that is me; I am never lost to myself."

This description of the co-existence of two qualitatively different states—a silent continuum of inner awareness along with the 'flurry' of daily activity—is consistent with EEG patterns of subjects reporting this integrated experience. For example, when these subjects are asleep, higher alpha EEG amplitude, which is indicative of wakefulness, is observed during Stage three and four delta sleep (Banquet and Sailhan, 1974; Mason et al., 1997). Also, during eyes-open resting, increased alpha EEG coherence is seen in subjects reporting more frequent TE compared with subjects reporting less frequent experiences (Travis, 1991). Thus, self-reports of integration of the transcendent with waking and sleeping states correlate with objective reports of the integration of EEG patterns normally seen during TE in meditation (high frontal alpha EEG power and coherence (Travis, 2001; Wallace, 1970)) with those seen during waking (low voltage, mixed frequency) and sleeping (delta activity).

Contingent negative variation (CNV) also appears to be sensitive to frequency of TE. CNV is an event-related potential occurring between a warning stimulus (S1) and a sond imperative stimulus (S2) requiring a response (Walter et al., 1964). Early CNV, measured in the 500–800 ms window after S1, reflects automatic, orienting processes (Tecce, 1972; Tecce and Cattanach, 1993). Late CNV, measured in the 200 ms window before S2, reflects proactive preparatory processes, including mobilization of motor (Brunia and Damen, 1988; van Boxtel and Brunia, 1994), perceptual, cognitive, and attentional resources (Tecce and Cattanach, 1993).

With more frequent TE, late CNV in a simple RT paradigm was reported to increase and distraction effects were reported to decrease (Travis et al., 2000). In contrast, CNV in a choice RT task was reported to be lower in subjects reporting more frequent TE (Travis et al., in press). The authors (Travis et al., in press) suggested that lower CNV in the choice trials may reflect a more balanced attentional set in which subjects waited for S2 before they initiated response processes. Early CNV was not sensitive to group membership in either of these two studies.

The current study extended earlier reports of the relation between brain functioning and frequency of TE by: (1) testing subjects with more extensive TM practice (24 vs. 7 years TM practice), who report the continuous integration of the transcendent with waking and sleeping states; (2) comparing EEG amplitude and coherence during tasks; and (3) presenting subjects both simple and choice CNV tasks. EEG coherence and late CNV were measured in this study, since they were sensitive to frequency of TE in the studies reported above. We hypothesized that subjects reporting more frequent TE would display higher frontal EEG amplitude and coherence, higher late CNV amplitudes in a simple CNV task, and lower late CNV amplitudes in a choice task.

2. Methods

2.1. Subjects

Fifty-one subjects participated in the study—none had participated in previous research. Subjects were assigned to groups based on self-reported frequency of TE. Subjects reporting rare if any TE formed the Rare-TE group ($<$ once per year, age $= 39.7 \pm 11.5$ years)[2]. This group was recruited from individuals who intended to learn the TM technique, but had not yet been instructed. Subjects reporting frequent TE during meditation practice, but only occasionally during waking and sleeping formed the Occas-TE group (one to ten times per year, age $= 42.5 \pm 11.5$ years, TM practice $= 7.8 \pm 3.0$ years). Subjects reporting the continuous co-existence of the transcendent with waking and sleeping states formed the Cont-TE group (age $= 46.5 \pm 7.0$ years, TM practice $= 24.5 \pm 1.2$ years). The age differences between groups were not statistically significant, $F(2, 48) = 1.90$, $P = 0.160$. Each group comprised eight females and nine males.

A semi-structured interview and two measures of TE were used to substantiate subjects' self-reports of inner experiences. The two scales were Hood's M-Scale (Hood, 1975), and Baruss's Physical-Transcendent Scale (Baruss and Moore, 1992). Hood's M-Scale contains 32 brief descriptions of a number of TE with a five-point Likert response-scale ranging from 'Definitely Agree' to 'Definitely Disagree.' Baruss's Physical-Transcendent Scale contains 38 statements that lie along a physical-transcendent dimension with a seven-point Likert response-scale. Baruss constructed this scale to quantify a subject's worldview.

The subjects were blind to the specific experimental hypotheses. All subjects were right-handed. Subjects had no history of accidents, hospitalization, or psychiatric diseases that might have affected their EEG. They were also free of prescription or non-prescription drugs that might affect EEG records. Informed consent was obtained before the testing, and the University Institutional Review Board approved the experimental protocol.

2.2. Recording details

EEG was recorded from F3, FZ, F4, C3, CZ, C4, P3, PZ, and P4 in the 10–20 system, using Ag/AgCl electrodes affixed with EC-2 cream, with a forehead ground and impedances at 5 kohms or less. Vertical electro-oculogram (EOG) was recorded with electrodes placed above and below the right eye to use in the eye-movement correction procedure. Heart rate was recorded with a Lead II configuration (Stern et al., 1976). A linked-ears reference was used (Picton and Hillyard, 1972).

EEG and EOG signals were recorded with a 0.01–100 Hz band pass filter (three down, 12 dB octave/slope). Heart rate was recorded with a 3.0–100 Hz band pass filter. All signals were digitized on line at 200 points per s, and stored for later

[2] Data are reported as mean $\pm$ standard deviation.

analyses using EEGSYS, a standardized research acquisition and analysis package developed in conjunction with researchers at the National Institutes of Health (Hartwell, 1995).

2.3. Procedure

Subjects were tested from 15:00 to 17:00 h, which was 6–8 h after the TM subjects' morning meditation, and just before their afternoon meditation session. Thus, any performance differences between groups should primarily reflect long-term TM effects rather than immediate TM effects. Subjects completed the M-Scale and the Physical-Transcendent Scale while the sensors were being applied.

Subjects were then visually presented a set sequence of four CNV tasks with 31 trials in each task. Each block of trials lasted approximately 7 min. Inter-trial intervals varied from 8 to 14 s. (1) The first task contained 31 simple trials. In these trials, S1 was an asterisk (150 ms duration, 1 cm in height) in the center of a computer screen, followed 1.5 s later by S2, a continuous computer-generated tone (1200 Hz, 72 dB). Subjects were asked to stop the tone as quickly as possible with a key press. (2) The second task contained both simple RT trials and simple trials with a divided-attention task in the S_1S_2 interval. These trials consisted of random presentation of 16 simple trials, as in the first task, and 15 divided-attention trials with three letters visually presented in the S_1S_2 interval. Subjects were asked to speak out the letters after terminating S2 with a key press. (3) The third task contained choice trials. In these trials, S1 was a one or two-digit number (150 ms duration, 1 cm in height) in the center of the computer screen, followed 1.5 s later by S2, another one or two-digit number. Subjects were asked to press a button in their left hand if the first number was larger, or in their right hand if the second number was larger. (4) The last task randomly presented choice RT trials and choice RT with divided-attention trials, similar to the second block of trials.

Data were recorded for 6 s, beginning 100 ms pre-S1, and ending 4.4 s after S2. According to a recent methodology paper (Picton et al., 2000), 100 ms is an acceptable baseline. Following the CNV trials, EEG was recorded during a 15-min eyes-closed rest period for the Rare-TE (non-meditating) subjects and during a 15-min TM session for the Occas-TE and the Cont-TE subjects. The purpose of this was: (1) to compare TM practice EEG patterns between the two TM groups to discern possible practice effects in short- and very long-term TM subjects; and (2) to detect cortical patterns seen during TM practice but not during eyes-closed rest. This comparison was not used for hypothesis testing, but to help guide investigation of EEG patterns that may distinguish the integration of the transcendent with waking and sleeping states in these subjects.

