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Cortical plasticity, contingent negative variation, and transcendent experiences during practice of the Transcendental Meditation technique

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Abstract

This study investigated effects of transcendent experiences on contingent negative variation (CNV) amplitude, CNV rebound, and distraction effects. Three groups of age-matched subjects with few (<1 per year), more frequent (10–20 per year), or daily self-reported transcendent experiences received 31 simple RT trials (flash (S_1)/tone (S_2)/button press) followed by 31 divided-attention trials — randomly intermixed trials with or without a three-letter memory task in the S_1–S_2 interval). Late CNV amplitudes in the simple trials were smallest in the group with fewest, and largest in the group with most frequent transcendent experiences. Conversely, CNV distraction effects were largest in the group with fewest and smallest in the group with most frequent transcendent experiences (the second group's values were in the middle in each case). These data suggest culminative effects of transcendent experiences on cortical preparatory response (heightened late CNV amplitude in simple trials) and executive functioning (diminished distraction effects in letter trials).

Keywords: Contingent negative variation; CNV rebound; Distraction effects; Cortical plasticity; Transcendent experiences; Transcendental Meditation

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1. Introduction

Experience-related cortical plasticity was first identified during critical periods of development. Sensory experiences establish the appropriate orientation and interconnection of cortical receptor fields (Hubel and Weisel, 1977) and is required for mature functioning of pattern recognition abilities (von Senden, 1960). Recent research suggests that experience shapes cortical connectivity not just during critical periods in development but throughout the life span. Even in adult human and primates, sensory, motor and sub-cortical representations are continually shaped by experience (Gilbert, 1993; Donoghue, 1995; Wang et al., 1995; Buonomano and Merzenich, 1998). For instance, string players have distinctly larger cortical representations in the primary somatosensory cortex of the fingers of their left hand (the hand that forms the chords) than do non-musicians (Elbert et al., 1995).

Elbert et al. (1997) suggest that consciously performing any task regularly over time may lead to cortical reorganization. This generalization is based on research that has primarily focused on the effect of overt behavior on reorganization of sensory and motor cotius. The cortical maps for these areas are well defined. Consequently, any structural changes are (fairly) straightforward to locate and to quantify.

The quality of experience also seems to shape cortical structure. Repeated stressful experiences lead to high secretion of glucocorticoids, which are thought to lead to decreased hippocampal mass (Sapolsky, 1996). Decreased hippocampal mass is reported in depressed patients and individuals diagnosed with post-traumatic stress disorder. Stress also plays an important role in decreasing cortical blood flow and adversely affecting behavior (Amen and Carmichael, 1997).

Our research has focused on the effects of transcendent experiences during Transcendental Meditation® (TM®) practice[1] on brain functioning. Transcendent experiences during TM practice are phenomenologically and physiologically distinct from other waking eyes-closed experiences and occur many times in each TM session. These experiences are subjectively characterized by 'silence' and the 'loss of boundaries of time, space and body sense' (Travis and Pearson, 2000; see also Maharishi, 1963). Time, space and body sense are the framework that give meaning to waking experiences (Velmans, 1993). During transcendent experiences, the very framework of ordinary waking experience is absent. In addition, these transcendent experiences are physiologically distinct from other eyes-closed states. Transcendent experiences are characterized by apneustic breathing up to a period of 40 s, with autonomic orienting at their onset (Travis and Wallace, 1997). Apneustic breathing has not been reported in non-clinical populations and, even in clinical populations, never for longer than 4–6 s (Plum and Posner, 1980). In addition, high amplitude global alpha activity is reported during transcendent experiences suggesting stable thalamo-cortical oscillations during this state (Travis and Wallace, 1999). Based on

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[1] ®Transcendental Meditation and TM are service marks registered in the US Patent and Trademark Office, licensed to Maharishi Vedic Education Development Corporation, and used under sublicense.

these unique phenomenological and physiological markers, Travis and Pearson (2000) argued that transcendent experiences during TM practice might constitute a unique state of consciousness (traditionally) called 'Transcendental Consciousness' (Maharishi, 1963) rather than an altered state of waking.

