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Autonomic and EEG patterns distinguish transcending from other experiences during Transcendental Meditation practice

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Abstract

This study compared EEG and autonomic patterns during transcending to 'other' experiences during Transcendental Meditation (TM) practice. To correlate specific meditation experiences with physiological measures, the experimenter rang a bell three times during the TM session. Subjects categorized their experiences around each bell ring. Transcending, in comparison to 'other' experiences during TM practice, was marked by: (1) significantly lower breath rates; (2) higher respiratory sinus arrhythmia amplitudes; (3) higher EEG alpha amplitude; and (4) higher alpha coherence. In addition, skin conductance responses to the experimenter-initiated bell rings were larger during transcending. These findings suggest that monitoring patterns of physiological variables may index dynamically changing inner experiences during meditation practice. This could allow a more precise investigation into the nature of meditation experiences and a more accurate comparison of meditation states with other eyes-closed conditions.
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1. Introduction

Basic and clinical research has documented the effectiveness of practice of the Transcendental Meditation® (TM®) technique[1] in decreasing anxiety (Eppley et al., 1989), decreasing hypertension (Alexander et al., 1994a; Schneider, et al., 1995), decreasing atherosclerosis (Castillo-Richmond et al., 2000), decreasing substance abuse (Alexander et al., 1994b), and enhancing self-actualization (Alexander et al., 1991). To understand how TM practice positively impacts mental and physical health, the constellation of psychophysiological patterns during TM practice needs to be understood.

Travis and Wallace (1997) compared physiological patterns during two main experience-categories during TM practice: transcending, described as:

> '...taking the mind from the experience of a thought to finer states of the thought' (Maharishi, 1969, p. 470)

and Transcendental Consciousness, described as:

> '...silence and full awareness of pure consciousness, where the experiencer is left all by himself.' (Maharishi, 1963, p. 288)

(see also Travis and Pearson, 2000). In this study, transcendental consciousness was distinguished by autonomic orienting at the onset of 10–40-s-long apneustic breathing periods (slow, continuous inhalation). Constrained by the subjects' spontaneous experiences, this prior research was only able to compare physiological patterns between these two experience categories during TM practice — transcending and Transcendental Consciousness.

The current study extends these earlier findings by comparing autonomic and EEG patterns during transcending to physiological patterns during 'other' experiences occurring within a TM session. This 'other' category comprises a range of possible experiences when the mind is out of the process of transcending, primarily characterized by an increase in mental and physical activity. Delineating physiological patterns during 'other' experiences will complete our characterization of sub-states within TM practice.

2. Method

2.1. Subjects

A total of 30 undergraduate students were asked to participate in this study, nine females and 21 males, with an average age of 22.50 years (S.D. 2.28, range 17.4–29.6). These subjects had been practicing the TM technique for an average of 5.40 years (S.D. 0.67, range 0.8–11.2).

2.2. Choice of physiological measures

Five different categories of physiological variables were measured, which in prior research were sensitive to practice of the TM technique (Wallace, 1970; Dillbeck and Bronson, 1981; Dillbeck and Orme-Johnson, 1987; Taneli and Krahne, 1987; Gaylord et al., 1989; Travis and Wallace, 1999). To index general metabolic levels, breath and heart rate were measured. To index differences in parasympathetic tone, heart rate variability in the breath frequency (respiratory sinus arrhythmia or 'high frequency' heart rate variability) was measured (Porges, 1995). To assess differences in sympathetic tone, skin conductance levels were measured (Edelberg, 1967). To index sympathetic reactivity, skin conductance responses to punctuate stimuli during TM practice were recorded. To probe central nervous system functioning, EEG amplitude[2] and coherence were calculated.