After the physiological recordings, subjects were interviewed using a semi-structured interview format. Subjects were asked three questions: What were your experiences during the computer tasks? What are your experiences during sleep? Please describe yourself. The interview format was flexible enough to probe experiences and issues important to each subject, as well as ask standard questions. The interview data helped to further support subject's self-reports of TE and provided detailed descriptions of the subject's inner experiences. These interview data will be presented elsewhere.

2.4. Data analysis

2.4.1. Late CNV amplitudes

The subjects were asked to focus on the center of the screen during each trial, and to rest their eyes after responding to S2. This resulted in very few eye-blinks in the first 2 s (containing the baseline period, S1, S2, and response selection periods), but frequent eye blinks towards the end of the 6 s recording window. To eliminate the majority of eye blinks from the CNV analysis, the first 2 s of data from the 6 s recording windows were used for subsequent data analysis. These 2 s windows were corrected for effects of partial saccades (< 50 μV) with the eye-movement correction procedure proposed by Gratton et al. (1983, 1983) and more generally implemented by Miller et al. (1988).

The partial-saccade-corrected trials were then read back into EEGSYS and any trial with artifacts—flat EEG or blinks (excursions > 50 μV)—were manually marked and eliminated from the average. Before averaging, the data were passed through a 3 Hz low pass filter to remove the effects of theta and alpha activity on the averaged waveforms. CNV trials were averaged within the four tasks. During the simple and choice trials, there were 20 or more, artifact-free trials for each subject. During the divided-attention trials, a third of the subjects had fewer than six artifact-free trials (out of a, possible 15 trials). With so few artifact-free trials, the divided-attention trials were not analyzed further. CNV presented below are from the first and third blocks—simple and choice trials only.

Late CNV was measured during the simple and choice trials in microvolts as the average amplitude in the 200 ms window before S2, relative to the 100 ms baseline. Simple-choice difference-scores were calculated ($CNV_{simple} - CNV_{choice}$) to assess the impact of the additional cognitive load of the choice trials independent of possible group differences in the simple trials.

2.4.2. EEG spectral analysis

The data 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 fast Fourier transformed in 2-s epochs during the first 2 min of the rest/TM sessions and for the 31 2-s epochs in the choice trials. Amplitude[3] was calculated for the nine electrodes measured. Coherence was calculated for nine coherence pairs: F3–F4, C3–C4, P3–P4, F3–C3, FZ–CZ, F4–C4, F3–P3, FZ–PZ, and F4–P4.

Spectral analysis was calculated for the first 2 min of the TM session because the first 2 min are reported to be representative of the entire session (Travis and Wallace, 1999). Spectral analysis was calculated for the choice trials rather than the simple trials, because the choice trials contain more cognitive processes than the simple trials and, therefore, may better distinguish possible effects of the integration of transcendental and waking states. Spectral analysis was calculated for the full 2 s of the choice trials to probe general cortical functioning across memory, categorization and response selection processes. While shorter epochs (300 ms) might reveal the relation between, for example, early or late CNV amplitude and spectral estimates, our intent was to characterize background brain states rather than specific components of processing. In addition, longer epochs yield more stable coherence estimates (Mocks and Gasser, 1984).

Spectral estimates were grouped into three frequency bins: 6–12, 12–25, and 25–45 Hz. These three bins resulted from a Principal Components Analysis of coherence estimates in 1 Hz bands during TM practice in another meditating cohort (Travis et al., in press). These three bins were used in this study to simplify data analyses.

2.4.3. Reaction time, accuracy, heart rate and eye-blink rate

Response time to S2 was measured to the nearest ms in the simple and choice trials and stored for later analysis. The stimulus/responses codes were also stored for later analysis of accuracy rates. Heart rate and eye-blinks were each summed in the 31 6-s epochs during the choice trials. This sum was divided by 3.1 to yield rate per min (186 total s/60 s per min = 3.1).

2.5. Statistical analysis

An omnibus MANCOVA was first performed to test for main effects and interaction effects with one between factor (group), two within factors (tasks and electrodes), one covariate (age) and CNV as the variate. Age was entered in the MANCOVA to test whether the 7-year age difference between groups, which was not statistically significant, might still differentially affect the results. Since significant task × group and electrode × group interactions were found, individual MANOVAs were performed to test for main effects and interaction effects during each CNV task, and for coherence and power during tasks. An alpha level of 0.05 was used for multivariate analyses; an alpha level of 0.015 for multiple comparisons with three variables; and an alpha level of 0.007 for multiple comparisons with nine variables- all reflecting Bonferroni corrections.

All variables that significantly differed between groups in the MANOVAs were entered into a Principal Components Analysis to reduce the significant variables identified in the MANOVAs to a smaller number of factors that retained most of the original information in the data. (This is discussed in detail below.) The resulting factor scores were entered into a stepwise regression with group as the criterion variable and the composite measures as the predictor variables. The stepwise regression identified the fewest cortical factors necessary to discriminate groups.

[3] EEGSYS calculates power values in each epoch and then estimates the amplitude of a sine wave throughout the epoch that would yield those power values if the Hartwell, J. (1995). EEGSYS User's Guide. Baltimore, MD: Friends Medical Science Research Center, Inc. These amplitude values are presented here.

3. Results

3.1. Outcome of pencil-and-paper tests of transcendent experiences

The scores on the M-Scale and the Physical-Transcendent Scale were highly correlated ($r(50) = 0.801$, $P < 0.0005$), suggesting that these instruments measure a similar construct. A MANOVA with group as the between factor and scores on these two tests as variates yielded a significant main effect for group ($F(2, 100) = 10.72$; $P < 0.0005$). Multiple comparisons using the 'Least Significant Difference' test revealed that these two experience variables distinguished the three groups. All paired comparisons were significant at the $p < 0.001$ level. Group means for M-Scale were: Rare-TE = 18.1 ± 6.47; Occas-TE = 39.5 ± 3.15; Cont-TE = 60.7 ± 0.61. Group means for the Physical-Transcendent Scale were: Rare-TE = 35.7 ± 5.21; Occas-TE = 61.4 ± 4.71; Cont-TE = 84.1 ± 2.96.

3.2. Descriptive statistics of CNV, EEG coherence and EEG amplitude patterns during tasks

3.2.1. CNV

Fig. 1 presents simple (solid lines) and choice (dotted lines) averaged waveforms in microvolts. EOG (top row) was flat in both tasks for all groups. The gray columns before S2 show the 200-ms period used to calculate late CNV. Simple CNV was lowest in the Rare-TE group (left column) and highest in the Cont-TE group (right column) at frontal, central and parietal midline electrodes (rows). In contrast, choice CNV exhibited the opposite pattern- highest in the Rare-TE group and lowest in the Cont-TE group, with the Occas-TE group again in the middle.[4]

3.2.2. EEG coherence

The group means for EEG coherence in the three frequency bins during the rest/TM session and the choice CNV task are presented in Table 1. Consistent group differences in both conditions are seen in F3F4 coherence, across all three frequency bins. Coherence estimates for other electrode pairs were similar across groups.

