Experimental

THE INNER ALCHEMY OF BUDDHIST TANTRIC MEDITATION: *A QEEG CASE STUDY USING LOW RESOLUTION ELECTROMAGNETIC TOMOGRAPHY (LORETA)*

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Abstract

Indo-Tibetan Buddhist Tantric practice employs structured self-healing meditations aimed at awakening emotional and spiritual qualities or energies whose seed already resides within us. This profound transformative practice, with written records dating back to at least 400 C.E., is investigated from several diverse orientations: depth psychology, neuropsychology, and neurophysiology. From a Jungian perspective, the psychological process of this practice involves the re-collection and development of these energies to engender emotional and spiritual growth. Using a phenomenological task analysis, the various neurocognitive processes involved in such practice are identified. Finally, we analyze the quantitative electroencephalographic (QEEG) characteristics of a Buddhist ex-monk during various aspects of a self-healing meditation practice. The QEEG was recorded with a Lexicor Neuroseatch 24 and data analyzed using NeuroRep, NeuroGuide, LORETA-KEY and EureKa!3 software, EEG reference database, as well as low resolution electromagnetic tomography (LORETA). Staristical comparison of baseline and meditation conditions using LORETA revealed areas of brain activation consistent with those reported in previous neuroimaging studies. The QEEG results are discussed in the context of the phenomenological processes involved in the different types of meditation as well as with results of previous studies.

KEYWORDS: Meditation, Buddhist tantra, QEEG, LORETA, guided imagery, visualization, delta waves

INTRODUCTION

Buddhist tantric (i.e., Vajrayana) practice has often been misunderstood and/or misrepresented. As a whole, the practice integrates the Hinayana or Theravadin Buddhist path of seeking self-realization along with the Mahayana Buddhist addition of working for the enlightenment of all sentient beings into a "quick path" that can be realized in one short lifetime. Thus, the tantric path builds upon the earlier Buddhist traditions and employs many of the same techniques. In all three "yanas" or vehicles of the Buddhist tradition, meditation is but one component of a much broader and more extensive spiritual practice. These steps to enlightenment, including various meditation practices, have been clearly laid out by previous Indian and Tibetan sages.[1] In this paper, we summarize the major types of meditation and then discuss Buddhist tantric meditation from several perspectives including depth psychology and neuropsychology. We also briefly review previous EEG and neuroimaging studies of these practices and present a QEEG of a Tibetan ex-monk during advanced highest yoga tantra meditation practice.

TYPES OF MEDITATION

The term "meditation" has become a common word in our culture that denotes a method for engendering a state of inner peace or tranquility (Sanskrit [Skt.], samadhi). However, there are many forms of meditation, some of which engage very different mental states and processes. Several methods including QEEG brain mapping as well as other neuroimaging techniques such as functional magnetic resonance imaging (fMRI), positron emission tomography (PET) or its variation single-photon emission computed tomography (SPECT) have been utilized in order to discern the workings of the mind/brain during meditation. Such studies can potentially lead to our better understanding the process involved in meditation and in particular, higher states and stages of human development. However, in order to truly expand our awareness of the nature of meditation, we need to clearly specify and describe the type of meditation practice we wish to study.

Concentration (Narrow Awareness):[2] This type of meditation, also referred to as calm abiding, is generally the most widely known in the West. Its purpose

is to stabilize the mind through the focus or concentration upon a single object such as the breath, a sacred word or mantra, or visualization of an image. Transcendental Meditation (TM) and Benson's Relaxation Response are the most well known examples of this technique.[3-6] The benefits of this practice to health and well-being have been espoused elsewhere.[5-7]

In novice subjects, the repetitive mental focus of RR resulted in a significant decrease in anterior cortical activation as reflected by decreased beta activity.[8] Typically, TM meditation results in an increase in alpha power in frontal and central areas. This is sometimes accompanied by theta trains or theta bursts in frontal regions.[9-11] These theta bursts, generally of one to eight second duration, arise from a background of alpha activity and are generally of equal amplitude over the left and right hemispheres with highest voltages mostly in frontal channels.[10]

Similar results were reported in a study of two western yogis practicing a mantra repetition meditation of raja yoga. These yogis evidenced increased theta and alpha centrally, with increased beta, particularly in the right temporal lobe area.[12] Recordings of experienced Zen Buddhist monks practicing Zazen with eyes open evidenced an initial period of alpha waves followed by an increase of alpha amplitude, a decrease in alpha frequency, and finally, the appearance of rhythmical theta.[13] In a study of Zen "Su-soku" meditation (i.e., a concentration exercise involving slow serial counting), meditators were shown to produce frontal midline (Fm) theta, presumably generated by an attentional network including the anterior cingulate gyrus.[14] Recent studies using high resolution EEG and magnetoenecephalography (MEG) have supported the connection between anterior attentional networks, frontal midline thera and the anterior cingulate gyrus.[15]

In addition to changes in EEG frequency and amplitude, concentration type meditation has also resulted in increased alpha coherence spreading to theta in fronto-central regions.[16,17] Moreover, TM meditators have been shown to produce hypersynchronous alpha, theta, and beta.[18] Alpha synchronization (i.e., high alpha power and coherence) is thought to reflect a cortical rest state or "idling" whereas desynchronization (i.e., decreased alpha power and coherence along with increased beta power and coherence) is reflective of task processing.[19] Thus, increased fronto-central alpha synchronization during TM

may reflect decreased motor and executive function processing.[18] Sahaja yoga meditation, involving internalized attention and the emotionally positive experience of bliss also leads to increased fronto-central midline theta power, coherence and synchronization.[20] Coherence "center of gravity" appeared to be in the left frontal region and related to the positive emotional experiences.

Neuroimaging studies of concentration meditation employing functional magnetic resonance imaging fMRI, SPECT and PET have also been undertaken in recent years. In a PET study of yogic meditators (repeating sentences or concentrating on a "central point of power"), ratios of glucose metabolism were shown to increase in anterior to posterior brain regions.[21] Inter-subject variability was decreased in the meditation versus control conditions, especially for posterior regions. The authors concluded that cerebral metabolic activity may be "synchronized" during meditation. Focal alterations in metabolism within either hemisphere were not observed. Increases in frontal and occipital regions were reported in a study of regional cerebral blood flow (rCBF) during TM meditation.[22]

In a fMRI study of Kundalini meditation which employed observation of the breath in combination with and mantra recitation, increased activation was reported in the following brain structures: putamen, midbrain, pre-genual anterior cingulate cortex, and hippocampal/parahippocampal formation.[23] Moreover, when comparing early versus late periods of the meditation sessions, multiple foci of activation were reported within prefrontal, parietal, and temporal regions as well as pre- and post-central gyri, hippocampal/parahippocampal formations, amygdala, hypothalamus, and septum. Lazar *et al.* concluded that neural structures involved in attention and arousal/autonomic control were activated during this form of meditation.[23]

Mindfulness (Open Awareness):[24] Mindfulness involves an awareness of the stream of consciousness at a stage prior to our normal tendency to conceptualize or identify it. Rather than having a single focus as in concentrative meditation, the focus of this technique is the experience of all objects that arise in consciousness such as sounds, physical sensations, or visual stimuli among other things. Forms of Zazen and Theravadin Buddhist Vipassana meditations employ mindfulness. The applications and benefits of this form of meditation have been studied rather extensively.[25] EEG activity during mindfulness

meditation is characterized by increased slow waves (i.e., delta and theta) and relatively fast alpha (i.e., C3, C4, Cz, T4, T5, P3, P4 and Pz) and beta1 (i.e., C3, C4, Cz, T4, T5, T6, P3, P4, Pz, F4 and Fp1) waves compared to concentration meditation.[26] Concentrative meditation evidenced greater beta2 activity at selected sites (i.e., Fp2, O1 and O2) while mindfulness produced greater beta2 amplitude at Fp1, F3, F4, T4 and T5. Differences were also evidenced in frontal and posterior delta, frontal theta, central and posterior alpha, frontal, central and posterior beta1, and frontal, temporal and posterior beta2. As such, the authors concluded that the two meditation techniques produced different EEG states. These authors described mindfulness meditation as a calm and relaxed mind though awake and alert.