While there is no evidence for structural changes through regular transcendent experiences during TM practice, evidence is growing for experience-related *functional* changes in a number of physiological systems. A quantitative meta-analysis (Dillbeck and Orme-Johnson, 1987) reported that meditating subjects exhibited lower basal arousal as suggested by significantly lower breath rates, heart rates, skin conductance levels and plasma lactate levels compared with controls. A comparison of age-matched subjects revealed significantly higher alpha power and coherence during eyes-open periods in subjects reporting more frequent transcendent experiences (Travis, 1991). Contingent negative variation (CNV), a measure of cortical preparatory processes, is enhanced immediately after a TM session (Paty et al., 1977) as well as being higher in subjects reporting more frequent transcendent experiences (Travis, 1998). Regular transcendent experiences are also reported to lead to enhanced nervous system functioning as measured by faster paired H-reflex, a measure of neural transmission speed (Dillbeck et al., 1981), inspection time, a measure of speed of perceptual processing (So Kam Tim, 1995), and choice reaction time, a measure of decision time and performance speed (Cranson et al., 1991).

The TM technique is practiced with eyes closed for 15–20 min in the morning and evening. It does not involve procedures practiced during eyes-open tasks. Thus, changes in performance outside of the TM session, i.e. during task performance, most probably reflect long-term effects of transcendent experiences occurring during the 15–20 min TM sessions in the morning and evening.

In the current study, we further probed possible effects of transcendent experiences on brain functioning as reflected in the CNV. The CNV is a slow increase in scalp recorded negativity observed in the interval between a warning or preparatory stimulus (S_1) and an imperative stimulus (S_2) that requires a response (Walters et al., 1964). When probe stimuli (like a short-term memory task) are introduced in the S_1–S_2 interval the amplitude of the late CNV decreases and reaction times slow, which is called a CNV distraction effect. When distracting stimuli are randomly omitted, late CNV amplitudes increase beyond baseline values, called CNV rebound, but reaction times again slow relative to baseline trials (Tecce, 1979; Travis and Tecce, 1998).

CNV amplitudes reflect processing resources (Kok, 1997), and the interaction between attention to task and arousal levels (Tecce et al., 1976). Transcendent experiences, which are described in terms of heightened inner alertness, may activate processing resources leading to greater attention to task. If transcendent experiences systematically affect processing resources, then CNV amplitude, CNV rebound and CNV distraction might be expected to fall on a 'dose–response' curve — systematically increasing with increasing frequency of transcendent experiences.

2. Method

2.1. Subjects

Age-matched subjects (41) participated in the study as paid volunteers. These subjects were matched on age to control for developmental differences in EEG. They constituted three groups based on self-reported frequency of transcendent experiences. The first group had seven females and seven males, mean age 20.5 years (S.D. = 2.6), who reported few transcendent experiences (< 1 per year). This group did not practice a meditation technique. The second group had seven females and six males, mean age 23.27 years (S.D., 7.46), who reported more frequent transcendent experiences (10–20 per year). This group had been practicing the TM technique for an average of 1.11 years (S.D., 1.62). The third group had six females and eight males, mean age 21.01 years (S.D., 7.16), who reported daily transcendent experiences. These subjects had been practicing the TM technique for an average of 8.53 years (S.D., 3.77).

The subjects were blind to the specific experimental hypotheses. The meditating subjects in groups 2 and 3 volunteered for the study as part of an optional freshman–senior evaluation program at the university and considered this recording as their 'baseline-freshman' data. The non-meditating subjects in group 1 were part of a psychology class at a nearby university. They volunteered for the study to better understand brain wave patterns during different tasks.

All subjects were right handed. Their preferred hand was used for key pressing. Subjects had no history of accidents or hospitalization that might have affected their EEG. Each subject was given $10.00 for participating in the research, to lessen motivation differences. The verbal informed consent, obtained prior to the research, and the experimental protocol were both approved by the university IRB.

2.2. Recording details

EEG was recorded from mid-line electrodes (Fz, Cz, and Pz in the 10–20 system) using Ag/AgCl electrodes affixed with EC-2 cream, with a forehead ground and impedances at 5 kΩ or less. A linked-ears reference was used to reduce the effects of skin potential on the scalp-recorded EEG (Picton and Hillyard, 1972). Vertical eye-blinks were recorded with electrodes placed above and below the right eye. Heart rate was recorded with a lead II configuration — bi-polar sensors placed on the left wrist and right ankle.

EEG and EOG signals were recorded with a 0.01–100 Hz band pass filter (3 dB down, 12 dB octave/slope). Heart rate was recorded with a 3.0–100 Hz band pass. All signals were digitized on line at 200 points per s, and stored for later analyses using EEGSYS, a standardized research acquisition and analysis package developed in conjunction with researchers at NIH (Hartwell, 1995).

