Research Proposal

THE EFFECTS OF THE TRANSCENDENTAL MEDITATION TECHNIQUE ON THE TEMPORAL AND SPATIAL MAPPING OF THE BRAIN—A MEG STUDY

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Abstract

Previous research has suggested that a unique "fourth state" of awareness, Transcendental Consciousness (TC), distinct from waking, dreaming, and sleeping, occurs during the practice of the Transcendental Meditation technique. Subjectively, this state has been described as free of mental content but with alert, broaden awareness. Objectively, this state has been characterized, in part, by very high levels of short- and long-range EEG (electroencephalographic) coherence along with spontaneous respiratory "suspension" and phasic adjustments of various autonomic variables. Research also suggests that brain rhythms centered on 40 Hz may participate in the mechanics of temporal binding of diverse brain activity underlying the content and unity of cognitive experience. This proposed study is designed to help clarify the unique nature of this state of TC and its relationship to 40 Hz rhythms using a multichannel magnetoencephalography (MEG) and electroencephalography (EEG) system. This meditative state (TC) is predicted to be (1) distinct from all three other states of awareness in the appearance of high levels of broadly distributed, phase-coherent MEG and EEG activity, in particular, 40 Hz oscillations, suggesting a higher degree of global brain integration and the presence of cognitive experience; and (2) distinct from the waking or dreaming states of consciousness in its lack of "resetting" of the 40 Hz oscillations reported by Llinas and Ribary (1993)—either 40 Hz reset to external evoked stimuli as in waking state, or to spontaneous, endogenous stimuli as in REM state..

Introduction

How diverse fragments of sensory information, spatially distributed across networks of neurons, are integrated into a unified cognitive experience is referred to as the “temporal binding” problem in cognitive neuroscience (Llinas and Pare, 1996; Singer, 1996; Von der Malsburg, 1996; Churchland, 1996). Investigation into cognitive processing and binding has been addressed with different neurocognitive experimental approaches in recent years (Cotterill, 1997; Crick & Koch, 1990; Desmedt & Tomberg, 1994; Jefferys, Traub, & Whittington, 1996; Llinas & Ribary, 1993; Llinas & Pare, 1991; Lumer, Edelman, & Tononi, 1997; MacDonald, Brett, & Barth, 1996; Naatanen, Ilmoniemi, & Alho, 1994; Singer, 1996; Steriade, Contreras, Amzica, & Timofeev, 1996). For example, Llinas and Ribary (1993) have proposed that temporal binding is a thalamocortical process. In the Llinas model, different patterns of thalamocortical synchronization generate the functional states that characterize human cognition. Llinas has conducted a number of magnetoencephalography (MEG) studies examining the dynamics of 40 Hz rhythms to support his model (For comprehensive review, see Llinas, Ribary, Contreras, & Pedroarena, 1998).

Mechanisms of Global, Integrated Brain Functioning

Research has implicated the spontaneous oscillatory electrical activity at a frequency of about 40 Hz in the human brain, and its reset by sensory stimulation, to be a central candidate in cognitive processing and the temporal binding of sensory stimuli. Llinas & Pare (1991) and Llinas & Ribary (1993) propose that binding depends upon interactions between specific and non-specific thalamocortical loops. In their model, conscious experience is believed to involve two components: 1) the **context** or the unifying mechanics related to cognitive experience and alertness, and 2) the **content** or the object experienced in that level. Fig. 1 describes the neuronal properties and circuits that are proposed to allow the relevant thalamocortical neurons to oscillate at 40 Hz and subserve temporal binding. The model features the oscillatory characteristic of neurons in the specific sensory thalamic nuclei, non-specific thalamic nuclei, cortical pyramidal cells, and inhibitory interneurons. In the Llinas model, 40 Hz activity is generated and organized by two complementary thalamocortical systems. These two systems are shown as loops. The first loop represents the specific sensory loop. This loop is a 40 Hz oscillation of specific thalamocortical neurons in resonance with cortical layer IV and local inhibitory interneurons. Such oscillations can re-enter the thalamus via layer VI pyramidal cells which, in turn, can resonate with both the nucleus reticularis thalami (NRT) and the corresponding specific thalamic nuclei.