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

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

The ratio of low-frequency (LF, 0.05–0.15 Hz) and high-frequency (HF, 0.15–0.40 Hz) heart rate variability was also measured in this study. Some authors suggest that the LF/HF ratio may index sympathovagal balance, reflecting the relative operating point on a continuum from parasympathetic to sympathetic dominance (Malliani et al., 1994). Recent papers argue that the LF/HF ratio is a confounded measure, because: (1) sympathetic and parasympathetic activity can vary independently (Berntson et al., 1993); and (2) parasympathetic contributions to LF and HF variability derive from partially different mechanisms — blood pressure-baroreflex vs. respiratory, respectively (Berntson et al., 1997). The LF/HF ratio was calculated in this study to empirically test whether it accounts for additional variance in physiological patterns during a TM session beyond skin conductance and respiratory sinus arrhythmia measures, which have been more closely tied to autonomic functioning.

2.3. Recording details

Breath rate was recorded with a Nicolet accelerometer secured around the abdomen. Heart rate was recorded with a Lead II configuration, right wrist to left leg. Skin resistance was recorded with Ag/AgCl electrodes secured to the distal phalanges of the left index and middle fingers (Scerba et al., 1992) with 1-cm double-stick collars. The saline and Unibase recipe proposed by Fowles et al. (1981) was used as electrode paste. EEG was recorded at the three frontal (F3, Fz, F4), central (C3, Cz, C4) and parietal (P3, Pz, P4) sites referenced to linked ears, using Ag/AgCl electrodes with EC_2 creme.

The output from the breath gauge accelerometer was fed through an AC amplifier with 0.1- and 100-Hz filter settings, and 50-mV/cm sensitivity. Heart rate was recorded on an AC amplifier with 3.0- and 100-Hz filter settings, and 15-μV/mm sensitivity. Electrodermal activity (skin resistance) was recorded on a DC amplifier with a constant 10 μA of current across the electrodes, and a sensitivity of 1.0 kΩ/cm. EEG was recorded with 0.1- and 100-Hz filter settings, and 5-μV/mm sensitivity. All signals were continuously recorded and digitized on-line at 256 points/s. The data were stored for later analyses using EEGSYS, a standardized research acquisition and analysis package developed in conjunction with researchers at NIH (Hartwell, 1995).

2.4. Procedure

After the subjects washed their hands with soap and water, the sensors were applied. Subjects then moved into a sound-attenuated room with a closed-circuit video monitor. Physiological measures were recorded during two computerized tasks (approximately 14 min for the two tasks) and then the subjects practiced the TM technique for 15 min. Data from the computerized tasks have been reported elsewhere. During the TM session, the experimenter rang a quiet bell (50 dB) at 5, 10 and 15 min into the meditation session. After the recording session, but before speaking with the experimenter, each subject classified his/her experiences before the three bell rings. All subjects reported both an unambiguous instance of 'transcending' and of 'other' experiences during this TM session.

2.5. Data quantification

Breath and heart rate, autonomic activity, and EEG amplitude and coherence estimates were calculated during the 60-s period before each bell ring. A 60-s period was selected to maximize the possibility that the experience reported before the bell occurred in the data window. Using a period longer than 60 s might have confounded the match between inner reported experiences and outer recorded physiological patterns, since the longer the time period, the greater the chance that multiple categories of experiences may have occurred.

Breath and heart rate were counted on the computerized record and are reported in breaths/min and beats/min. HF and LF heart rate variability were calculated using the moving polynomial algorithm suggested by Porges et al. (1982). Skin resistance levels at the beginning and end of each 60-s window, and the peak skin resistance deflection in a 1–3-s window following the bell ring (Levinson & Edelberg, 1985) were converted to skin conductance levels (µS = 1000/kohms, Dawson et al., 1990). Skin conductance levels at the beginning and end of the 60-sec periods were averaged to yield an estimate of skin conductance levels during each period. Skin conductance levels at the end of the 60-sec period and at the peak deflection to the bell-ring were differenced to yield the magnitude of skin conductance response to the bell stimulus.

The EEG was manually inspected for movement and eye artifacts (excursions >150 µV). These were marked and removed from the analysis. The artifacted data were conditioned with a Hanning window, spectral analyzed in two-sec epochs (giving 1/2 Hz frequency resolution), and then averaged over the 60-sec analysis period. Due to high inter-subject variability in EEG patterns during practice of the Transcendental Meditation technique (Travis & Wallace, 1997), the spectral estimates were not arbitrarily averaged into conventional broad-band 4-Hz wide bins (theta, alpha, etc.). Rather, the frequency of peak amplitude in a 6-12 Hz window was identified in the amplitude and coherence spectra. The amplitude and coherence estimates at these peak 1/2 Hz frequencies were compared between conditions.