Analytical Meditation (Contemplation): This method, also known as special insight, employs the focused mind developed through the practice of concentration meditation for the purpose of analyzing an object. The latter object can be a scriptural passage or concept such as the preciousness of human life or the nature of emptiness (Skt., sunyata). Actually, concentrative and insight meditation are meant to be practiced in tandem, typically starting with the former.[27] On the other hand, analytical meditation is thought to form the primary basis of spiritual practice.[1] That is, this practice helps us infuse and employ these values, views, insights and so forth into our daily life thereby helping us to actually change our behavior, and become a better person.

Guided Imagery/Visualization: While not truly a separate form of meditation, advanced Indo-Tibetan Buddhist meditation practices, specifically those of the vajrayana or tantric path, rely heavily upon these techniques. Nevertheless, concentration meditation forms the basis for visualizing elaborate and complex forms (e.g., deities and their habitats or mandalas as well as subtle body "anatomy" such as the chakras and channels) and processes (e.g., dissolution through the eight stages of death). These advanced meditations employ very detailed "guided scripts" or liturgies (Skt., sadhanas) that the practitioner follows. Moreover, the internal structure of these meditations, though somewhat flexible, have fixed and required components and sequence of processes. In the case of highest yoga tantric meditations, such as the method employed in this study, practice without an initiation or empowerment from a qualified lineage master is prohibited. In fact, additional teachings from a qualified teacher are necessary to fully understand the layers of symbolism and meaning contained within these meditation manuals.[28]

Benson and his colleagues report EEG findings of several monks engaged in the practice of gTum-mo, a method for generating "inner heat" (also translated as "fierce woman").[29-31] While this technique relies heavily on visualization, it also employs physical manipulation of the breath. As such, comparison of this particular meditation practice to methods employing only visualization may yield slightly different results. Benson's group compared "stabilization" meditation (presumably concentration meditation) with the gTum-mo practice. During gTum-mo practice, the brain waves of two of the three monks were consistent with previous studies of "deep," "transcendent" or "samadhi" states of meditation.[18,32,33] That is, there was increased fast activity or beta waves. Moreover, marked asymmetry was noted, with greater alpha and beta power in the right and left hemisphere, respectively.

Newberg *et al.* conducted SPECT scans of eight Tibetan Buddhist meditators engaged in advanced visualization techniques.[34] The meditation process started with concentration on a visualized image leading to a "sense of absorption into the visualized image." Although not specifically stated, it was likely a highest yoga tantra practice in which the meditator visualizes him or herself arising as the deity or enlightened being. Newberg *et al.* indicate that this meditation practice was accompanied by a clarity of thought and a loss of the usual sense of space and time.[34] Results revealed increased regional cerebral blood flow (rCBF) in the cingulate gyrus, inferior and orbital frontal cortex, dorsolateral prefrontal cortex, and thalamus. In addition, increased activity in the left prefrontal cortex correlated significantly with decreased activity in the left superior parietal lobe. The authors had hypothesized decreased activity in parietal areas associated with the subjective experience of space and time. Contrary to their expectations, Newberg *et al.* reported an increase rather than decrease in activity in the sensorimotor areas.[34] The increases in frontal activity as reported by Newberg and colleagues are consistent with the increases in fronto-central alpha and theta activity identified in EEG studies of meditation.[34]

In a recent study of EEG gamma activity (35 - 44 Hz) during meditation by a western Buddhist monk of the Tibetan Karma Kagyü lineage, Lehmann and colleagues analyzed the results using Low Resolution Electromagnetic Tomography (LORETA).[35] The authors were particularly interested in studying self-induced changes in consciousness following different meditation conditions:

(1) visualizing Buddha in front (this corresponds to our Eyes Closed Visualization condition described below); (2) visualizing Buddha above one's head; (3) visualization of the "100 syllable mantra" including mantra repetition; (4) visualizing one dissolving into a boundless unity (i.e., Skt., sunyata or emptiness); (5) visualizing one reconstituting from that boundless state (methods 4 and 5 correspond to our Eyes Closed Visualization of Self-Generation meditation described below).

Results for the gamma activity revealed a right posterior (inferior) area for the visualization meditation, a left central (medial) area for the verbalizing meditation, and a right anterior (superior) area for the self-dissolving meditation. The self-reconstitution meditation showed a combination of results similar to but with stronger effect than the other meditation types. The latter is not surprising given that it utilizes visualization, verbalization and changes in self perception. Lehmann and colleagues concluded that the meditations did in fact represent distinct brain states.[35] That is, the visualization and verbalization tasks produced changes consistent with known functional brain anatomy while the dissolution and reconstitution meditations described novel data. The dissolving meditation activated superior and anterior regions such as the right superior frontal gyrus. According to Lehmann *et al.*, right prefrontal areas have been related to self-recognition and self-evaluation and psychiatric depersonalization or detachment experiences.[35-40] In fact, Simeon reported that depersonalization was related to decreased metabolic activity in the right middle and superior temporal gyri (areas 21 and 22).[40]

Highest Yoga Tantra Meditation

Indo-Tibetan Buddhist tantric meditation employs powerful methods for emotional and spiritual development.[41] These guided meditations or sadhanas, employ a series of scripted visualizations containing many layers of symbolism. Thus, portions of the text and/or objects being visualized are often a form of "short-hand" that cue the practitioner into recalling more elaborate text, prayers, feeling states, and/or visualizations in order to engender a deeper or fuller experience of the process. Codification of texts also provide a level of security and secrecy of the material and, as such, receiving teachings from a spiritual master qualified in a particular practice is essential for correct practice and development.

Psychological Process: In part, these structured meditation exercises focus on the development of positive qualities and energies embodied by enlightened beings and Buddhas through the process of projection and re-collection.[42] Jung considered this process of projection and re-collection to play a major role in personal growth or individuation. Simply stated, the process involves making conscious those projected thoughts, feelings and energies within our unconscious and re-integrating them in order to engender wholeness. The typical process of projection involves a tendency to project unwanted feelings, qualities and so forth into the unconscious or shadow. Sometimes, this material represents feelings we believe we dare not acknowledge or own. In other instances, we may project positive feelings and qualities into this dark, secret place because we feel unworthy to own or express them. There are numerous other reasons or rationales for projecting such "untouchable" material into one's shadow. In any event, the shadow represents unconscious material, a repository of sorts for "the good, the bad, and the ugly."