—Insert Figure 1 here—
Thalamocortical circuits proposed by Llinas et al.
to subserve temporal binding.

The second loop is represented by the "non-specific" thalamic intralaminar input to layer I of the cortex and its return pathway projection via layer V and VI pyramidal cells to the intralaminar nuclei. The re-entry flow also has collaterals to the nucleus reticularis thalami. The key point in Llinas's model is that the conjunction of the two loops, specific and non-specific, is proposed to generate temporal binding. Llinas and his group (1998) proposed:

> *… neither of these two circuits alone generate cognition...The 'specific' system would thus provide the* ***content*** *that relates to the external world, and the non-specific system would give rise to the temporal conjunction, or* ***context*** *(on the basis of a more interoceptive context concerned with alertness), that would together generate a single cognitive experience. (p. 1847-8)*

Therefore, according to Llinas's model, the 40 Hz resonance activity in the thalamocortical system requires a synchronous coactivation of specific and the non-specific loops that generate temporal binding. The impairment of either of these would disallow the normal function of the thalamocortical system during cognitive processes. Conversely, enhancement of these circuits could lead to improved cognitive processing.

Recordings of spontaneous and evoked magnetic activity during waking, REM sleep, and NREM sleep in the human brain indicate the 40 Hz rhythm varies across cognitive states (see Table 1 and 2; Linas &Ribary, 1993; Llinas et al. 1998). Llinas and Ribary (1993) have shown that the electrical activity at 40 Hz during dreaming state is similar in general distribution, phase, and amplitude to that observed during waking state. In contrast, the amplitude of 40 Hz activity is very much reduced during delta sleep state (see Table 2). The overall speed of the rostrocaudal "scan" is similar in waking and REM, the scan averaging near 12.5-milliseconds, corresponding to half a 40 Hz period. Moreover, the 40 Hz activity in REM state appears to be more ‘coherently’ organized than in waking state. Perhaps more importantly, the ongoing 40 Hz activity is not reset by sensory inputs during dreaming, as it is in waking state. These results are interpreted to suggest the thalamocortical system during dreaming shuts out external sensory signals (see below).

—Insert Table 1 here—

State-dependent patterns of 40 Hz activity

The extent of brain processing of external sensory signals is known to be state-dependent. Research has shown that presentation of an auditory stimulus during waking, REM sleep, and NREM sleep can elicit a series of auditory evoked potentials (AEPs). These potentials are classified by latency—the time from presentation of stimulus to the positive (or negative) peak—into early, middle and late waveforms. In the first 10 or 12 msec after an auditory stimulus, the auditory brainstem response (ABR) is observed with seven waveforms labeled Waves I-VII. The middle latency components (N0, P0, Na, Pa, and Nb) range from 10 to 80 msec and are related to initial thalamocortical activity. After 80 msec, long-latency components, notably the N1, P2, N2 and P3 can be detected.

Middle and Late AEPs, but not early, potentials are found to be state-dependent. For example, although ABR shows little state-dependent variation during the sleep-waking cycle (Picton & Hillyard, 1974), the amplitude of middle-latency components decreased from waking to stage IV (Chen & Buchwald, 1986)**.** In addition, the long-latency components following sensory stimuli are abolished in REM sleep (Velasco, Velasco, Cepeda, & Munoz, 1980). This last result suggests that in the presence of intrinsic cognitive activity (“dreaming”) during REM sleep, sensory stimuli are not processed after about 80 msec and therefore rarely enter awareness and are not usually included in an individual’s cognitive experience, i.e., dream mentation.