To reduce the number of variables tested, and so increase the degrees of freedom, the EEG data were averaged in two ways. Peak amplitudes in the 6-12 Hz window at the nine electrode sites were averaged at frontal, central, and parietal sites. For instance, F3, Fz, and F4 were averaged together. Prior research suggests high lateral symmetry during practice of the TM technique (Bennett & Trinder, 1977), and so hemispheric information was not considered important in this analysis. The 45 possible coherence pairs were reduced to four averages that reflect coherence over broad cortical areas: (1) Bilateral frontal (F3-F4), (2) Frontal-central (F3C3 + FzCz + F4C4), (3) Central-Parietal (C3P3, CzPz, C4P4), and (4) Frontal-parietal (F3P3, FzPz, F4P4).

<u>Statistical Analysis</u>

Four repeated measure MANOVAs were performed to test possible condition differences in the five general categories of physiological variables: (1) breath and heart rate (general arousal), (2 LH/HF ratio, skin conductance levels and skin conductance response (sympathetic functioning), (3) EEG amplitude at frontal, central and parietal sites, and (4) EEG coherence in frontal-central, central-parietal, frontal-parietal, and bilateral-frontal pairs. An ANOVA was used to assess condition differences in respiratory sinus arrhythmia (parasympathetic functioning). A Bonferroni correction (alpha level = .01) was used to minimize Type I error arising from five analyses being performed on the same data set.

To probe the relationship of the physiological patterns during the different experience-categories of a Transcendental Meditation session, percent difference scores were calculated for all physiological variables that were significantly different in the MANOVA analyses. An exploratory factor analysis (principal component analysis) was conducted on these percent difference scores. To test for possible gender differences, a between MANOVA was conducted with gender as the between factor, and the percent difference scores as the variate.

3.0. Results

Table 1 presents means and standard errors for the physiological measures during these two experience-categories during TM practice (columns), with <u>p</u>-values from the MANOVAs in the right column.

<u>Repeated Measure ANOVA and MANOVAs</u>

The data were first tested for normality (Kolmogorov-Smirov test in SYSTAT). EEG amplitude and skin conductance responses differed significantly from normality and so were log transformed before analyses. A repeated measures ANOVA and four repeated measures MANOVAs with experience-category as the repeated measure and the physiological variables as the variates were conducted.

The ANOVA with respiratory sinus arrhythmia as the variate revealed significantly higher vagal

Table 1
Means and standard errors of the physiological variables measured during transcending and other experiences in a TM session[a]

Variable	Transcending	Other experiences	P value (d.f. = 1,29)
Breath rate (beats/min)	11.42 (0.408)	12.71 (0.428)	0.0067
Heart rate (beats/min)	71.72 (1.294)	71.14 (1.248)	NS
Respiratory sinus arrhythmia	7.07 (0.194)	6.55 (0.233)	0.00082
LF/HF	0.92 (0.020)	0.96 (0.046)	NS
SCL (μS)	12.07 (1.137)	12.23 (1.104)	0.072
SCR (μS)	1.30 (0.301)	0.25 (0.096)	0.00001
Frequency of peak amplitude (Hz)	9.3 (0.27)	9.5 (0.28)	NS
Alpha amplitude (μV)			
Frontal	1.85 (0.404)	1.26 (0.259)	
Central	2.05 (0.333)	1.33 (0.194)	
Parietal	3.23 (0.405)	1.90 (0.270)	0.00001
Alpha coherence			
F3F4	0.786 (0.020)	0.729 (0.027)	
FzCz	0.677 (0.031)	0.619 (0.033)	
CzPz	0.422 (0.035)	0.391 (0.041)	
FzPz	0.566 (0.053)	0.536 (0.051)	0.0021

[a]Table entries are mean (standard errors).

tone during transcending, $F(1,29) = 13.93$, $P = 0.00082$.