In their infinite wisdom, the progenitors of these Indo-Tibetan Buddhist practices have taken this normal neurotic process of projection and turned it upon its head.[43] That is, one visualizes a deity or enlightened being, "projects" or focuses on their positive qualities, and then re-collects those energies back into oneself. The process of re-collection differs according to the level of tantric meditation practice one is engaged in. For example, in the lower tantras, one visualizes these qualities coming back to oneself in a flow of healing nectar, white light or energy.[41] In highest yoga tantric practice, a properly initiated practitioner dissolves into emptiness by visualizing traversal of the eight stages of the death process and then arises out of emptiness as the deity in light-body form, replete with all the deity's qualities. In this state, the deity's world or environment (i.e., mandala) and its inhabitants are no longer of the relative or mundane level of existence. Rather, the environment is divine and all inhabitants are enlightened beings in similar form. In this manner, such meditations become a self-healing practice aimed at awakening and developing specific emotional and spiritual qualities and/or energies. Meditation deities (Skt., yidam) are chosen to personify specific qualities and energies. For example, White Tara, one of the many female Buddhas or enlightened beings, represents the culmination of all of the love and compassion of all the enlightened beings. Meditation on White Tara is useful for longevity of life and especially healing and self-healing. Other deities can be utilized to

represent other qualities such as overcoming obstacles, attachment, anger and so forth.

By describing portions of these meditation practices as employing projection and re-collection, we do not mean to trivialize the process. That is, we do not intend to pigeon-hole these very powerful sacred practices into some western or reductionistic framework. Certainly for Jung, projection and re-collection referred to a process involving parts of the self (with a small "s"), and that is true here as well. More importantly, we are also referring to a process of projection and re-collection of Self spelled with a big "S." Thus, these liturgies provide a process of re-collecting the divine, our inherent Buddha nature (Skt., tathatagarba), that seed of the divine in each of us that yearns to be awakened and developed.[44]

Phenomenological Task Analysis: This form of elaborate scripted or guided meditation entails a complex sequences of varied practices resting upon numerous cognitive and spiritual processes. First and foremost, the practice rests upon a foundation of concentration meditation involving sustained attention and the ability to ignore external stimuli. Sustained attention or concentration to the task at hand is essential as well as the ability to repeat mantras and hold a visual image with clarity. As the practice involves a written guide accompanied by specific visualizations, both verbal processing and visual imagery is involved. The former entails both the development of clarity of the object visualized as well as the mental manipulation of images as visual forms are manifested and/or transformed (e.g., think of the mental rotation of objects as being a very simplistic example of this skill). The latter involves reading and reading comprehension (for those who have not memorized the text) as well as speech as one verbalizes the text. Memory skills, both verbal and visual are required. That is, for many long time practitioners (i.e., monks and nuns), these guided texts or sacred liturgies are recited from memory. The visualizations are also memorized and may be accompanied by specific symbolic hand gestures (Skt., mudras). Given the length of these practices, working memory and sequencing skills are also necessary as is the ability to shift conceptual set. In addition, depending on the specific part or sequence of the practice being engaged, the practitioner will also generate emotional states such as love and compassion, the desire to free all beings from suffering (i.e., Bodhimind), great bliss, and the experience of emptiness (Skt., sunyata). The latter may require,

or at least rest on, higher-order cognitive skills such as abstraction, reasoning and insight. All of these cognitive processes are involved in a meditation "session." Some of the activities occur continuously, others may occur only once, while still others may be repeated several times at different points of the practice. Processes that occur on the subtle body level are beyond the scope of this paper.

HYPOTHESES

Although this study was initially conceived as an exploratory venture, several general hypotheses were derived from the results of previous studies and the phenomenological task analysis. Given that the highest yoga tantric form of meditation rests upon the practice of concentration meditation, similar results are expected. That is, we expect increases in alpha and theta power, particularly in anterior regions as well as an increase in alpha coherence. The frontal activity is expected to be related to activation of the anterior cingulate gyrus. As these meditations contain both recall and "playing through" of verbal scripts and visualizations, both temporal lobes should show increased activity. In fact, the significant use of internal visualization and manipulation of visual imagery should be particularly reflected in right temporal and parietal lobe activation. Emotional or feeling states of love, compassion and bliss may be reflected in right fronto-temporal regions as is the experience of the self.

SUBJECT

For this case study analysis, we recruited a 30-year old, right-handed Tibetan male (AT). AT is a Buddhist ex-monk who lived and trained in India at the Loseling monastery of the Gelukpa sect of Tibetan Buddhism from ages 9 through 17 years. He then studied for another nine years as a monk in Varanasi, India. He received his first highest yoga tantra initiation at age nine from Trijang Rinpoche, junior tutor to His Holiness the Dalai Lama. In addition to receiving additional initiations from Trijang Rinpoche, AT also received several from Ling Rinpoche (senior tutor to the Dalai Lama) as well as directly from the Dalai Lama. AT is fluent in five Asian languages and has taught

Tibetan language in India and Nepal. AT currently resides in the eastern United States and is continuing to improve his mastery of the English language.

METHOD

QEEG Recording: QEEGs were recorded using a Lexicor Neurosearch 24 and V151 software with an appropriate size Electrocap. EEG activity was sampled from 19 scalp electrode sites in the standard International 10-20 montage with reference to ear lobes (monopolar recording) and ground just forward of site Fz.[45] Sampling rate was 128 Hz with 32K gain, high-pass filter on. Electrode skin impedances were maintained at or below 3K. AT was seated upright and asked to remain still.

Conditions: Several conditions were recorded: "Baseline Eyes Open," "Baseline Eyes Closed (Baseline)" (80 seconds), "Eyes Open Visualization," "Eyes Closed Visualization (Visualization)" (88 seconds), "Eyes Closed Visualization of Self-Generation (Self-Generation)" (108 seconds). For the activation conditions, "Eyes Open Visualization" involves the subject focusing on a printed image of a Buddhist tantric deity or enlightened being, in this case, four-armed Mahakala, a protector deity of the Gelukpa sect of Tibetan Buddhism. The "Eyes Closed Visualization" entails the subject visualizing the same deity as appearing directly in front of oneself. Finally, AT visualized himself as manifesting or appearing as Mahakala (i.e., "Self- Generation" of the deity).[46] In the standard "Eyes Open" and "Eyes Closed" baseline conditions, AT was instructed not to meditate. In this analysis, we will only report the results of the Eyes Closed conditions.

QEEG Data Analysis: EEG wave forms for all conditions were inspected off-line and eye movement, eye blinks, muscle and other artifacts eliminated by an experienced QEEG technician (R.D.). All samples contained at minimal 80 seconds of artifact-free EEG activity. Data analysis involved the use of several different software packages.

In the first instance, data analysis was completed using NeuroRep Version 4.0 software which incorporates the Adult QEEG Reference Database and is also compatible with the Thatcher Lifespan EEG Reference Database.[47,48]

Frequency bands used were: *delta* (0.5 - 3.5 Hz), *theta* (3.5 - 7.0 Hz), *alpha* (7.0 - 13.0 Hz), and *beta* (13.0 - 22.0 Hz). Measures of coherence, phase, and amplitude asymmetry were computed in four frequency bands among all combinations of left and right intra-hemispheric sites and between homologous inter-hemispheric sites. Coherence is considered to be the amount of shared activity between 2 regions, while phase is the timing of shared rhythms between 2 regions. Asymmetry can be viewed as the power balance between two sites and relative power represents the relative distribution of activity across bands. Absolute and relative power in each of the same frequency bands at each of 19 electrode sites was calculated. Raw scores were transformed into *z*-scores and printed along with indications of which scores differed significantly from the reference database norms for the subject's age, gender and handedness. Specifically, a difference was considered significant if the probability of it occurring by chance was equal to or less than two and one-half times in 100 (i.e., $p < 0.025$, two-tailed test of significance).