3.2.3. EEG amplitude

Fig. 2 presents the group means and standard errors for the Rare-TE group (solid), Occas-TE group (diagonal-lines) and Cont-TE group (open) at frontal, central and parietal electrodes in the 6–12, 12–25, and 25–45 Hz frequency bins. Consistently higher 6–12 Hz amplitudes are seen in the Cont-TE amplitude group at frontal, central and parietal electrodes.

[4] The P300 component following S1 also appears to have an inverse pattern across groups. While a MANOVA revealed significant group × task interactions, individual MANOVAs within task yielded no significant main effects for group. Future research can investigate the relation of P300 and CNV in these subjects.

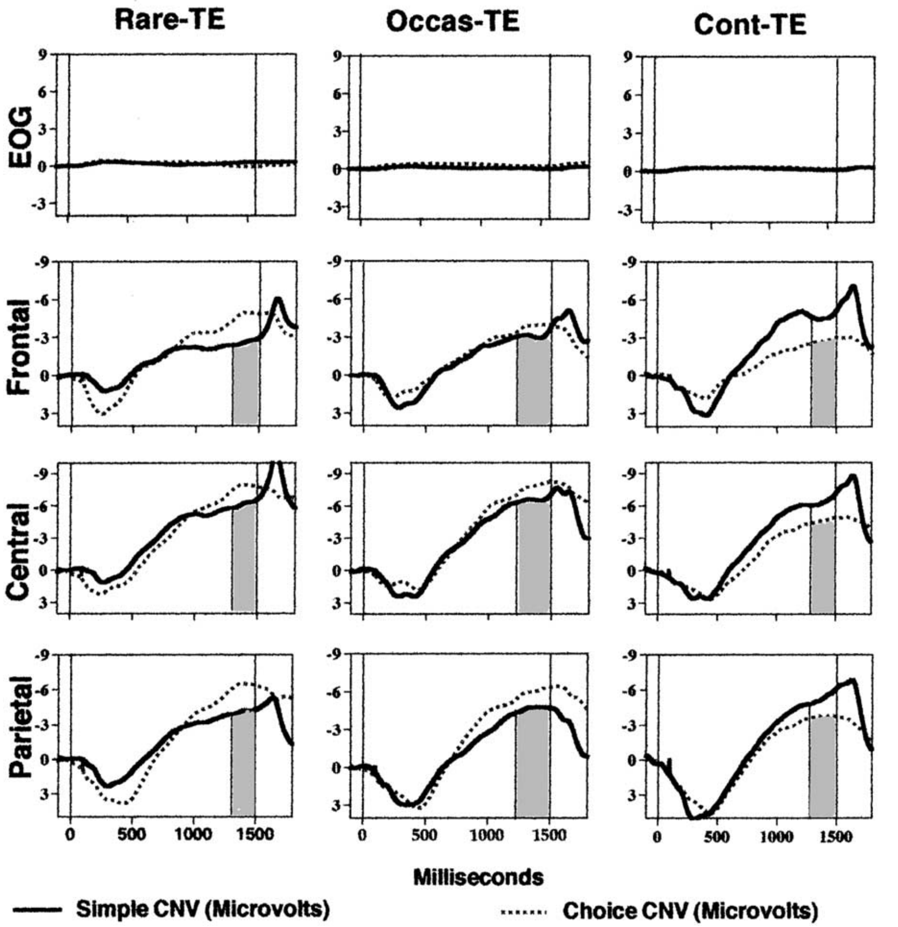

Fig. 1. CNV group averages at EOG, frontal, central and parietal midline electrodes. The vertical lines near the left side of each graph indicate the onset of S1 (an asterisk in simple trials and a one- or two-digit number in choice trials). The line near the right side of each graph indicates the onset of S2 (a tone in simple trials and a sond one- or two- digit number in choice trials). The gray column to the left of S2 represents the 200-ms period used to calculate late CNV. Note that CNV amplitudes are highest in the simple trials (solid lines) and lowest in the choice trials (dotted lines) for the group reporting continuous TE (Cont-TE) relative to the subjects reporting occasional (Occas-TE) or rare TE (Rare-TE).

3.3. Inferential statistics

A mixed MANCOVA was performed with one between factor (group), two within factors (tasks and electrodes), one covariate (age) and CNV as the variate. This analysis revealed significant task × group interactions ($F(2, 48) = 4.87$, $P = 0.012$) and electrode × group interactions ($F(16, 376) = 2.33$, $P = 0.003$). Age was not a

Table 1
Mean EEG Coherence in three frequency bands for the three experimental groups during the Rest/TM session and the choice CNV task

Coh pair (Hz)	Rest/TM			Choice task		
	Rare-TE	Occas-TE	Cont-TE	Rare-TE	Occas-TE	Cont-TE
F3–F4						
6–12	0.564	0.718	0.719	0.331	0.441	0.482
12–25	0.284	0.489	0.527	0.169	0.264	0.347
35–45	0.150	0.349	0.442	0.155	0.209	0.301
F3–C3						
6–12	0.515	0.645	0.551	0.398	0.529	0.469
12–25	0.352	0.549	0.433	0.275	0.365	0.339
35–45	0.285	0.441	0.386	0.266	0.315	0.326
FZ–CZ						
6–12	0.719	0.764	0.750	0.586	0.683	0.649
12–25	0.655	0.733	0.720	0.571	0.657	0.618
35–45	0.582	0.665	0.643	0.568	0.638	0.595
F4–C4						
6–12	0.574	0.616	0.553	0.539	0.503	0.467
12–25	0.395	0.515	0.464	0.371	0.310	0.328
35–45	0.318	0.414	0.384	0.374	0.264	0.296
F3–P3						
6–12	0.176	0.231	0.135	0.131	0.195	0.098
12–25	0.084	0.194	0.104	0.088	0.138	0.076
35–45	0.144	0.194	0.156	0.154	0.175	.0169
FZ–PZ						
6–12	0.312	0.316	0.253	0.287	0.329	0.249
12–25	0.229	0.308	0.251	0.239	0.295	0.216
35–45	0.322	0.328	0.298	0.368	0.391	0.333
F4–P4						
6–12	0.204	0.238	0.127	0.210	0.201	0.141
12–25	0.109	0.186	0.123	0.138	0.122	0.106
35–45	0.161	0.192	0.174	0.208	0.143	0.195
C3–C4						
6–12	0.496	0.479	0.478	0.522	0.596	0.509
12–25	0.360	0.299	0.297	0.401	0.321	0.351
35–45	0.352	0.287	0.328	0.293	0.362	0.276
P3–P4						
6–12	0.564	0.504	0.506	0.541	0.566	0.524
12–25	0.448	0.381	0.373	0.403	0.391	0.349
35–45	0.464	0.420	0.463	0.429	0.472	0.437

significant covariate, $F(1, 49) = 1.15$, $P = 0.28$). Thus, age was not included in further analyses. Since the group × task interactions were highly significant, individual MANOVAs were performed to test group differences within each task individually. Fig. 3 presents the mean simple and choice CNV amplitudes, collapsed