The first repeated-measure MANOVA with breath and heart rate revealed a near-significant phase × variable interaction [$F(1,29) = 6.69$, $P = 0.0149$]. Individual ANOVAs revealed significantly slower breath rates during transcending [$F(1,29) = 8.52$, $P = 0.0067$] and no significant differences in heart rate, $F(1,29) < 1.0$, ns.

The next repeated-measure MANOVA, with LF/HF ratio, skin conductance levels and log of skin conductance response as variates, also revealed a significant phase × variable interaction, $F(2,28) = 8.57$, $P = 0.00125$. Individual ANOVAs revealed significantly higher log skin conductance responses to the bell ring during transcending [$F(1,29) = 38.79$, $P < 0.00001$], but no significant differences in skin conductance levels [$F(1,29) = 3.49$, $P = 0.072$] or the LF/HF ratio [$F(1,29) = 1.06$ $P = 0.312$].

The third repeated-measure MANOVA, with EEG log amplitude at frontal, central, and parietal leads as the variates, revealed a significant main effect for phase [$F(1,29) = 33.66$, $P < 0.00001$] with higher log alpha amplitude during transcending; a significant main effect for location [$F(2,58) = 37.19$, $P < 0.00001$] with log EEG amplitude increasing from frontal to parietal sites; and no significant interactions, $F(2,58) = 2.83$, $P = 0.094$.

The final repeated-measure MANOVA, with coherence at bilateral frontal, frontal–central, central–parietal, and frontal–parietal leads, revealed a significant main effect for phase [$F(1,29) = 11.43$, $P = 0.0021$] with higher coherence during transcending; a significant main effect for coherence pair [$F(3,27) = 88.62$, $P < 0.0001$] with lowest coherence at central–parietal pairs and highest at bilateral–frontal pairs; and no significant interactions, $F(3,27) < 1.0$, ns.

3.2. Correlation of LF / HF, skin conductance levels and respiratory sinus arrhythmia

A Pearson correlation was conducted among LF/HF ratio, skin conductance levels, and respiratory sinus arrhythmia values during transcending and 'other' experiences. Their correlations were very low (0.08–0.15).

3.3. Test for gender effects

A between MANOVA was conducted with gender as the between factor and the % difference scores for breath rate, respiratory sinus arrhythmia, skin conductance response, the three EEG amplitude estimates and the four EEG coherence estimates as variates. The main effect for gender was not significant, Wilk's lambda $F(10,19) < 1.0$, ns.

4. Discussion

Transcending and 'other' experiences during a TM session, which were subjectively delineated, were physiologically distinct. Transcending was characterized by lower breath rates, higher respiratory sinus arrhythmia levels, higher EEG alpha amplitude, and higher coherence. In addition, skin conductance responses to a quiet punctuate stimulus were greater during transcending. These data suggest that TM practice may be comprised of phenomenologically and physiologically distinct sub-states that cycle during the TM session.

4.1. Consideration of breath rate and respiratory sinus arrhythmia patterns

Respiratory frequency is non-linearly related to respiratory sinus arrhythmia amplitude (Eckberg, 1983). Respiratory frequencies below 7 beats/min are associated with elevated respiratory sinus arrhythmia amplitudes (Hirsch and Bishop, 1981). Above 7 beats/min, this relationship quickly falls away. In these data, breath rates were well above 7 beats/min (average of transcending 11.42, and 'other' experiences 12.71 beats/min). However, to assess possible interactions between breath rate and respiratory sinus arrhythmia in these data, we conducted a simple correlation of the difference scores between conditions for these two variables. If lower breath rate during transcending led to higher respiratory sinus arrhythmia, independent of changes in parasympathetic tone, then this correlation would be expected to be negative (an inverse relation) and substantial. Their correlation was negative, but very low ($r = -0.101$). Thus, elevated respiratory sinus arrhythmia levels during transcending seem to have been largely independent of changes in breath rates in these data.