2.3. Procedure

After being introduced to the lab, the sensors were applied. Then the subjects entered the experimental room and sat in a comfortable chair in front of a CRT screen. They were presented the computer tasks (same order for all subjects). The subjects were tested 6–8 h after their morning TM session, and prior to their afternoon meditation session. Thus any performance differences among groups would more reflect long-term TM effects and not immediate effects of TM practice.

Subjects were visually presented a set sequence of 31 simple and divided-attention RT trials. The 31 simple trials consisted of an asterisk as S_1 (150-ms duration, 1 cm in height) in the center of a CRT screen followed by a continuous computer-generated tone (1200 Hz, 72 dB) as S_2, 1.5 s later. Subjects were told to terminate the tone as quickly as possible with a key press. The 31 divided-attention trials consisted of two types of trials randomly intermixed. One type (no-letter trials, $n = 16$) was identical to the simple trials — a flash/tone/key press sequence. The other type (letter trials, $n = 15$) differed in that three letters were visually presented in the S_1-S_2 interval as a short-term memory task. Subjects were asked to spontaneously speak out the letters after terminating S_2 with a key press. The letter-trigrams were chosen in advance from this list: A, C, E, H, K, L, N, P, S, and U. The first letter occurred 200 ms after the onset of S_1. Each letter appeared on the screen for 200 ms with a 200-ms blank screen in between. This left a 300-ms blank screen between the last letter and the onset of S_2. The simple and divided-attention conditions both lasted approximately 7 min.

Data were recorded for 6 s, beginning 100 ms pre-S_1 and ending 4.4 s after S_2. Intertrial intervals varied from 8 to 14 s. Picton et al. (2000) in a recent committee-report on guidelines for ERP recording standards recommended using baselines of 100 ms or more to reduce the effects of residual noise (for instance in a 50-ms baseline) on the averaged wave forms. In addition, 100 ms baselines have been most often used in ERP research and should serve as an adequate baseline to test the experimental hypotheses in this study.

Heart rate (beats per minute) and eye-blink rate (blinks per minute) were measured during simple and divided-attention trials to assess arousal levels during the task.

2.4. Data quantification

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 with a key press to terminate the tone. This resulted in few eye-blinks in the first 2 s (containing the baseline period, S_1 and S_2), but frequent eye blinks towards the end of the 6 s recording a window. To eliminate the majority of eye blinks from the CNV analysis, the first 2 s of data were extracted from the 6-s recording windows. These 2-s windows were then corrected for effects of partial saccades with an eye-movement correction procedure proposed by Gratton et al. (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 — were manually marked and eliminated from the average. The data were then averaged by condition — simple, letter, and no-letter trials. Late CNV was measured in μV as the average amplitude in the 200-ms epoch prior to S2 relative to the 100-ms baseline.

The CNV amplitude during the no-letter and letter trials were converted into difference-scores relative to CNV during the simple trials ($CNV_{simple} - CNV_{no\text{-}letter}$) and ($CNV_{simple} - CNV_{letter}$). This was done to assess the rebound and distraction mechanisms themselves, free of possible initial group differences in CNV levels during the simple trials.

2.4.2. Reaction time

Mean response time to S_2 (key press that terminated the S_2 tone) was measured to the nearest 10 ms for each trial and stored on hard disk for later off-line analysis. RT difference-scores were calculated for no-letter and letter trials, relative to RT during the simple trials.

2.4.3. Autonomic measures

Mean heart rate (beats per minute) was determined by summing the number of beats occurring in the 31 6-s windows and dividing by the total time (31 trials × 6 s = 186 s). Similarly, mean blink rate (blinks per minute) was calculated by summing the number of blinks occurring in the 31 6-s windows and dividing by the total time. HR and eye-blink difference-scores were calculated for no-letter and letter trials, relative to the values during the simple trials.

2.5. Statistical analyses

The CNV is a frontal–central component (Tecce and Cattanach, 1993) with higher CNV amplitude at central sites, if tasks involve more motor processes, and at frontal sites, if tasks involve more cognitive processes (Leynes et al., 1998). Consequently, frontal and central CNV amplitudes were included as variates in between MANOVAs (Jennings et al., 1987) used to analyze the data. We tested three research questions, (1) did the divided-attention task result in significant rebound and distraction effects? (2) did the groups significantly differ in the CNV, RT, and autonomic variables during simple trials? and (3) did the groups differ significantly in CNV rebound and distraction effects?