In addition to analysis of the individual conditions, NeuroRep allows for the comparison of two conditions allowing for a subtraction type analysis. In this case, we performed two such analyses: (1) Visualization minus Baseline and (2) Self-Generation minus Visualization.

In the second instance, we employed the NeuroGuide (version 1.5.0) software package.[49,50] For each condition, this program provides the reliability of the sample at each individual electrode site as well as an averaged measure of reliability across all 19 sites. Frequency bands used were: *delta* (1.0 - 3.5 Hz), theta (4.0 - 7.5 Hz), *alpha* (8.0 - 12.0 Hz), and *beta* (12.5 - 25 Hz), *gamma* (25.0 - 30.0 Hz), *smr* (12.0 - 15.0 Hz), *beta1* (15.0 - 17.5 Hz), and *beta2* (18.0 - 25.0 Hz). Raw and *z*-transformed scores for absolute power, relative power and power ratios were obtained for the latter broad band frequency ranges. Single band analysis from 1 to 30 Hz for raw and *z*-transformed data was provided for absolute and relative power. Raw and *z*-transformed results were also output for amplitude asymmetry, coherence, phase lag, and power ratios. All *z*-transformations were computed using the NeuroGuide EEG norms.[50]

Finally, we also subjected the data to analysis using low-resolution electromagnetic tomography (LORETA) employing the LORETA-KEY and EureKa3!

software packages.[51-56] This technique allows for localizing the source of electrical activity within the three-dimensional space of the brain using a generic MRI image as a visual reference. The use of cross-registration techniques allows the EEG measurements made from any human head to be adjusted to the geometry of the Talairach reference brain.[57] Moreover, this method provides high time resolution information on the three-dimensional distribution of electrical activity within the brain. Frequency bands used were: *delta* (0.5 - 4.0 Hz), *theta* (4.0 - 8.0 Hz), *alpha* (8.0 - 13.0 Hz), and *beta1* (13.0 - 18.0 Hz), *beta2* (18.0 - 22.0 Hz).

LORETA Statistical Analysis: We investigated the absolute (LORETA) average power in the specified frequency bands. Data points for each broad frequency band consisted of 1,024 samples (i.e., 8 seconds) EEG epochs for each condition. The number of epochs available for analysis for the Baseline, Visualization and Self-Generation conditions were 10, 10, and 13, respectively. Fourier cross-spectral matrices were derived for the available epochs and LORETA images for each band-pass were computed. Data were then pre-processed in two ways. LORETA images were normalized to allow for analysis of changes through the subtraction process in the spatial distribution of brain activity. For statistical analysis purposes, the current density power was subjected to log transformation in order to approximate gaussianity of the frequency distribution of the data in all conditions. Conditions were then compared by subtracting out one condition from another, with the results showing what differences were statistically significant. In the first analysis, we compared the Baseline and the Visualization conditions while in the second analysis, we compared the Visualization and the Self-Generation conditions.

LORETA activity for all available epochs was treated as multiple observations. All images were statistically tested for distribution differences using voxel-by-voxel *t*-statistics with non-parametric correction for multiple observations, thus allowing for control of the rate of false positives.[58,59] Multiple comparisons of all voxels for which the null hypothesis is rejected (i.e., declared significant) were controlled with family-wise error (FWE) at 0.01. Such a control ensures that the probability to erroneously reject even a single null hypothesis is 0.01. Assumptions of equal variance and symmetricity were both satisfied.

Analysis was carried out on absolute average power using *t*-max combination of unpaired *t*-tests (for equal variances); all tests were two-tailed and based on

5,000 random data permutations. The three-dimensional distribution of the selected frequency band generators were analyzed using LORETA in the version that yields current density values of 2,394 voxels (spatial resolution: 7 mm) in the cortical areas as defined by the digitized Talairach Human Brain Probability Atlas (Brain Imaging Centre, Montreal Neurological Institute; MNI305).[51,52] The voxel locations of maximally significant differences were identified in terms of Broadman areas in the Talairach atlas using the "Talairach Daemon" software program.[57,60]

RESULTS

Table I shows the relative power and absolute magnitude raw scores for the EEG frequency bands by electrode site for the Eyes Closed Baseline and two meditation conditions; data were generated with the NeuroRep software package. For each condition, we used the NeuroGuide program to assess the individual reliability across all 19 electrode sites. Reliability estimates averaged 0.97 (range = 0.95 to 1.00), 0.98 (range = 0.93 to 1.0) and 0.97 (range = 0.96 to 0.99) for the Baseline, Visualization and Self-Generation conditions, respectively.

Eyes Closed Baseline Condition

Figure 1 presents the absolute power in major broad frequency bands for all three conditions; data were generated by the NeuroGuide software program. In the baseline condition, absolute delta band power showed an increase centrally at Cz - Pz with decreases in frontal and bilateral temporal areas. For theta, there was an increase in activity at Cz and surrounding areas (more so than delta levels), including some increase in the left occipital area (i.e., at O1). Alpha absolute power was increased in the occipital regions, though slightly more so in the left hemisphere. For the beta band, there were increases in power in both temporal regions (i.e., T3 and T4). The same pattern was evident for the gamma range with the exception of activity in the right temporal area spreading centrally (i.e., T4 and C4). When compared to the normative age and gender based sample, there were no significant differences in coherence. However, there were some instances of decreased phase lag mostly in the alpha

Table 1

Raw Score Spectrum-Relative Power and Absolute Magnitude Frequency Band x Electrode Site for the Eyes Closed Baseline and Meditation Conditions.

Baseline | Visualization | Self-Generation

Relative Power (%):

	DELTA	THETA	ALPHA	BETA
F1	13.39	22.38	23.54	40.68
F2	14.06	22.89	22.95	40.08
F7	12.72	19.44	22.34	45.51
F8	12.60	18.76	21.21	47.44
F3	15.87	24.56	22.20	37.56
F4	14.78	23.36	22.66	39.01
T3	7.15	10.85	14.54	67.36
T4	9.38	12.41	16.36	61.85
C3	18.34	23.59	22.17	35.71
C4	13.83	17.38	19.76	48.03
T5	11.80	17.69	25.84	44.67
T6	17.51	17.84	25.64	39.22
P3	17.58	21.01	28.33	33.07
P4	17.67	19.58	25.45	37.33
O1	11.72	17.10	34.44	36.75
O2	14.95	17.73	30.27	37.04
Fz	18.04	26.05	23.28	34.64
Cz	20.98	24.84	22.96	31.82
Pz	18.90	21.22	28.39	31.48