4.2. Consideration of higher EEG amplitude and coherence estimates during transcending

4.2.1. In light of a two-phase neural model of TM practice

Travis and Wallace (1999) proposed a two-phase model to explain significant EEG and autonomic differences observed in the 1st min of TM practice compared to eyes-closed rest, and to explain why these differences continued throughout the session. The *first phase* of this neural model involves orbital and basal frontal cortices shutting down specific and non-specific thalamic afferents to the cortex, leading to initial quieting of mind and body. The *second phase* maintains these quieter levels of functioning, *not* by active evaluation and manipulation, but by automatic threshold regulation circuits (Alexander et al., 1986). These circuits involve basal ganglia thalamocortical structures that funnel frontal, central and parietal inputs back to the cortex via a single output (Delong and Georgopoulos, 1981). This threshold regulation circuit modulates cortical arousal underlying attention (Elbert and Rockstroh, 1987), and controls the generation, maintenance, switching, and blending of a wide range of motor, mental, and emotional behaviors (Elsinger and Grattan, 1993; Nader, 1994; St. Cyr et al., 1995).

This threshold regulation circuit, proposed to underlie the second phase of TM practice, includes subcortical areas known to modulate state of consciousness, rather than processing of specific perceptual and cognitive content (Baars, 1995). The physiological signature of activity in these threshold regulation circuits is alpha synchronization (Elbert and Rockstroh, 1987), which is blocked by sensory processing or motor output. Thus, according to this two-phase model, alpha synchronization observed during transcending may indicate greater activity in these threshold regulation circuits, maintaining the background state of consciousness. In contrast, alpha desynchronization during the 'other' conditions may indicate processing of specific environmental stimuli (Pfurtscheller, 1992).

4.2.2. In light of an attention/intention model

The attention/intention model of alpha reactivity of Mulholland (1969) and Wertheim (1974) comes to a similar conclusion about these data, albeit from a different angle. They defined *attention* as visual focus on environmental stimuli (Wertheim, 1974) to actively guide motor behavior (Mulholland, 1995), and *intention* as inner focus on mental plans, irrespective of ongoing sensory information (Wertheim, 1974), usually accompanied by 'behavioral stillness' (Mulholland, 1995). Intention has been tied with a 'look ahead' device (Jeannerod, 1994), whereby a given scheme remains active until the completion of the task, or as an invariant that underlies specific sets of movements (Luria, 1973). Intention is inner-directed and results in alpha synchronization, while attention is outer-directed and results in alpha desynchronization (Shaw, 1996).

In terms of this attention/intention model, alpha synchronization during transcending may indicate a state of intention — the mind has been given a direction towards decreased mental and physical activity and is continuing in that direction until the task is complete. Desynchronized alpha observed during the 'other' conditions could indicate the state of attention — active processing of environmental stimuli.

4.3. Implications of enhanced skin conductance response during transcending

If transcending involves automatic threshold circuits (two-phase model) or the state of intention (attention/intention model), then it is conceivable that there will be a larger 'interrupt' by the external bell-ring during transcending compared to the 'other' condition. Skin conductance response is the hallmark of attention switching from automatic to controlled processing (Sokolov, 1963; Spinks et al., 1985); the larger the 'interrupt', the greater the skin conductance response. Heightened skin conductance responses during transcending suggest that automatic inner processes may predominate during this state (greater contrast with the bell ring). The lack of skin conductance responses during the 'other' condition suggests that controlled cognitive processes may predominate during this state (less contrast with the bell ring).

5. Conclusion

These data indicate that a TM session is comprised of phenomenologically and physiologically distinct sub-states. This conclusion has important design implications. Most previous studies have averaged physiological patterns over the entire 20–30-min TM session. This averaging has combined significantly different physiological patterns during transcending and 'other' experiences (reported in this study), and during transcendental consciousness (see Travis and Wallace, 1997) to form a pattern unlike any real meditation experience. This smearing of physiological patterns would have confounded previous condition-comparisons and understanding of meditation experience. This smearing can be avoided by monitoring ongoing EEG and autonomic patterns to target specific sub-states during TM practice, and so more accurately compare different meditation practices and other eyes-closed conditions.

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