3. Results

The distributions of CNV, CNV rebound, CNV distraction, reaction time, heart rate and blink rate were first tested for normality. As suggested by Hair et al. (1992), skewness values greater than 1.28 (with 14 subjects per group) would indicate significant deviance from normality at the $P = 0.05$ level. None of the variables differed significantly from normality. Therefore, the raw data were analyzed.

Table 1 presents means and S.E.M. for all physiological variables (columns) during simple, no-letter and letter trials (rows) for the three groups.

3.1. Question one: did the no-letter and letter trials result in rebound and distraction effects

To test whether the protocol elicited rebound and distraction effects, late CNV amplitudes and reaction time during the simple 'baseline' trials were subtracted from values during the no-letter and letter trials. The magnitude of the difference-scores were then assessed with MANOVAs. If the no-letter and letter trials resulted in significant rebound and distraction effects, then these difference-scores should be significantly different than zero.

A MANOVA of CNV rebound and distraction difference-scores revealed highly significant late CNV rebound and distraction effects collapsing across groups, $F(4,37) = 14.04$, $P < 0.0001$. During the no-letters trials CNV rebounded at Fz (1.26 μV (0.58)); Cz (2.80 μV (0.71)) and Pz (2.81 μV (0.68)). In contrast, during the distracting letters trials, CNV amplitudes decreased at Fz (− 2.50 μV (0.65)); Cz (− 4.88 μV (0.85)), and Pz (− 6.52 μV (0.88)) (all values are mean (S.E.)).

While CNV amplitudes diverged during the letter and no-letter trials, reaction times significantly slowed during both letter (F (1,40) = 27.45; $P < 0.0001$) and no letter trials, $F(1,40) = 12.28$; $P < 0.001$ [mean (S.E.) reaction time for simple trial = 298 ms (45); letter trials = 337 ms (77), and no-letter trials = 328 ms (59)]. Similarly, heart rates and blink rates were significantly higher during both the letter ($F(2,39) = 9.61$, $P < 0.0005$) and no-letter trials, $F(2,39) = 4.00$, $P = 0.0282$ [mean (S.E.) heart rate increased 2.78 bpm (0.95) in the letter trials and 1.32 bpm (0.76) in the no-letter trials. Blink rate increased 3.09 bpm (0.87) in the letter trials and 1.38 bpm (0.82) in the no letter trials].

3.2. Question two: did the groups significantly differ in CNV amplitudes during the simple trials

Fig. 1 presents group average tracings (dashed line, group 1 with fewest transcendent experiences; dotted line, group 2 with infrequent transcendent experiences; solid line, group 3 with daily transcendent experiences) for the simple trials, letter trials, and no-letter trials (columns) at frontal, central and parietal midline sites (rows).

The late CNV is the average CNV amplitude in the 200-ms period before S_2 in all tracings.

Group differences in CNV amplitude on the simple trials were tested with a MANOVA with group as the between factor and late CNV amplitudes at the frontal and central midline sites as the variates. It revealed a significant main effect for group ($F(2,38) = 4.46$; $P < 0.02$) with the largest differences at the central site, $F(1,39) = 6.93$; $P < 0.015$. The group means at Cz best fit a straight line with smallest values in the group with fewest transcendent experiences (− 6.93 uV), medium in the middle group (− 8.10 uV), and largest in the group reporting most frequent experiences (− 12.60 uV).

Table 1

Means and S.E.M.s for late CNV amplitude at Fz, Cz, and Pz, reaction time, heart rate, and blink rate for each group for simple trials, no-letter trials and letter trials[a]