	DELTA	THETA	ALPHA	BETA
F1	14.53	21.47	27.81	36.19
F2	14.63	22.85	26.54	33.98
F7	13.09	21.30	25.19	40.42
F8	13.43	21.00	24.97	40.60
F3	19.00	24.25	25.87	30.89
F4	17.79	24.99	27.40	29.82
T3	10.52	14.41	19.47	55.60
T4	13.38	16.58	18.86	51.18
C3	23.04	22.01	25.40	29.55
C4	18.02	19.67	24.96	37.35
T5	12.59	18.60	31.35	39.46
T6	18.12	17.40	29.81	34.67
P3	17.70	18.77	38.40	27.12
P4	20.23	17.41	32.42	29.94
O1	11.39	13.58	45.02	30.00
O2	15.70	15.60	37.65	31.05
Fz	19.66	25.93	26.74	27.67
Cz	24.57	22.62	27.57	25.23
Pz	19.83	18.69	38.03	23.26

	DELTA	THETA	ALPHA	BETA
F1	14.47	24.03	27.83	33.67
F2	16.01	24.41	27.13	32.45
F7	13.68	23.25	27.61	35.46
F8	13.29	19.86	25.49	41.24
F3	15.85	25.70	28.90	29.56
F4	15.62	24.39	29.37	30.43
T3	14.33	16.90	22.37	46.40
T4	14.47	18.89	25.69	41.14
C3	20.01	22.33	28.31	29.36
C4	13.48	17.24	24.63	44.65
T5	12.81	18.23	35.48	33.68
T6	17.16	16.85	32.45	33.55
P3	16.24	18.01	41.94	23.81
P4	17.85	17.52	34.32	30.35
O1	10.74	13.55	47.83	27.78
O2	14.85	16.11	38.87	30.06
Fz	18.42	26.91	29.65	27.03
Cz	19.68	24.04	30.19	25.89
Pz	17.88	18.88	40.51	24.98

Absolute Magnitude (uV):

	DELTA	THETA	ALPHA	BETA
F1	0.11	0.14	0.14	0.19
F2	0.11	0.15	0.15	0.19
F7	0.09	0.12	0.12	0.18
F8	0.12	0.14	0.15	0.23
F3	0.12	0.16	0.15	0.19
F4	0.13	0.16	0.16	0.21
T3	0.11	0.14	0.18	0.34
T4	0.12	0.13	0.15	0.30
C3	0.14	0.16	0.15	0.19
C4	0.14	0.16	0.17	0.27
T5	0.14	0.17	0.20	0.27
T6	0.12	0.12	0.15	0.18
P3	0.17	0.18	0.21	0.23
P4	0.15	0.16	0.19	0.22
O1	0.18	0.22	0.31	0.32
O2	0.16	0.17	0.22	0.25
Fz	0.15	0.19	0.18	0.22
Cz	0.19	0.21	0.20	0.24
Pz	0.19	0.20	0.24	0.25

	DELTA	THETA	ALPHA	BETA
F1	0.13	0.18	0.18	0.21
F2	0.14	0.18	0.20	0.22
F7	0.10	0.12	0.14	0.17
F8	0.14	0.18	0.19	0.25
F3	0.15	0.17	0.18	0.20
F4	0.17	0.20	0.20	0.21
T3	0.10	0.12	0.14	0.23
T4	0.14	0.15	0.16	0.27
C3	0.17	0.17	0.18	0.19
C4	0.18	0.18	0.21	0.25
T5	0.15	0.17	0.24	0.27
T6	0.15	0.14	0.19	0.20
P3	0.20	0.20	0.30	0.25
P4	0.20	0.18	0.25	0.24
O1	0.22	0.24	0.43	0.35
O2	0.20	0.20	0.31	0.28
Fz	0.19	0.22	0.22	0.23
Cz	0.25	0.24	0.27	0.25
Pz	0.25	0.23	0.35	0.28

	DELTA	THETA	ALPHA	BETA
F1	0.15	0.20	0.21	0.23
F2	0.17	0.21	0.22	0.25
F7	0.11	0.14	0.15	0.17
F8	0.16	0.19	0.22	0.28
F3	0.15	0.19	0.21	0.21
F4	0.17	0.21	0.23	0.23
T3	0.11	0.12	0.14	0.19
T4	0.13	0.15	0.17	0.22
C3	0.16	0.17	0.19	0.20
C4	0.18	0.20	0.24	0.32
T5	0.16	0.18	0.26	0.28
T6	0.15	0.15	0.20	0.21
P3	0.20	0.20	0.32	0.25
P4	0.19	0.19	0.29	0.24
O1	0.21	0.24	0.44	0.34
O2	0.19	0.20	0.31	0.27
Fz	0.19	0.24	0.25	0.24
Cz	0.23	0.25	0.28	0.26
Pz	0.24	0.23	0.36	0.28

band; these represented anterior- central to posterior connections in both hemispheres (e.g., F3 to T5 and O1 as well as F4 to T6 and O2).

Eyes Closed Visualization Meditation

In the Visualization meditation condition (see Figure 1), delta absolute power showed a strong increase centrally at Cz - Pz. Figure 2 shows delta absolute power in broad- and single-band ranges and corresponding LORETA activity. There were concomitant decreases in delta activity in both temporal lobe areas (i.e., T3 and T4). Both temporal lobes evidenced decreased theta absolute power; only minimal increases in activity were noted centrally.

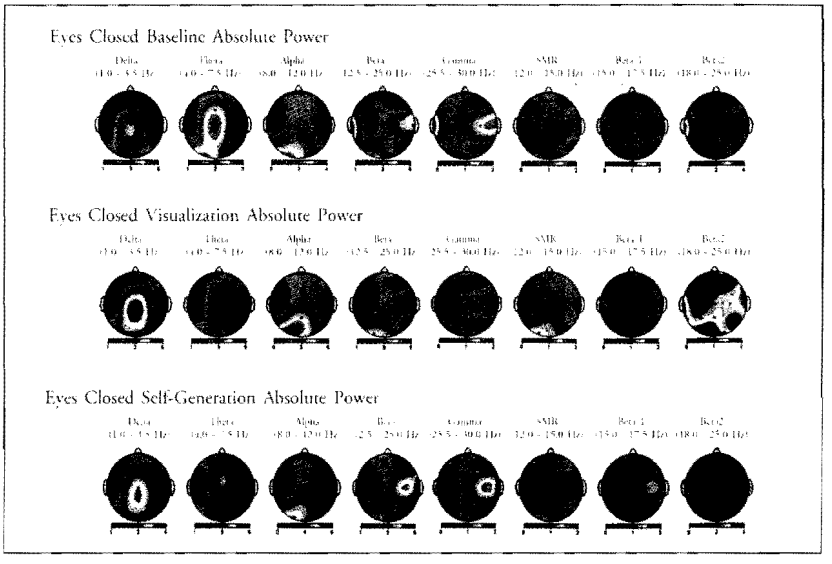

Figure 1. *Broad band absolute power for Baseline, Visualization and Self-Generation meditation conditions.*