In summary, the lack of sensory reset of 40 Hz activity during dreaming is believed to be a finding similar in implication for cognitive processing as the reduction of middle and long latency AEPs in dreaming. Thus, although evoked potential responses indicate that the thalamocortical system is at least initially accessible to external sensory input in dreaming and waking, both the reduction of longer latency AEPs and the lack of 40 Hz resetting argue against higher order cognitive processing of external stimuli during REM sleep. It should be noted that during NREM sleep, as in REM sleep, there is no 40 Hz sensory response. Thus, experience is externally driven during waking, internally driven during REM, and experience is generally not reported during NREM.

—Insert Table 2 here—
Brain State Correlates of 40 Hz Activity

Proposed Research

In response to these current findings, we propose to evaluate whether the Transcendental Meditation®(TM®) technique[1] generates unique patterns of 40 Hz oscillation.

Transcendental Consciousness

The Transcendental Meditation technique has been shown to produce very high levels of short- and long-range EEG (electroencephalographic) coherence along with respiratory "suspension" (Figure 2). Subjectively, these periods of respiratory suspension are characterized by the cognitive experience of full alertness of an abstract experience without mental boundaries (Badawi, Wallace, Orme-Johnson, & Rouzere, 1984; Farrow & Hebert, 1982; Kesterson & Clinch, 1989; Travis & Pearson, 2000; Travis & Wallace, 1997; Wallace, 1970)

—Insert Figure 2 here—
Period of spontaneous respiratory suspension correlated with the subjective experience of TC during the practice of the Transcendental Meditation technique.

During the TM technique, awareness is maintained, unlike sleep and dreaming states. Individuals report experiences either with or without content. The contentless (no spatial and temporal boundries) experience can be clearly reported as a fully alert state wherein, the usual "content" of experience is now characterized as unbounded, empty and silent. This state, defined by

[1]Transcendental Meditation® is registered in the U.S. Patent and Trademark Office, licenced to Maharishi Vedic Education Development Corporation, and used under sublicense.

objective and subjective criteria, is referred to as a 'ground state' of awareness or Transcendental Consciousness (Domash, 1975).

40 Hz Rhythms and Transcendental Consciousness

The state of TC can be examined under either spontaneous or sensory-evoked conditions. If the 40 Hz rhythms contribute to the mechanics underlying cognitive experience by 'binding' or coupling distributed thalamocortical processors, then the direct experience of Transcendental Consciousness should be accompanied by coherent 40 Hz activity. Thus, it is expected that the TC experience during the TM technique will have a corresponding unique pattern or signature of 40 Hz activity. High levels of coherently distributed 40 Hz MEG activity would suggest a high degree of thalamocortical synchrony underlying a high degree of cognitive binding, corresponding to a highly unified cognitive experience.

Furthermore, during this alert, contentless experience of TC, the specific sensory thalamocortical circuits would be active, but with essentially no processing of normally diverse sensory parameters. As noted by Llinas:

> *…if the sensory input coming to the brain is not put in the context of the thalamocortical reality by being correlated temporally with the ongoing activity, the stimulus does not exist as a functionally meaningful event (Llinas and Ribary, 1995, page 117).*

Since the experience of TC is reported to be a state of inwardly directed high alertness—a state devoid of normal spatiotemporal sensory activity patterns—processing of external stimuli would be considerably or completely reduced and, thus, resetting of the 40 Hz rhythm should not occur. Therefore, during TC, the resetting of 40 Hz oscillations by sensory (auditory) stimuli is predicted to be significantly reduced compared to the eyes-closed, waking condition.

Choice of Technique

The TM program is the method of choice for this research. The TM technique is the simpliest and most effective procedure available (For review of 8 meta-analysis of 597 studies, see Orme-Johnson and Walton, 1998). The technique is simple to learn and practice. Over 6 million people around the world have been instructed in a standardized format, making it easy for any laboratory to access standardized 'subjects' of meditation. It is a natural technique requiring no mental effort or concentration; the latter instructional modes employed in all other techniques.