	CNV			Reaction time (ms)	Heart rate (bpm)	Eye-blink (bpm)
	Fz (uv)	Cz (uV)	Pz (uV)			
Group 1, few transcendent experiences (<1 per year)						
Simple trials	−4.71 (0.55)	−6.93 (0.76)	−4.71 (.67)	301 (12)	71.9 (2.22)	24.0 (1.58)
No-letters	−6.01 (0.95)	−8.76 (1.17)	−6.21 (1.34)	327 (20)	73.1 (2.44)	26.0 (1.85)
Letters	3.12 (0.90)	3.18 (1.17)	5.67 (1.16)	361 (19)	75.1 (2.91)	28.9 (1.84)
Group 2, more transcendent experiences (10–20 per year)						
Simple trials	−6.09 (1.23)	−8.10 (1.14)	−5.85(.96)	311 (11)	71.3 (3.90)	22.2 (2.54)
No-letters	−7.38 (1.19)	−13.40 (1.43)	−8.49 (1.00)	332 (16)	74.2 (2.99)	24.3 (2.20)
Letters	−4.8 (1.34)	−6.5 (1.71)	−0.97 (1.78)	348 (19)	75.6 (3.32)	25.0 (3.32)
Group 3, daily transcendent experiences						
Simple	−8.16 (0.60)	−12.60 (1.06)	−6.21 (.91)	284 (11)	75.0 (4.22)	21.1 (2.08)
No-Letters	−10.3 (0.91)	−15.90 (1.40)	−11.10 (1.02)	324 (16)	74.9 (4.14)	21.2 (2.43)
Letters	−9.54 (1.41)	−11.04 (1.78)	−3.09 (1.32)	361 (22)	75.8 (4.11)	21.2 (2.43)

[a] Table entries are mean (S.E.).