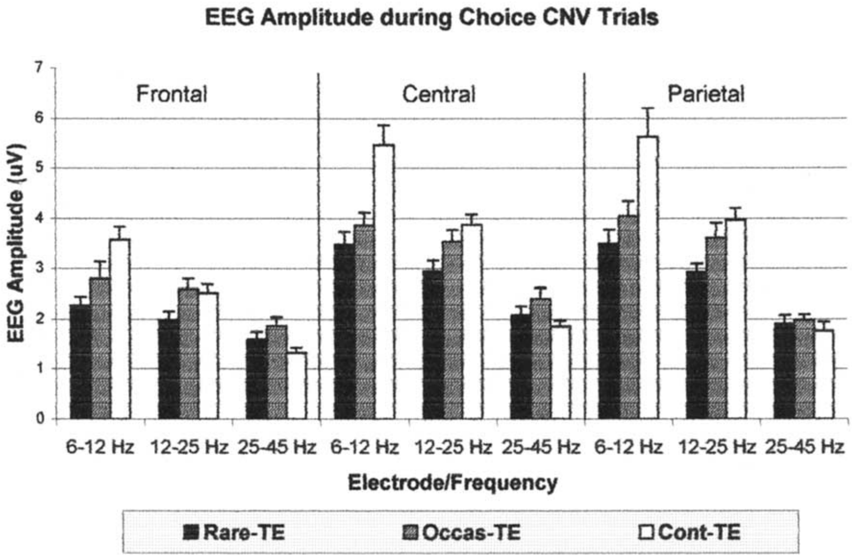

Fig. 2. EEG amplitude at frontal, central and parietal leads during the choice CNV trials. Means and standard errors are presented for the Rare-TE group (solid), Occas-TE group (diagonal lines) and Cont-TE group (open) at frontal, central and parietal electrodes in the 6–12, 12–25, and 25–45 Hz frequency bands.

across electrode site, for the three groups of subjects. The group × task interaction is clearly seen in the figure.

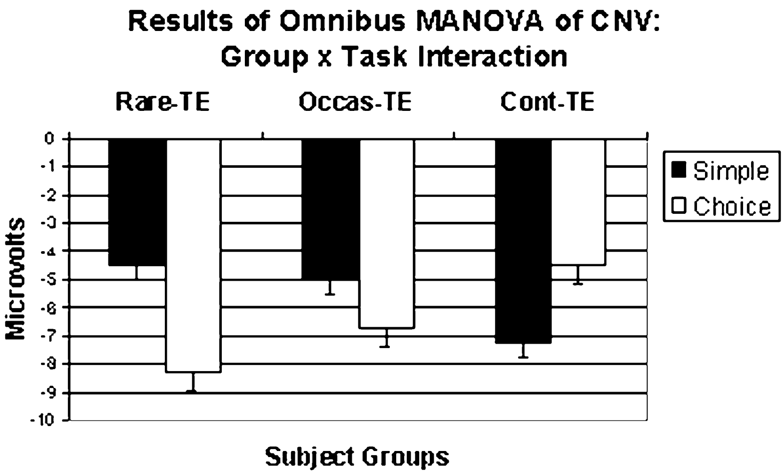

Fig. 3. Group × task interaction effects on CNV amplitude from the MANOVA. This figure presents the means for simple and choice CNV amplitude collapsing across electrode site. The group × task interaction is seen in this figure as a clear inverse pattern of CNV amplitudes during the tasks across the groups.

3.3.1. MANOVA of simple CNV

A MANOVA was performed with group as the between factor and simple CNV from the nine measured electrodes as the variates. This analysis revealed significant main effects for group (multivariate $F(9, 41) = 2.56$, $p = 0.019$). This overall significance resulted from main effects for group at F3, FZ, F4, and C3 electrodes only (F3: $F(2, 48) = 5.60$, $p = 0.007$; FZ: $F(2, 48) = 7.21$, $p = 0.002$; F4: $F(2, 48) = 7.00$, $p = 0.002$; C3: $F(2, 48) = 4.67$, $p = 0.014$). Multiple comparisons (Least Significant Difference) revealed significantly higher simple CNV in the Cont-TE subjects compared with the Rare-TE subjects at frontal and C3 electrodes (F3: $t(33) = -3.32$, $p = 0.002$; FZ: $t(33) = -3.28$, $p = 0.002$; F4: $t(33) = -3.36$, $p = 0.002$; C3: $t(33) = -2.80$, $p = 0.008$) and compared with the Occas-TE subjects at FZ, F4, and C3 ($t(33) = -333$, $p = 0.002$; $t(33) = -3.14$, $p = 0.003$; $t(33) = -2.53$, $p = 0.015$, respectively). Differences between the Occas-Te and Rare-TE groups were not statistically significant.

3.3.2. MANOVA of simple-choice CNV difference scores

Table 2 contains the means and standard deviations (S.D.) for simple-choice CNV difference scores at each of the nine electrodes. These difference scores reflected the impact of the increased cognitive load of the choice task, independent of the significant group differences on the simple task. Since CNV is a negative potential, a positive simple-choice CNV difference-score indicates that CNV during the choice trials was greater than during the simple trials. For instance,

$$(-7\ \mu V)_{\text{simple trials}} - (-10\ \mu V)_{\text{choice trials}} = +3\ \mu V_{\text{difference score}}$$

In Table 2, notice the pattern of more positive difference-scores (higher CNV during choice trials) in the Rare-TE subjects compared with Cont-TE subjects.

A MANOVA was performed with group as the between factor and simple-choice difference scores at the nine electrodes as variates. This analysis revealed significant main effects for group (multivariate $F(9, 41) = 3.0$, $p = 0.008$). This overall significance reflected significant main effects for groups at all nine electrodes. The ANOVA table is presented in Table 3. Multiple comparisons revealed significantly lower simple-choice difference scores in the Cont-TE subjects compared with the Rare-TE subjects at all electrodes (F3: $t(33) = -3.19$, $p = 0.003$; Fz: $t(33) = -4.29$, $p < 0.0001$; F4: $t(33) = -3.77$, $p < 0.001$; C3: $t(33) = -4.58$, $p < 0.0001$; Cz: $t(33) = -3.61$, $p = 0.001$; C4: $t(33) = -4.19$, $p < 0.0001$; P3: $t(33) = -3.84$, $p < 0.001$; Pz: $t(33) = -3.27$, $p = 0.002$; P4: $t(33) = -3.73$, $p < 0.001$) and Cont-TE subjects compared with the Occas-TE subjects at frontal and central electrodes (F3: $t(33) = -3.24$, $p = 0.002$; Fz: $t(33) = -2.98$, $p = 0.004$; F4 $t(33) = -3.48$, $p = 0.001$; C3: $t(33) = -2.97$, $p = 0.005$; Cz: $t(33) = -2.83$, $p = 0.007$; C4: $t(33) = -2.87$, $p = 0.006$). There were no significant differences between the Rare-TE and Occas-TE subjects.

Table 2
Simple-choice difference scores: means (S.D.)