The nature of the technique thus provides two key benefits: 1) the success of practice is independent of the individuals' unique cognitive state and history, i.e., intellectual, philosophical, and religious background, and current mind/body condition; and 2) the mind and body are allowed to spontaneous settle down to a minimum or "ground state", TC. Thus, the TM technique is the only procedure with reproducible, documented evidence of the systematic shift from waking to a transcendental state of consciousness (see Jevning, Wallace, & Beidebach, 1992).

—Insert Table 3 here—
Physiological Correlates of States of Consciousness

Research suggests that the practice of the TM technique leads to a unique, laboratory-definable experience of mental and physiological quiescence (Farrow & Hebert, 1982; Travis & Wallace, 1997; Wallace, 1970; Wallace, 1972). The primary physiological indicator of TC is the period of spontaneous respiratory suspension. There is a close correlation between subject reported experience of TC and the ongoing period of respiratory suspension during the practice of the TM technique (Farrow & Hebert, 1982; Travis & Pearson, 2000)

Because subjective and physiological correlates of TC are available, it becomes possible to use MEG analysis of 40 Hz activity in conjunction with respiration to examine the mechanics of cognitive 'binding' as it occurs within the cognitive state of restful alertness, TC, and to compare brain dynamics during TC with the other three major states of consciousness.

Hypotheses

We propose two experiments to test the two hypotheses shown in Table 4:
(1) The examination of *spontaneously* occurring 40 Hz activity during TC, and
(2) The examination of *evoked* 40 Hz activity during TC.

TABLE 4. Two hypotheses for the proposed research

Experiments	Hypotheses	Expected results
Exp. 1 **Spontaneous** **40 Hz**	H_0: $EC_{Spon} = TC_{Spon}$ H_1: $EC_{Spon} < TC_{Spon}$	Greater coherence (level & distribution)
Exp. 2 **Evoked** **40 Hz**	H_0: $EC_{Reset} = TC_{Reset}$ H_2: $EC_{Reset} > TC_{Reset}$	Significantly reduced stimulus-induced resetting in TC compared to waking using time-locked signal averaging data.

EC, eyes-closed state, waking; Spon, spontaneous periods with no external sensory stimulation.

Methods

Subjects

The study will involve 10 long-term practitioners of the TM technique. Subjects will be screened for inclusion in the study during the initial intake interview. Inclusion criteria include repeated respiratory suspension during meditation, minimal eye movements, and report of TC experience, good health, and free from neurological and psychiatric disorders by standard inventories. Respiratory suspension will be assessed using a chest transducer at the time of intake interview.

Recording Condition

Breath rate will be recorded to define the periods of spontaneous respiratory suspension, a main correlate of Transcendental Consciousness. Magnetic recording will be obtained from both cerebral hemispheres with a 148-channel MEG system Magnes 2500 WH (4-D Neuroimaging; previously Biomagnetic Technologies, Inc., San Diego). 700 ms (evoked) and 3000 (spontaneous) ms epochs will be employed at a sample rate of 1041 Hz with a bandpass 0.1-400 Hz. For EEG recording, a bandpass of 0.1-100 Hz will be employed. The data will then be filtered to provide a power spectrum between 0.1 and 60 Hz. Individual frequency bands will be filtered and grouped into six blocks: delta, theta, alpha1, alpha2, beta1, and gamma (20-60 Hz). Recording of heart rate and skin conductance is anticipated.

Procedure

There will be three sessions in each experiment—a 20-minute session for the practice of the TM technique and two 5-min eyes-closed (EC) sessions, before and after the practice of the TM technique. Continuous recordings will be made and subsequently analyzed as single epochs and/or averaged epochs. In the second experiment, auditory stimuli will be presented binaurally. Subjects will be exposed to the stimuli for a 5 mins eyes-open period before the experiment and instructed not to attend to the stimuli during the experiment. Stimuli will be presented every 2 sec as a tone of 500 Hz at 60 dB (9.9 ms rise/fall, 50 ms plateau).