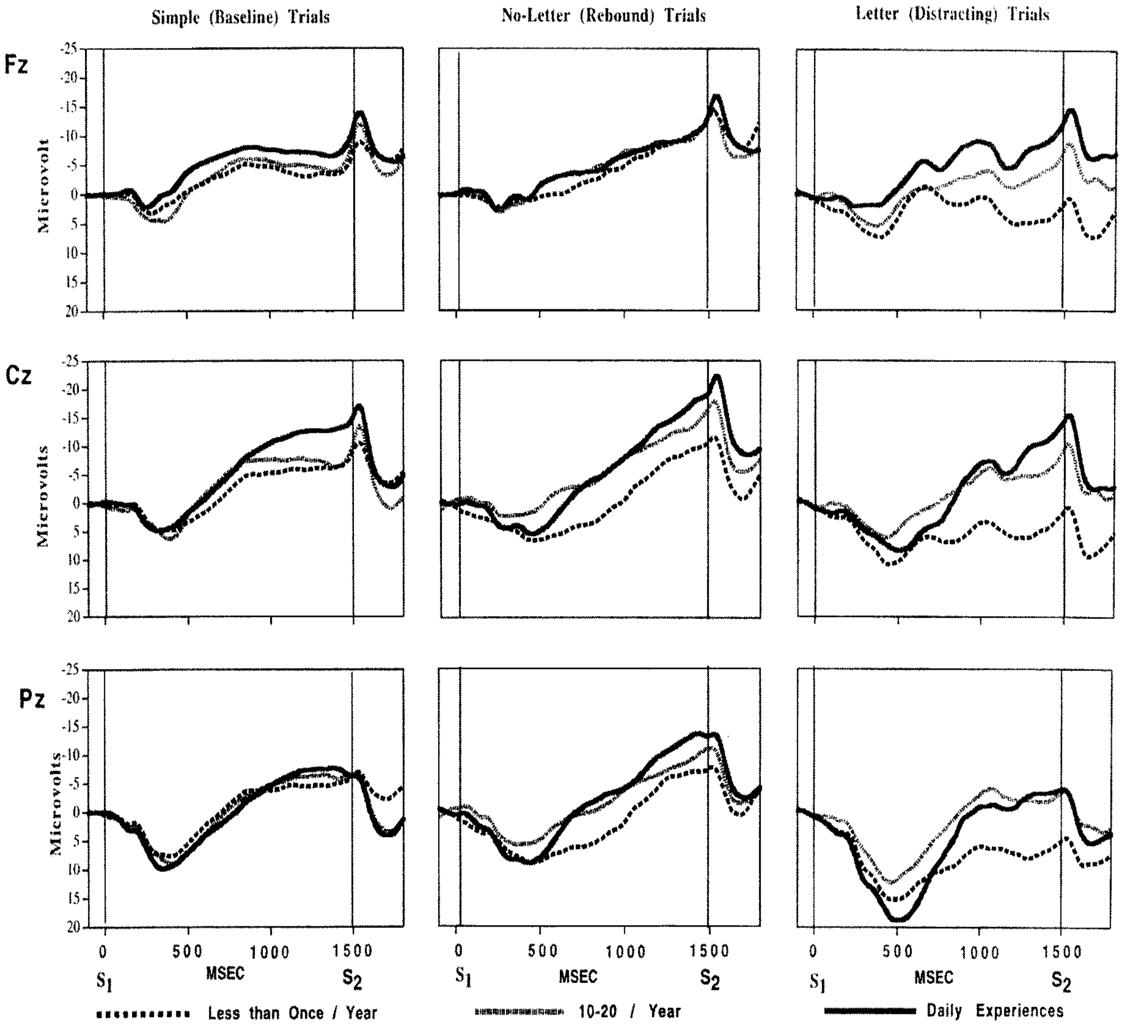

Fig. 1. Group averages during the three tasks at the three mid-line sites. This figure presents group-average tracings (dashed line, group 1 with fewest transcendent experiences; dotted line, group 2 with infrequent transcendent experiences; solid line, group 3 with daily transcendent experiences) for the simple trials, letter trials, and no-letter trials (columns) at frontal, central and parietal mid-line sites (rows).

Group differences in RT, heart rate, and blink rate during the simple trials were assessed with a second MANOVA. There were no significant main effects for group for these variables ($F < 1.0$).

3.3. Question three: did the groups differ in rebound and distraction effects

3.3.1. Rebound effects

Group differences in rebound were tested with two MANOVAs. Each had group as the between factor. One had difference-scores in CNV at frontal and central sites as variates; the other had difference-score in reaction time, heart rate, and blink rate as variates. There were no significant group differences in either MANOVA (all $F < 1.0$, ns).

3.3.2. Distraction effects

Group differences in distraction were also assessed by two MANOVAs. The first MANOVA tested group differences in CNV distraction difference-scores. In this analysis, there was a significant main effect for group ($F(2,38) = 9.06$; $P < 0.0005$) with the largest difference at the frontal site, ($F(1,39) = 15.75$; $P < 0.0003$). The group means of distraction difference-scores best fit a straight line with the greatest distraction effects seen in the group with fewest transcendent experiences (-7.86 μV), medium in the middle group (-1.2 μV) and smallest in the group reporting most frequent experiences (1.40 μV).

The second MANOVA tested distraction effects in RT, heart rate, and blink rate difference-scores. There were no significant main effects in this MANOVA ($F < 1.0$).

3.4. Post hoc analysis

A Pearson correlation was conducted to test whether the observed group differences in distraction effects during the letter trials reflected the same mechanisms that resulted in increased CNV amplitudes during the simple trials. The Pearson correlation coefficients were very low (all $r < 0.18$; $\mathrm{df} = 40$) between late CNV amplitude during the simple trials and the CNV difference-scores during the distracting letter trials ($\mathrm{CNV}_{\text{letter trials}} - \mathrm{CNV}_{\text{simple trials}}$). This low correlation suggests that different mechanisms may underlie the observed group differences in CNV amplitude during simple trials than during the distracting letter-trials.

4. Discussion

These findings replicated the ability of this divided-attention task to elicit robust rebound and distraction effects. These data also revealed 'dose dependent' increases in late CNV amplitude and 'dose dependent' decreases in CNV distraction with increasing frequency of self-reported transcendent experiences.

4.1. Consideration of task effects

4.1.1. Reaction time, heart rate and eye-blink patterns

It is noteworthy that slower reaction time, heightened heart rate and heightened blink rates were seen in both the letter and no-letter trials suggesting heightened arousal during both kinds of trials. Sanders (1983) cognitive-energetic model of information processing identifies energetic (arousal and activation) mechanisms that bias the flow of information through a set structure of perceptual and cognitive processes. In Sanders's model, arousal primarily affects stimulus evaluation (processing of the three-letter short-term memory task) and not response selection and execution (reaction time). Subjects may have increased arousal levels to prepare for the heightened cognitive demands of the short-term memory task in the S_1S_2 interval. In the debriefing after the experiment, all subjects mentioned that they felt 'more alert' or 'more focused' during the divided-attention trials. Heightened arousal may have increased stimulus evaluation processes at the expense of response selection and execution leading to slower RTs in both letter and no-letter trials.

4.1.2. CNV rebound

Subjects appeared to increase energetic mechanisms (arousal) during the divided attention trials in preparation to process the added load of the short-term memory task — if it appeared in the S_1S_2 interval. Elevated energetic mechanisms during the trials in which the three-letter memory task were omitted may have resulted in the CNV rebound observed during these no-letter trials.