Electrode	Group	Mean
F3	Rare-TE	1.74 (2.43)
	Occas-TE	2.25 (5.21)
	Cont-TE	−2.54 (3.26)
FZ	Rare-TE	2.35 (3.00)
	Occas-TE	0.61 (2.33)
	Cont-TE	−2.06 (3.53)
F4	Rare-TE	1.52 (2.60)
	Occas-TE	0.94 (1.80)
	Cont-TE	−2.27 (3.99)
C3	Rare-TE	4.01 (4.92)
	Occas-TE	1.56 (2.64)
	Cont-TE	−2.27 (3.95)
CZ	Rare-TE	3.20 (5.02)
	Occas-TE	1.72 (3.85)
	Cont-TE	−2.03 (3.35)
C4	Rare-TE	3.28 (4.22)
	Occas-TE	1.50 (2.13)
	Cont-TE	−1.61 (2.78)
P3	Rare-TE	3.44 (4.74)
	Occas-TE	0.705 (3.22)
	Cont-TE	−1.68 (3.30)
PZ	Rare-TE	3.49 (5.56)
	Occas-TE	1.68 (3.77)
	Cont-TE	−1.26 (2.59)
P4	Rare-TE	3.41 (4.67)
	Occas-TE	0.968 (2.47)
	Cont-TE	−0.921 (2.16)

Since CNV is a negative potential, a positive difference in the table indicates that CNV during the choice trials was higher than during the simple trials.

Table 3
Simple-choice difference scores: ANOVA table reporting main effects for group

Dependent variable	d*f*	*F*	Significance
F3	2.48	7.740	0.001
FZ	2.48	9.118	0.000
F4	2.48	8.006	0.001
C3	2.48	10.571	0.000
CZ	2.48	6.927	0.002
C4	2.48	9.992	0.000
P3	2.48	7.419	0.002
PZ	2.48	5.408	0.008
P4	2.48	7.091	0.002

There were significant main effects for group at all electrodes measured.

3.3.3. Reaction time, accuracy, heart rate and blink rate during CNV trials

There were no significant main effects for group in reaction time, accuracy, heart rate, or blink rate for the simple trials or the choice trials (all $F < 1.0$). The means and S.D. for these variables are presented in Table 4.

3.3.4. MANOVA of EEG coherence estimates during the choice trials

A third MANOVA was performed with group as the factor and coherence during the choice trials as variates. This analysis revealed a significant main effect for group (multivariate $F(27, 23) = 5.55$, $P < 0.001$). This overall significance resulted from main effects for group for interhemispheric F3F4 coherence in the 6–12, 12–25, and 25–45 Hz frequency bands: $F(2, 48) = 11.64$, $P < 0.0001$; $F(2, 48) = 11.81$, $P < 0.0001$; and $F(2, 48) = 7.87$, $P = 0.001$, respectively. Individual comparisons revealed significantly higher F3F4 coherence in the Cont-TE subjects in the three bands compared with the Occas-TE subjects ($t(33) = -2.33$, $P = 0.024$; $t(33) = -3.10$, $P = 0.003$; and ($t(33) = -2.93$, $P = 0.005$, respectively) and to the Rare-TE subjects ($t(33) = -4.82$, $P < 0.001$; $t(33) = -4.80$, $P < 0.001$; $t(33) = -3.80$, $P < 0.001$, respectively). Occas-TE subjects had higher frontal coherence than the Rare-TE subjects in the 6–12 Hz band only, $t(33) = 2.51$, $P = 0.015$.

3.3.5. MANOVA of EEG amplitude estimates during the choice trials

MANOVA of amplitude estimates during the choice trials. A fourth MANOVA was performed with group as the factor and amplitude during the choice trials as variates. This analysis revealed a significant main effect for group (multivariate $F(27, 23) = 2.56$, $P = 0.014$). This overall significance resulted from main effects for group for 6–12 Hz amplitude at all electrodes except the midline parietal site (F3: $F(2, 48) = 6.27$, $P = 0.004$; Fz: $F(2, 48) = 6.21$, $P = 0.004$; F4: $F(2, 48) = 7.20$, $P = 0.002$; C3: $F(2, 48) = 5.56$, $P = 0.007$; Cz: $F(2, 48) = 6.18$, $P = 0.004$; C4: $F(2, 48) = 10.81$, $P < 0.001$; P3: $F(2, 48) = 8.63$, $P = 0.001$; P4: $F(2, 48) = 5.45$, $P = 0.007$). Multiple comparisons revealed significantly higher 6–12 Hz amplitude at eight electrodes in the Cont-TE subjects compared with the Rare-TE subjects (F3: $t(33) = 3.49$, $P = 0.001$; Fz: $t(33) = 3.52$, $P < 0.001$; F4: $t(33) = 3.79$, $P < 0.001$; C3: $t(33) = 3.28$, $P =$

Table 4
Means (S.D.) for reaction time, accuracy, heart rate and breath rate during the simple and choice trials

Variable	Task	Rare-TE	Occas-TE	Cont-TE	P-value
Reaction time (ms)	Simple trials	421 (129)	389 (102)	378 (0.097)	ns
	Choice trials	699 (121)	673 (166)	664 (136)	ns
Accuracy (%)	Simple trials	na	na	na	na
	Choice trials	97.0 (5.62)	97.1(3.28)	98.0(4.39)	ns
Heart rate (bpm)	Simple trials	76.1 (13.9)	74.1 (8.3)	73.7 (10.3)	ns
	Choice trials	79.0 (10.8)	74.3 (7.2)	75.6 (8.6)	ns
Blink rate (bpm)	Simple trials	26.3 (9.1)	25.7 (9.3)	25.8 (10.3)	ns
	Choice trials	26.9 (8.9)	26.1 (12.3)	25.9 (15.7)	ns

na, Not available; ns, not significant.

0.002; Cz: $t(33) = 3.10$, $P = 0.003$; C4: $t(33) = 4.45$, $P < 0.001$; P3: $t(33) = 3.893$, $P < 0.001$; P4: $t(33) = 3.23$, $P < 0.002$) and compared with the Occas-TE subjects at Cz, C4 and P3 (Cz: $t(33) = 3.02$, $P = 0.004$; C4: $t(33) = 3.49$, $P = 0.001$; P3: $t(33) = 3.19$, $P = 0.003$). There were no significant amplitude differences between the Rare-TE and Occas-TE subjects.

3.3.6. MANOVA of EEG amplitude and coherence during the rest/TM period

Two MANOVAs were conducted to test group differences in amplitude and coherence during the rest/TM sessions. One MANOVA used group as the factor and EEG amplitude during rest (Rare-TE subjects) and TM practice (Occas-Te and Cont-TE subjects) as the variates. The other used EEG coherence as the variate.

The MANOVA of EEG amplitude did not reveal significant main effects for group (multivariate $F(27, 23) = 1.2$ ns). This finding replicates earlier research reporting that EEG coherence better differentiates TM groups than EEG amplitude (Dillbeck and Bronson, 1981).

The MANOVA of EEG coherence revealed a significant main effect for group (multivariate $F(27, 23) = 3.53$, $P = 0.005$). This overall significance resulted from main effects for group for F3F4 coherence in the 6–12, 15–25, and 35–45 Hz frequency bands: $F(2, 48) = 7.87$, $P = 0.001$; $F(2, 48) = 13.87$, $P < 0.0001$; and $F(2, 48) = 15.43$, $P < 0.0001$, respectively. Multiple comparisons revealed significantly lower F3F4 coherence in the 6–12, 15–25 and 35–45 Hz bands in the Rare-TE subjects compared with Occas-TE subjects ($t(33) = 2.50$, $P = 0.016$; $t(33) = 3.61$, $P = 0.001$ ($t(33) = 2.41$, $P = 0.018$, respectively) and in comparison to the Cont-TE subjects ($t(33) = 4.52$, $P < 0.0001$; $t(33) = 3.10$, $P = 0.004$; $t(33) = 4.40$, $P < 0.0001$). EEG coherence during TM practice did not significantly differ between the Occas-TE and Cont-TE subjects (all $t(33) < 1.0$, ns), even though these two groups widely differed in years of TM practice (7.8 compared with 24.5 years) and in self-reported experience of the integrated state (< 10 per year compared with continuous experiences). This apparent lack of TM ‘practice effects’ as measured by broadband EEG coherence replicates earlier findings (Travis, 1991), and is discussed below.