Experimental Analysis

Periods of TC will be defined by respiratory changes (onset and offset of suspension). Secondary criteria will be the presence of high levels of EEG and MEG coherence in the alpha 1 & 2 bands, as well as phasic changes in autonomic activity. To analyze differences between TC and EC on patterns of spontaneously occurring 40 Hz activity, two three-way analyses of variance (ANOVA) with 3 within factors will be computed. For power analysis, factors include (1) condition, with two levels (EC vs. TC), (2) spectral bands, with 6 levels (delta, theta, alpha1 &2, beta1, and gamma frequencies), and (3) brain regions, with 6 levels (FL[1], FR, CL, CR, PL, PR). For coherence analysis, factors include (1) condition, with two levels (EC vs. TC), (2) spectral bands, with 6 levels (delta, theta, alpha1 &2, beta1, and gamma frequencies), and (3) brain regions, with 9 levels (inter- and intra-hemispheric sensor pairs as FF[2], CC, PP, FC, FC, FP, FP, CP, CP). Several sets of 9 sensor pairs representing the main regions can be selected and run.

The second study will include the introduction of auditory stimuli during EC and the meditative period, and is designed to examine evoked 40 Hz activity to help differentiate the mechanisms of temporal binding of sensory stimuli during waking and TC states. Each epoch will be 700 ms (200-ms prestimulus baseline and 500 ms poststimulus period) and averages of 300 epochs (total ~3.5 min) will be analyzed for power in the 40 Hz frequency band (20-60 Hz). Resetting

[1] F, frontal cortex; L, left hemisphere; R, right; C, central; P, parietal.
[2] FF, frontal-frontal; CC, central-central; etc.

occurs when an external stimulus evokes a 40 Hz oscillation detectable in cortical activity. As a measure of “resetting,” if the amplitude of average evoked epochs is not zero and a 40 Hz spindle is present following the stimulus presentation, then there is time- or stimulus-locked appearance of 40 Hz rhythm. In contrast, if the averaged amplitude following stimulus presentation is zero (flat) and no 40 Hz spindle is evident, then there is no time-locked 40 Hz rhythm and no resetting. Averages of maximum amplitude of stimulus-induced spindles, as a measure of 40 Hz resetting, will be compare between EC and TC periods.

The evoked 40 Hz experiment will employ a two-way analysis of variance (ANOVA) with 2 within factors will be computed for the amplitude values from the gamma frequency window. For evoked spindle analysis, factors include (1) condition, with two levels (EC vs. TC), and (2) brain regions, with 6 levels as above. We will also analyze other possible differences before, during, and after the periods of respiratory suspension, as well as, the practice of the TM technique on patterns of sensory-induced 40 Hz activity including power and coherence. For all statistical tests, the significance level is set at 0.05.

Conclusion and Significance

Although numerous studies of EEG power and coherence have been published, this study will be the first to use MEG technology to examine the effect of the Transcendental Meditation technique on brain function. It will also be the first study to specifically examine the spontaneous and evoked 40 Hz brain rhythms during the meditative state. Two experiments have been designed to help clarify the conditions within which sensory processing of external stimuli occurs as a function of cognitive state. In particular, we expect to find highly coherent, broadly distributed 40 Hz activity, as a measure of widely spread thalamocortical integration and temporal binding during a unique, fourth state of awareness—Transcendental Consciousness—that occurs during the practice of the TM technique. Furthermore, we predict that the specific meditative state of TC will demonstrate significantly reduced 40 Hz resetting compared to the normal waking state as an indication of a unique state of inner attention. More broadly, we hope to advance the understanding of neuroscience in the area of the physiological basis of conscious experience. Because the meditative state of the TM technique, in particular TC, is unique and offers reproducible physiological correlates, one can systematically examine the brain dynamics of a very simplified state of cognitive experience.

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