4.2. Consideration of group differences in simple, letter, and no-letter trials

The Pearson correlation of late CNV amplitudes (simple trials) and CNV distraction effects was very low. This suggests that different mechanisms may have led to the observed group differences in these two CNV variables.

4.2.1. Significant group differences in CNV during simple trials

CNV amplitude has been linearly related to attention and curvilinearly related to arousal (Tecce, 1972). The highly significant group differences in CNV during simple trials were accompanied by no group differences in reaction time or measures of arousal. This suggests that these group differences could not be explained by a simple arousal explanation. Since the arousal levels were similar among groups, significant group differences in CNV during simple tasks may reflect graded increases in attention to task with increasing frequency of transcendent experiences. Transcendent experiences may facilitate brain activity during simple (undivided attention) tasks.

4.2.2. Lack of group differences in no-letter trials

The lack of group differences in CNV rebound could reflect the simplicity of the primary and secondary tasks used in this study — the flash/tone/response and the letter-memory task. It is conceivable that a comparable increase in energetic resources may have been automatically allocated during the divided-attention task by most subjects in the three groups resulting in similar increases in CNV amplitude during the no-letter trials.

4.2.3. Significant group differences in CNV distraction effects during letter trials

Distracters are the most powerful and robust source of disruption of CNV development (Tecce, 1972; Rockstroh et al., 1993) and are typically similar across subject populations. Comparable distraction effects have been seen in young subjects, in elderly subjects (Michaelewski et al., 1980; Tecce et al., 1982) and in Alzheimer subjects (Tecce et al., 1986).

The 'dose–response' decrease of distraction effects with increasing frequency of self-reported transcendent experiences suggests that these inner experiences may either facilitate processing in general or 'protect' processing from interfering stimuli. Distracting effects by a secondary task on a primary task have been explained by *allocation of limited resources* in single (Kahneman, 1973) or multiple-resource (Wickens, 1980) capacity models, or by *bottlenecks in central processing* in structural models (Pashler, 1994a; Sanders, 1997). The data better fit a central bottleneck explanation. For instance, Pashler (1994b) systematically varied the ISI between two choice RT tasks by 1 s. Capacity models would predict maximal interference at zero ISI. Structural models would predict a bi-modal distribution of interference — subjects would carry out central processing of one task before the other. Most subjects exhibited a bimodal distribution of interference supporting a central bottleneck explanation.

What central processes may be facilitated by transcendent experiences? Central processes, which are necessary to initiate response preparation, do not appear necessary to *sustain or continue* response preparation once it has begun (Ilan and Miller, 1998). Increasing frequency of transcendent experiences is reported to enhance speed of neural processing (see above). Increased neural processing speed may allow faster initiation of response preparation processes — within 200 ms between S_1 onset and the onset of the first distracting letter. If the subjects initiated response preparation before the onset of the three-letter memory task (which requires central processing Ilan and Miller, 1999), then these response preparation processes, reflected in CNV amplitude, would continue in parallel with memory processes. This could explain increasing CNV amplitude with increasing transcendent experiences during the distracting letter trials.

4.3. Consideration of findings in terms of cortical plasticity

Research on cortical plasticity has primarily focused on structural changes in the somatosensory (Elbert et al., 1995) and motor cortices (Buonomano and Merzenich, 1998) with repeated experience. The somatosensory and motor cortices are well defined and so any reorganization in these regions can be readily identified and quantified. The current data do not suggest that transcendent experiences lead to *structural* changes in cortical areas. However, the data do suggest that transcendent experiences may modulate cortical *functioning*. With increasing frequency of transcendent experiences, baseline late CNV amplitude increased and distraction effects decreased. This conclusion is tentative because we used a differential group design with pre-existing groups. Consequently, the observed group differences in CNV variables may be explained by initial group differences. However, Paty et al. (1977) reported that CNV amplitudes were increased, relative to baseline amplitudes, in trials presented after TM practice. These immediate effects on CNV amplitude, observed by Paty, may be progressively maintained more and more in activity with regular transcendent experiences, as suggested by the 'dose–response' relation of CNV amplitudes and transcendent experiences observed in the current study. The possible effects of repeated inner experiences on brain functioning needs to be tested with longitudinal research monitoring the relation of frequency of transcendent experiences and CNV measures in different groups (i.e. meditation, exercise, and controls). This line of research could extend our understanding of how cortical connectivity may be dynamically sculpted throughout life.

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