3.4. Principal components analysis

Significant main effects were seen in 24 variables: simple CNV amplitude at four electrodes, simple-choice difference scores at nine electrodes, choice task EEG coherence between F3F4 in three frequency bands, and choice task 6–12 Hz EEG amplitude at eight electrodes. Hair and colleagues (Hair et al., 1992) propose a minimum of five subjects/variable to obtain stable classification results. With 51 subjects, this criterion suggests a maximum of ten variables. Principal components analysis were, used to reduce the 24 significant variables from the MANOVAs to a smaller number of factors that retained most of the information in the original data. The significant factors resulting from the principal components analysis were entered into a Pearson correlation analysis to identify relations among the cortical factors and scores on the paper and pencil tests, and in a stepwise regression to identify the fewest cortical factors necessary to discriminate groups.

Principal Components Analysis with a varimax rotation reduced the 24 variables to five factors that accounted for 83.4% of the original variance. The factor loadings are presented in Table 5. The first factor included frontal, central and parietal amplitude estimates in the 6–12 Hz band; the second included simple-choice difference scores at all electrodes except F3; the third included F3F4 EEG coherence at all frequencies; the fourth included simple CNV and simple-choice CNV difference scores at F3 only; and the last included simple CNV at FZ, F4 and C3. The variables loading >0.60 on a specific factor were combined to form five composite measures. This was done by (1) converting the variables to z-scores, (2) weighting each variable by its factor loadings, and (3) averaging the weighted z-scored variables that loaded >0.60 on each factor. These five composite measures were used in the analyses below.

3.5. Pearson correlation between the five factor scores and the two paper-and-pencil measures of transcendental experiences

A Pearson correlation assessed the relation between each of the five brain-based composite measures and the self-report measures of mystical experiences (M-Scale) and of worldview along a Physical-Transcendent Scale (Baruss's Scale). This exploratory analysis revealed significant correlation's between the two self-report measures with all five factors: (1) simple-choice difference scores ($r(50) = -0.478$, $P < 0.001$); (2) 6–12 Hz global amplitude during the choice trials ($r(50) = 0.462$, $P = 0.001$); (3) F3F4 EEG coherence at all frequencies ($r(50) = 0.434$, $P = 0.0012$); (4) simple CNV at FZ, F4 and C3 ($r(50) = -0.326$, $P = 0.021$); and (5) simple CNV and simple-choice CNV difference scores at F3 ($r(50) = -0.447$, $P = 0.001$).

3.6. Stepwise regression

The five composite measures were entered into a stepwise regression with group as the criterion variable and the composite measures as the predictor variables. The stepwise regression entered three variables into the final model: F3F4 EEG coherence at all frequency bands, simple-choice CNV difference scores, and frontal, central and parietal 6–12 Hz amplitude estimates. The final model accounted for 55% of the total variance, and was highly significant, $F(3, 48) = 18.52$, $P < 0.0001$. Table 6 contains the output from the stepwise regression listing the variables that were included in and excluded from the final model.

3.6.1. Scatter plot of factor scores: a brain-based integration scale

The composite scores for the three factors entered in the model were arithmetically combined- the frontal EEG coherence factor plus the EEG amplitude factor minus the simple-choice CNV difference-score factor. The sign of the simple-choice CNV difference-score factor was changed because it was inversely related to group membership. This created a composite z-score for each subject. These composite z-scores are presented in the scatterplot in Fig. 4. The regression line through these points depicts the possible transformation in cortical functioning corresponding to

Table 5
Principal component analysis matrices of simple CNV, simple-choice CNV difference scores, EEG coherence, and amplitude

	Factor				
	1	2	3	4	5
Simple CNV					
F3	−0.147	−0.001	0.003	**0.830**	0.299
FZ	−0.045	0.245	−0.045	0.375	**0.807**
F4	−0.010	0.257	−0.047	0.548	**0.609**
C3	−0.190	0.212	−0.021	0.423	**0.743**
Simple-choice difference scores					
F3	−0.271	0.346	−0.053	**0.834**	0.018
FZ	−0.139	**0.717**	−0.143	0.350	0.305
F4	−0.190	**0.629**	−0.041	0.539	0.130
C3	−0.162	**0.736**	−0.107	0.072	0.481
CZ	−0.170	**0.863**	−0.027	0.200	0.144
C4	−0.129	**0.914**	−0.080	0.188	0.124
P3	−0.082	**0.918**	−0.126	0.048	0.049
PZ	−0.145	**0.915**	−0.060	0.026	0.123
P4	−0.061	**0.942**	−0.144	0.095	0.057
F3F4 EEG coherence during choice tasks					
6–12 Hz	0.061	−0.149	**0.870**	−0.007	−0.064
12–25 Hz	0.078	−0.124	**0.960**	−0.032	0.012
25–45 Hz	−0.048	−0.117	**0.910**	−0.031	−0.012
6–12 Hz EEG amplitude during choice tasks					
F3	**0.889**	−0.147	−0.037	0.050	−0.145
FZ	**0.936**	−0.118	−0.025	−0.004	−0.061
F4	**0.908**	−0.181	0.033	0.013	0.017
C3	**0.923**	−0.094	−0.008	0.033	−0.159
CZ	**0.811**	−0.070	0.107	−0.196	−0.052
C4	**0.883**	−0.119	0.169	−0.080	−0.124
P3	**0.906**	−0.092	0.068	−0.174	−0.034
P4	**0.816**	−0.128	−0.016	−0.225	0.185

The 24 variables that loaded on five factors (> 0.600) are bolded for easier identification.

increasing integration of the transcendental and waking states, and could be called an 'Integration Scale.' Individuals would score low on this Scale when (1) bilateral frontal EEG task coherence was low, (2) frontal, central and parietal 6–12 Hz task EEG amplitude was low, and (3) cortical preparatory processes were greater during choice trials than during simple trials. In contrast, individuals would score high on this Scale when (1) bilateral frontal EEG task coherence was high, (2) frontal, central and parietal 6–12 Hz task EEG amplitudes were high, and (3) cortical preparatory processes were lower during choice trials than during simple trials.

Table 6
The final model

Variables included	Beta	Partial correlation	t-statistic	P-value
Constant	–	–	3.42	0.001
6–45 Hz F3F4 EEG Coherence during choice trials	0.371	–	3.45	0.001
Frontal, central and parietal simple–choice CNV difference scores	−0.362	–	−3.41	0.001
Frontal, central and parietal 6–12 Hz EEG amplitude during choice trials	0.278	–	2.61	0.012
Variables excluded				
Simple CNV at FZ, F4, and C3	−0.099	−0.1029	−0.873	ns
Simple and simple-difference scores at F3	−0.130	−0.143	−0.969	ns

Stepwise regression was performed with group as the criterion variable and the five factor scores as predictor variables. Three of the five factor scores were significant and were included in the final model in the order they are presented in the table.