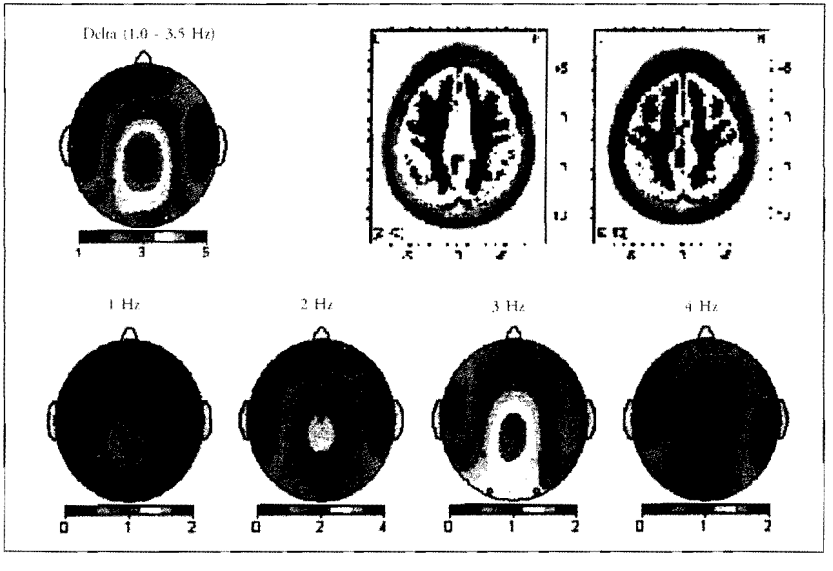

Figure 2. *Visualization condition-increased central delta activity. Broad band delta absolute power (top left). LORETA delta poisson distribution (top right). Single band delta absolute power (bottom)*

The decreased bilateral temporal lobe activity was also evident in the alpha band. Alpha absolute power was clearly increased in the occipital regions (i.e., O1 and O2), although primarily on the left side. For beta absolute power, there were some left frontal-temporal (i.e., F7 and C3) and right frontal (i.e., midway between Fp2 and F8) decreases in activity. Only slight increases in beta activity were evident in the occipital region. However, closer inspection of the beta2 range (i.e., 18.0 - 25.0 Hz) showed increases absolute power in both temporal regions and the occipital region; the latter was not evident for the beta1 band (i.e, 15.0 - 17.5 Hz). There were no outstanding increases or decreases in gamma activity evident. Compared to the NeuroGuide normative database, there were some instances of increased coherence in this condition. For delta, it was centrally in the right hemisphere (i.e., between F4 and T6); in the posterior left hemisphere for theta (i.e, between T3 and O1); and for beta, in the right hemisphere (i.e., between F4 and T6) as well across hemispheres in the posterior regions (i.e., between P3 and P4 as well as O1 and O2). There were no coherence differences for absolute alpha power. Phase lag differences were minimal. There were some lags between prefrontal regions of the two hemispheres; the latter were decreased in delta and increased for alpha and theta activity.

Eyes Closed Self-Generation Meditation

In this meditation condition, which also involves visualization, the results for absolute delta, theta and alpha power were similar in some respect to that in the Visualization condition described above. However, the increases in delta absolute power were slightly attenuated. There was a slight increase in central theta power (i.e., Fz - Cz) and occipital alpha activity was slightly lower. Nevertheless, the overall patterns of activity for the two conditions were quite similar. However, there were demonstrable differences in beta and gamma activity for this condition as compared to the Visualization condition. That is, clear increases in beta and gamma absolute power were evident in the right hemisphere (i.e., C4 region). Decreased beta1 and gamma activity were evident in the anterior (i.e., between Fp2 and F8) and posterior regions (i.e., between T6 and O2) of the right hemisphere. Also, the bi-temporal and occipital increases in beta2 activity evident in the visualization condition were not at all evident in the self-generation condition. For this meditation condition, there

were no significant differences from the NeuroGuide normative database in delta, theta and alpha coherence. There were two instances of increased coherence: right central (i.e., between F4 and T6) and occipital regions (i.e., between O1 and O2). There were minimal instances of decreased phase lag was evident in delta (i.e., F3 and O1), theta (i.e., F8 and P4), alpha (i.e., F8 and T4), and beta (i.e., F3 and T5; F4 and O2; Fp1 and T6). There was increased phase between prefrontal regions (i.e., Fp1 and Fp2) for both alpha and beta absolute power.

Eyes Closed Visualization versus Eyes Closed Baseline Condition

Using the comparison procedure of the NeuroRep program, we were able to subtract out the Baseline condition from the Visualization meditation condition. There were increases in delta absolute amplitude centrally (i.e., Cz - Pz) as well as increases in alpha activity in the occipital region (i.e., O1 and O2 extending to P3 and Pz). The weighted average topographical analysis for the subtraction process was consistent with the latter results. Beta absolute amplitude (i.e., 13 to 22 Hz) was decreased in the temporal regions (i.e., T3 and T4) using the NeuroRep program. However, the latter finding is not consistent with the rather strong increase in beta2 (i.e., 18 to 25 Hz) observed in both temporal areas for the absolute power using the NeuroGuide program (see the Visualization condition shown in Figure 1).

Eyes Closed Self-Generation versus Eyes Closed Visualization Condition

A similar subtraction procedure was used to compare the Visualization and Self-Generation meditation conditions, again using the NeuroRep software program. Slight decreases in central delta and posterior alpha absolute amplitude were evidenced and are consistent with a visual inspection of the individual conditions shown in Figure 1. Also evident in this analysis was the increased beta amplitude in the central region of the right hemisphere (i.e., C4). For the weighted average analysis of this subtraction procedure, increases in activity were primarily evident at 24 to 26 Hz at C4.

LORETA Analysis of Baseline and Meditation Condition Comparisons

Statistical analyses of differences in the absolute power across separate EEG frequency bands were computed for the two subtraction conditions using LORETA.[51-56] The first analysis compared the Baseline and Visualization conditions. The second analysis compared the Visualization and Self-Generation meditation conditions. This analysis allowed the determination of significantly different ($p < 0.01$) brain activity or current density distribution in three-dimensional intra-cerebral space. Table II shows the number of significant voxels for each EEG frequency for the two comparison conditions as well as corrected *t*-value thresholds.[58,59]

Baseline versus Visualization Conditions: Tables III thru VII identify the brain areas of increased and decreased activity by hemisphere, lobe, location and Broadman area; areas are separated according to increased or decreased activity. Figures 3 thru 7 show the corresponding visual location of increased and decreased broad band activity between the two conditions using a generic

Table II
Absolute LORETA Average Power: Number of Significant Voxels for each EEG Frequency for the Two Comparisons and Their Corrected t-value Thresholds.*

EEG Frequency	Number of Significant Voxels	Threshold *t*-values
Eyes Closed Baseline vs. Eyes Closed Visualization		
Delta	0	—
Theta	0	—
Alpha	316	4.89*
Beta1	0	—
Beta2	0	—
Eyes Closed Visualization vs. Eyes Closed Visualization of Self-Generation		
Delta	0	—
Theta	0	—
Alpha	0	—
Beta1	121	4.76*
Beta2	365	4.67*

* $p < 0.01$, two tailed.[58,59]

MRI slice map for reference. Areas of increased and decreased activity are shown in black and grey, respectively.

For the delta band absolute power (see Table III and Figure 3), there was increased activity in the frontal areas, bilaterally. Delta activity spread to temporal areas in the left hemisphere in more superior regions. On the other hand, delta activity decreased in posterior regions, although more so in the right hemisphere.