4. Discussion

Significant group differences in electrocortical measures during waking support the hypothesis that distinct CNV and EEG patterns characterize the integration of the transcendent with waking states. The three factors entered in the final model

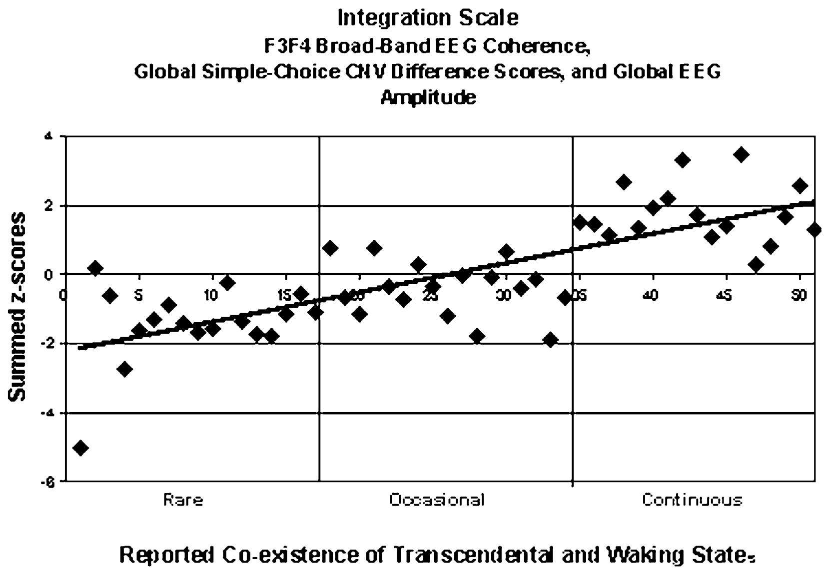

Fig. 4. A brain-based integration scale. The three factors entered in the stepwise regression were transformed to z-scores, combined for each subject, and plotted according to self reported integration of transcendental and waking states. The regression line through these points represents possible transformations in cortical functioning corresponding to increasing integration of the transcendent and waking states, and may thus represent an ‘integration scale’.

suggest least three cortical characteristics of this integrated state: (1) high frontal 6–12 Hz EEG coherence during tasks, (2) high frontal, central and parietal 6–12 Hz amplitude during tasks, and (3) different patterns of CNV amplitude during simple and choice tasks.

4.1. Implications of the factors in the final model: broad-band frontal EEG coherence

4.1.1. Role of the frontal cortex

The frontal cortex is reciprocally connected with nearly all other cortices, with subcortical structures and with brainstem nuclei (Fuster, 1993). This extensive neural connectivity supports the executive role that the frontal cortices are considered to play in generating and guiding goal-directed behavior. Deficits in frontal functioning have been linked to impairments in encoding and recognition tasks, judgment, emotion regulation, delayed response and planning processes (Davidson et al., 2000; Donaldson and Rugg, 1998; Fuster, 1999; Godefroy and Rousseaux, 1996). Relevant to this research, the frontal cortices are also essential to neuronal implementation of a 'self-model'- one's self-concept, sense of personal identity, body-centered spatial perspective, self-evaluation, and long-term unity of beliefs and attitudes (Ben Shalom, 2000; Keenan et al., 2000; Vogeley et al., 1999). Thus, a changed pattern of frontal functioning might be expected in subjects reporting a greater sense of self during activity.

4.1.2. EEG coherence

EEG coherence is understood to be a measure of cortical connectivity (Florian et al., 1998). Lower values of EEG coherence are associated with white matter lesions and decreased cerebral blood flow (Leuchter et al., 1997), schizophrenia (Wada et al., 1998), depression (Leuchter et al., 1997), and normal aging (Kayama et al., 1997). Higher levels of coherence are associated with functional coupling (Thatcher et al., 1986), information exchange (Petsche et al., 1997; Pfurtscheller and Andrew, 1999), and functional co-ordination (Gevins et al., 1989) between brain regions. Higher frontal EEG coherence suggests greater functional co-ordination of the frontal circuits involved in the neuronal implementation of one's self-model. This may give prominence to the experience of one's self-model during task processing, as was reported by the Cont-TE subjects. Increased values of executive control and the enhancement of sense of self could provide a different vantage point, for processing stimuli, as evidenced in the different patterns of CNV data in the Cont-TE subjects.

4.1.3. Broad-band changes

Finally, it was unexpected that coherence differences between groups would be seen over a wide range of frequencies (6–45 Hz). Typically EEG during tasks is maximal in more narrow bands. For instance, the alpha band is generally associated with relaxation and meditation (Banquet, 1973; Pfurtscheller et al., 1996; Travis and Wallace, 1999); the beta band is associated with task processing (Pfurtscheller and Andrew, 1999); and the gamma band is associated with perceptual binding and possibly the unity of conscious experience (Basar-Eroglu et al., 1996; Bertrand and

Tallon-Baudry, 2000; Llinas and Ribary, 2001). Varela et al. (2001) have suggested that coherence over multiple frequency bands may be a mechanism that links distributed functional regions into a pattern that supports a 'unified cognitive moment.' In this light, broad-band coherence during tasks may underlie the integration of TE (alpha) with cognitive processes (beta and gamma) during tasks.

4.2. Implications of the factors in the final model: frontal, central and parietal 6–12 Hz EEG amplitude estimates

What mechanisms contributed to increased 6–12 Hz EEG amplitudes at frontal, central and parietal sites during eyes-open tasks? EEG amplitude varies with skull thickness (Nuñez, 1981). However, differences in skull thickness would not explain the current data, because EEG amplitudes only differed during tasks—not during meditation. The increased 6–12 Hz EEG amplitude during tasks may indicate that a global functional brain state associated with TM practice may co-existence with brain processes associated with task processing.

Earlier, we proposed a physiological model of TM practice comprising two complementary neural networks (Travis and Wallace, 1999). First, prefrontal and basal forebrain areas act as a 'neural switch' to inhibit thalamocortical activity. This leads to reduced levels of mental activity without loss of self-awareness—a 'de-excited' state of mind and body. Second, cortico-basal ganglia-thalamocortical (CBGT) oscillations, which modulate cortical excitability (Elbert and Rockstroh, 1987) and sequencing of cognitive events (Alexander et al., 1986; Bernes and Sejnowski, 1996), maintain this de-excited meditative state. Five parallel CBGT modules have been traced (Alexander et al., 1986). Two loops, which originate in the premotor and parietal multimodal sensory areas, probably contribute little to loop dynamics during TM practice, because TM is practiced sitting quietly with eyes-closed. The remaining three modules may contribute to maintaining a de-excited state during TM practice. These loops, which originate in the dorsal–lateral frontal, orbito–frontal and anterior cingulate cortices, modulate attention allocation (Carter et al., 1999), modulation of emotional tone (Bush et al., 2000), and implementation of a self model (Vogeley et al., 1999). The TM technique doesn't overtly engage these modules, rather it permits them to maintain resting rhythms of CBGT oscillations. During TM practice, these CBGT loops may generate a oscillatory state that facilitates mental and physical de-excitation. Recent preliminary data localized MEG dipoles in ventral medial and cingulate cortices during TM practice (Yamada, personal communication, 20 June 2002), supporting the possible involvement of these areas during TM practice. These three CBGT modules, engaged during TM practice, may over time become self-sustaining and co-exist with sensory processing characteristic of waking (Llinas and Pare, 1991). The characteristic brain signature of TM practice, global alpha EEG, might then be seen during ongoing waking processes.

4.3. Implications of the factors in the final model: inverse CNV amplitudes during simple and choice tasks

The three groups exhibited an inverse pattern of late CNV during simple and choice tasks: Rare-TE subjects exhibited lower simple CNV and higher choice CNV, while the Cont-TE subjects exhibited the opposite. Late CNV in simple trials primarily reflects attentional (Kok, 1997; Tecce and Cattanach, 1993) and motor resources (Gaillard, 1986; van Boxtel and Brunia, 1994) recruited for task processing. Late CNV in choice trials includes an additional component, called the stimulus preceding negativity (SPN), which is observed preceding a stimulus that provides information needed to make a correct response (Brunia, 1988; Brunia and van Boxtel, 2001; Ruchkin et al., 1986). While choice CNV amplitudes include additional negativity from the SPN, choice CNV might be expected to be lower than during simple trials, because the contribution of attentional and motor preparatory processes would be less during choice trials since subjects needed the information from S2 before initiating response processes.

Rare-TE subjects exhibited higher choice CNV. These subjects appeared to initiate preparatory processes—committing attentional resources and/or initiating motor processes—before they knew what they needed to do. In contrast, the Cont-TE subjects exhibited lower CNV in the choice trials. Apparently, the Cont-TE subjects did not initiate preparatory responses until they knew the correct response. This more efficient approach of information processing reflects better executive control over preparatory and motor response processes—allocating resources at a more appropriate time to carry out the task effectively. This improved 'executive control' during the CNV tasks, along with heightened interhemispheric frontal EEG coherence, suggests a general enhancement of frontal cortical functioning in the Cont-TE subjects.

The inverse relation of CNV during simple and choice trials across groups did not appear to reflect increased difficulty of the choice trials, since there were no significant group differences in reaction time, in accuracy, or in physiological arousal, as reflected in heart rate and breath rate, during either simple or choice trials. Nor does this inverse relation appear to reflect intentional, conscious control, since none of the subjects reported using different strategies for the two tasks.

4.3.1. Relation of EEG coherence and CNV patterns

While EEG coherence is a measure of stability of phase relations among surface-recorded scalp potentials (Thatcher et al., 1986), and could be termed 'horizontal' coherence, research also reports coherence between cortical, thalamic, and muscle potentials during voluntary muscle movement in humans (Marsden and Werhahn, 2000). This could be called 'vertical' coherence. Marsden and colleagues (Marsden et al., 2000) suggest that 'vertical' coherence could provide the temporal framework for guiding motor output. While 'vertical' coherence was not measured in this study, one could speculate that the 'horizontal' coherent EEG activity observed between frontal cortices in the Cont-TE subjects may be part of a 'vertically' coherent circuit between cortex, basal ganglia, thalamus, and muscles controlling response preparation in these subjects. This 'vertically' coherence circuit may have contributed to the observed inverse pattern in CNV in these subjects. Multiple cortical and subcortical areas implicated in CNV generation support this speculation, including: bilateral frontal, motor cortex, superior-parietal, anterior cingulate gyrus, and basal ganglia (Gomes, et al., 2001; Rektor, 2000).

4.4. Implication of the lack of observed TM 'Practice effects'

The lack of TM 'practice effects' in EEG patterns may be an important datum to help guide future research. This finding suggests that TM practice can be mastered in a relatively short period of time, and that the effects of TM practice over time may be more evident in behavior outside of meditation. Early efficacy of practice combined with progressive changes in brain dynamics in waking behavior may constitute a fundamental set of criteria for comparing TM practice with other types of meditation practice.

4.5. Design considerations

The group differences are empirically strong, but we cannot conclude what caused those group differences. Since a cross-sectional design was used, we do not know the pre-TM EEG patterns of subjects in the Occas-TE and Cont-TE groups. The published immediate effects of TM practice on CNV amplitude and EEG coherence suggest that the group differences reported here may have resulted from TM practice. Paty and colleagues (Paty et al., 1978) reported that CNV amplitude in simple tasks increased immediately following TM practice compared with CNV before the TM session. They suggested that TM practice might make available different levels of attention, leading to higher CNV amplitude after TM practice (p. 164). In addition, EEG coherence during eyes-open rest is reported to be higher in matched subjects with 8 years' TM practice compared with those with 4 months' TM practice (Travis, 1991). These documented immediate and short-term effects of transcending on brain dynamics may stabilize over time leading to the long-term effects observed in the Cont-TE subjects. Ongoing longitudinal research is testing this hypothesis.

4.6. Comparison with earlier CNV data

These present findings are similar to the findings from our earlier investigation of non-TM, short term and long-term TM subjects (Travis et al., 2000). The previous study reported significantly higher simple CNV amplitude at frontal and central midline sites with greatest differences at CZ; the current study found significant group differences in simple CNV amplitude at two frontal sites (FZ, F4), and at C3-roughly over the motor cortex governing right-hand finger movement. In both studies, inner experiences were associated with changes in cortical preparatory response at frontal and central sites.

One surprising difference between the two studies is that the CNV amplitudes reported in the previous work were consistently higher. This could be due to (1) the age of subjects (around 20 years in the previous study compared with 40 years in the current study); (2) the addition of choice trials and choice divided-attention trials in the current study (leading to greater total testing time, greater challenge and possibly greater fatigue); and (3) possible experimenter effects. For instance, if the experimenter more strongly emphasized eye-movement control in the current study, then subjects may have focused on inhibiting blinks. This might have reduced a 'unified attentional set' to S2 leading to lower CNV amplitudes (Tecce and Cattanach, 1993). Future research will look at these different issues.

4.7. Application of an integration scale

The Integration Scale, which was constructed from the current data, could be used to measure the interdependence of integrative experiences, brain executive functioning and sense of self in various subject populations. Through the language of brain functioning, this brain-based scale could provide the opportunity to conduct comparative research of various cognitive techniques, including relaxation techniques and other traditional meditation practices. It also could be used to probe the contribution of integrative experiences to success in business, arts, and sciences. Furthermore, scores on this Scale appear to represent the transformation in brain functioning corresponding to the integration of the transcendent with waking and sleeping. This integrated state is distinct from waking, sleeping or dreaming, and is traditionally termed 'enlightenment' (Maharishi Mahesh Yogi, 1967; Shear, 1999). It is possible that this brain-based Integration Scale may help elucidate the development and characteristics of the state of enlightenment, augmenting current phenomenological and psychological investigations (Gallagher and Shear, 1999; Shear and Jevning, 1999). This line of research could dramatically impact our understanding of the possible range of human development.

5. Conclusion

In summary, these data suggest that distinct patterns of EEG coherence, EEG amplitude, and late CNV amplitude are associated with the progressive integration of the transcendent with waking and sleeping states. These results indicate the efficacy of objective measures for characterizing the growth of subjective experiences. The brain-based Integration Scale, resulting from this research, is a preliminary scale. It accounted for 55% of the variance in-group membership. Researchers are invited to participate in confirming, refining, and extending this scale. We anticipate this research strategy will further the exploration of the possible range of human experience and associated brain-state dynamics.

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