For theta (see Table IV and Figure 4), there was increased activity in limbic regions, particularly the posterior cingulate and cingulate gyri. Decreased activity was evident in bilateral temporal areas, superior frontal gyrus in both

Table III

LORETA Delta Absolute Power: Areas of Increased and Decreased Activity Between Baseline Versus Visualization Meditation Conditions

Hemisphere	Lobe	Location	Broadman Area
Increased Activity			
Left	Frontal	Precentral Gyrus	4
Right	Frontal	Inferior Frontal Gyrus	44
Right	Sub-lobar	Insula	13
Right	Frontal	Superior Frontal Gyrus	6, 8, 10
Left	Frontal	Medial Frontal Gyrus	25
Left	Frontal	Inferior Frontal Gyrus	47
Right	Frontal	Middle Frontal Gyrus	10
Left	Frontal	Superior Frontal Gyrus	8, 9
Left	Limbic	Uncus	38
Left	Temporal	Superior Temporal Gyrus	38
Left	—	Claustrum	—
Left	Sub-lobar	Insula	13
Decreased Activity			
Right	Frontal	Middle Frontal Gyrus	9
Right	Frontal	Superior Frontal Gyrus	8
Left	Parietal	Superior Parietal Lobule	7
Left	Parietal	Precuneus	7
Right	Parietal	Precuneus	7
Right	Temporal	Middle Temporal Gyrus	21
Right	Parietal	Postcentral Gyrus	1, 3
Right	Parietal	Superior Parietal Lobule	7

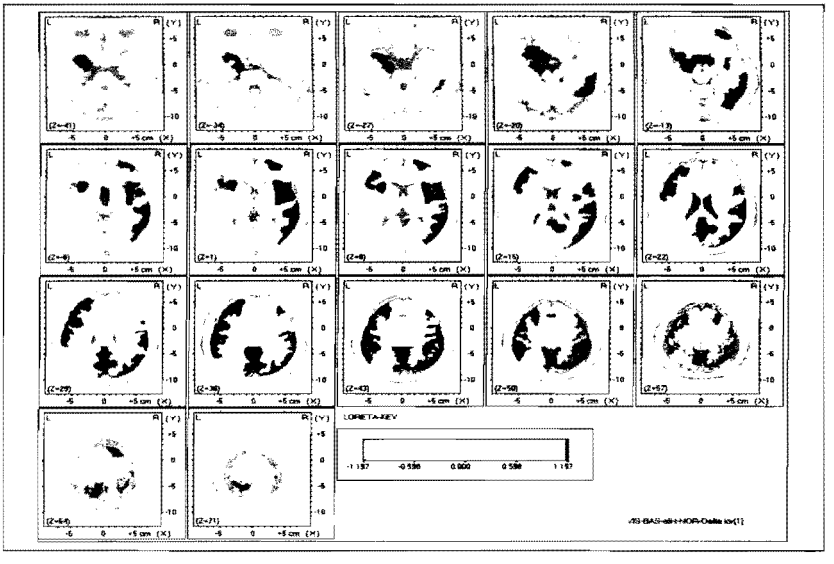

Figure 3. *LORETA delta absolute average power: areas of increased and decreased activity between Baseline and Visualization meditation conditions.*

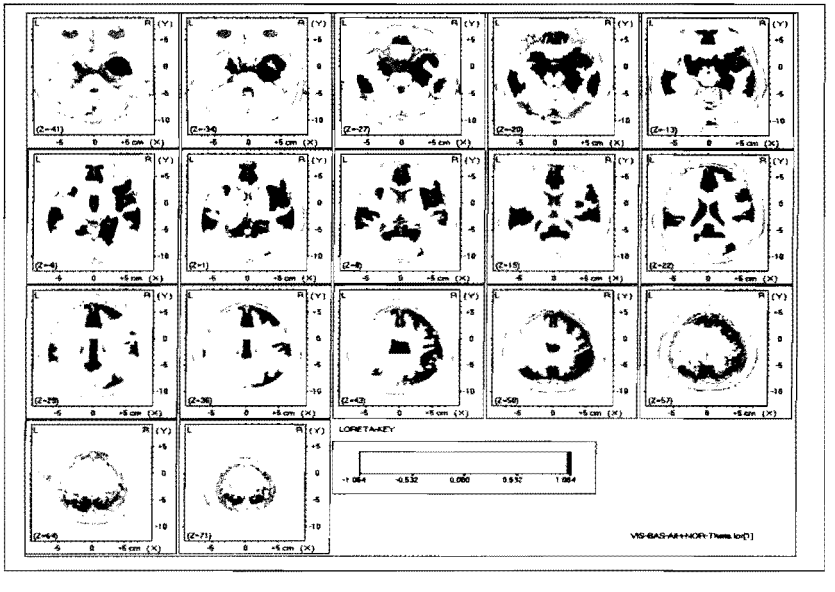

Figure 4. *LORETA theta absolute average power: areas of increased and decreased activity between Baseline and Visualization meditation conditions.*

Table IV

LORETA Theta Absolute Power: Areas of Increased and Decreased Activity Between Baseline Versus Visualization Meditation Conditions

Hemisphere	Lobe	Location	Broadman Area
Increased Activity			
Right	Anterior	Culmen	—
Right	Limbic	Posterior Cingulate Gyrus	23
Right	Limbic	Parahippocampal Gyrus	—
Right	Frontal	Inferior Frontal Gyrus	44
Left	Sub-lobar	Extra-nuclear	—
Right	Sub-lobar	Extra-nuclear	—
Right	Sub-lobar	Insula	13
Left	Limbic	Cingulate Gyrus	23
Right	Limbic	Cingulate Gyrus	23
Left	Limbic	Posterior Cingulate Gyrus	—
Left	Anterior	Culmen	—
Left	—	Insula	13
Left	Frontal	Sub-gyral	—
Decreased Activity			
Right	Occipital	Middle Occipital Gyrus	—
Left	Frontal	Superior Frontal Gyrus	—
Right	Frontal	Superior Frontal Gyrus	8
Right	Frontal	Precentral Gyrus	—
Right	Parietal	Postcentral Gyrus	3
Right	Frontal	Middle Frontal Gyrus	8
Left	—	Superior Temporal Gyrus	—
Right	Parietal	Superior Parietal Lobule	—
Right	Parietal	Precuneus	—

hemispheres, and in right posterior regions. On the other hand, alpha activity was increased in limbic areas bilaterally and occipital regions, particularly in the left hemisphere (see Table V and Figure 5). Areas included the cingulate and posterior cingulate as well as the superior temporal gyrus. By contrast, decreased alpha activity was prevalent in parietal and frontal regions, bilaterally.

There was also increased beta1 activity in the posterior regions similar to that of alpha (see Table VI and Figure 6). However, beta1 appeared to be more symmetrically spread across both hemispheres in occipital and parietal regions. Decreased beta1 activity was evident in the left inferior and superior temporal

Table V

LORETA Alpha Absolute Power: Areas of Increased and Decreased Activity Between Baseline Versus Visualization Meditation Conditions

Hemisphere	Lobe	Location	Broadman Area
Increased Activity			
Left	Temporal	Superior Temporal Gyrus	39
Right	Limbic	Posterior Cingulate Gyrus	31
Left	Limbic	Cingulate Gyrus	31
Right	Limbic	Cingulate Gyrus	31
Left	Limbic	Posterior Cingulate Gyrus	29, 31
Right	Occipital	Precuneus	31
Decreased Activity			
Left	Temporal	Fusiform Gyrus	20
Left	Sub-lobar	Insula	13
Left	Parietal	Postcentral Gyrus	1
Left	Frontal	Middle Frontal Gyrus	10
Left	Frontal	Superior Frontal Gyrus	8, 10
Left	Frontal	Precentral Gyrus	6
Right	Temporal	Inferior Temporal Gyrus	20
Right	Frontal	Precentral Gyrus	6
Right	Frontal	Middle Frontal Gyrus	8
Right	Frontal	Superior Frontal Gyrus	10

regions. Differential activation patterns for beta2 activity were more striking (see Table VII and Figure 7). That is, major portions of the right hemisphere and the bilateral limbic region evidenced increased activity while left hemisphere regions evidenced decreased beta2 activity.

Visualization versus Self-Generation Conditions: Tables VIII thru XII identify the brain areas of increased and decreased activity by hemisphere, lobe, location and Broadman area. Figures 8 thru 12 show visual representations of these regions on the basis of this subtraction procedure between the Visualization and Self-Generation meditation conditions. Areas of increased and decreased activity are shown in black and grey, respectively.

In comparing the Visualization and Self-Generation meditation conditions, delta activity was somewhat attenuated in the central areas in the latter case

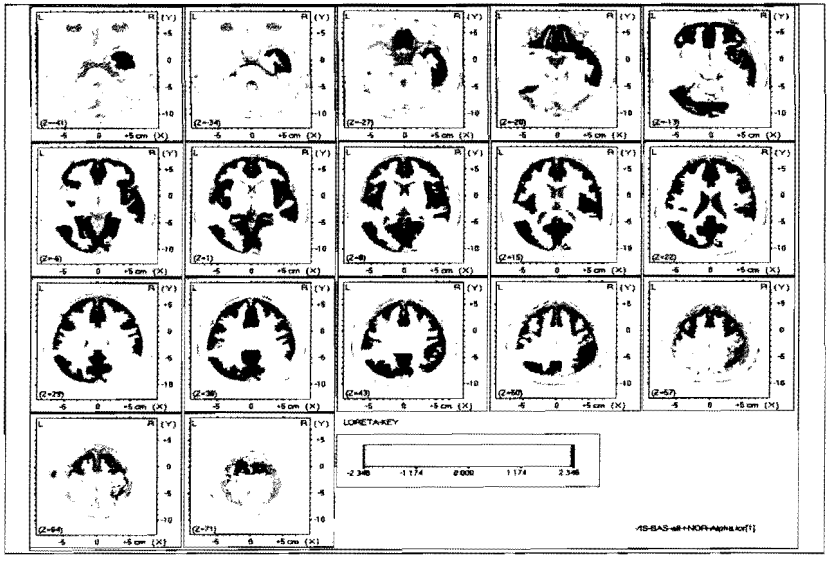

Figure 5. *LORETA alpha absolute average power: areas of increased and decreased activity between Baseline and Visualization meditation conditions.*

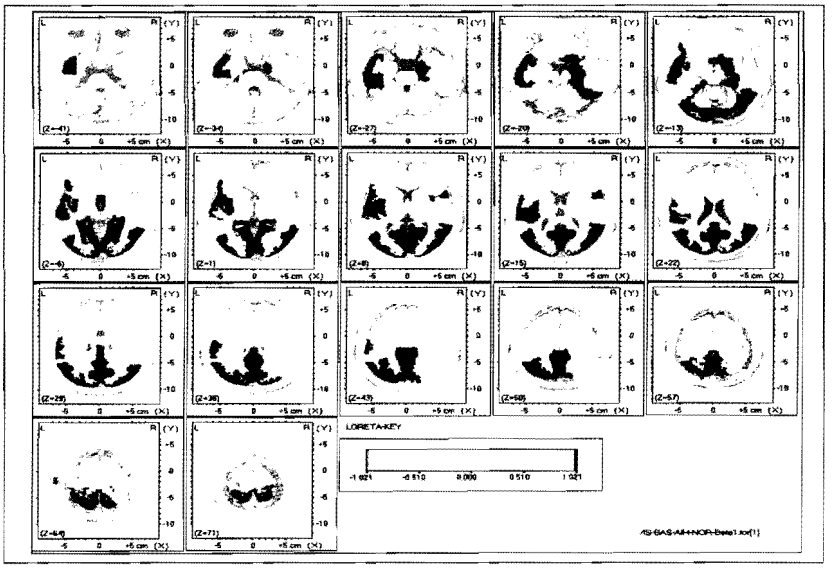

Figure 6. *LORETA Beta1 absolute average power: areas of increased and decreased activity between Baseline and Visualization meditation conditions.*

Table VI

LORETA Beta1 Absolute Power: Areas of Increased and Decreased Activity Between Baseline Versus Visualization Meditation Conditions

Hemisphere	Lobe	Location	Broadman Area
Increased Activity			
Right	Parietal	Precuneus	7
Right	Occipital	Cuneus	19
Right	Occipital	Inferior Occipital Gyrus	18
Right	Limbic	Parahippocampal Gyrus	19, 28, 30, 35
Left	Parietal	Angular Gyrus	39
Left	Parietal	Inferior Parietal Lobule	40
Left	Parietal	Precuneus	7
Right	—	Middle Temporal Gyrus	37
Right	Parietal	Postcentral Gyrus	7
Right	Brainstem	Mammillary Body	—
Left	Occipital	Fusiform Gyrus	19
Right	Frontal	Inferior Frontal Gyrus	44
Right	Sub-lobar	Insula	13
Decreased Activity			
Left	—	Inferior Frontal Gyrus	45, 47
Left	Parietal	Inferior Parietal Lobule	40
Left	Sub-lobar	Insula	13
Left	—	Claustrum	—
Left	Temporal	Fusiform Gyrus	20

(see Table VIII and Figure 8). Increased delta was evident bilaterally in the anterior cingulate and medial frontal areas, as well as in posterior regions. There were some focal areas of decreased delta activity in the more superior frontal regions (i.e., dorsolateral) and in the left parahippocampal area.

Theta absolute power evidenced increases in anterior cingulate, frontal, limbic, and temporal areas (see Table IX and Figure 9). There was also an increase in theta activity in parietal regions of the right hemisphere. On the contrary, decreased theta activity was evident in right frontal and left posterior regions. Alpha activity increased in several regions including the anterior cingulate bilaterally and right frontal, temporal and posterior regions (see Table 10 and Figure 10). Decreased alpha was evidenced in left, and to a lesser degree, right temporal areas.

Table VII

LORETA Beta2 Absolute Power: Areas of Increased and Decreased Activity Between Baseline Versus Visualization Meditation Conditions

Hemisphere	Lobe	Location	Broadman Area
Increased Activity			
Right	Temporal	Middle Temporal Gyrus	21
Right	Temporal	Fusiform Gyrus	20
Right	Frontal	Inferior Frontal Gyrus	47
Right	Occipital	Cuneus	19
Right	Limbic	Posterior Cingulate Gyrus	31
Right	—	Parahippocampal Gyrus	30
Right	Occipital	Precuneus	31
Right	Limbic	Cingulate Gyrus	24
Right	Frontal	Superior Frontal Gyrus	10
Left	Limbic	Anterior Cingulate Gyrus	24
Left	Limbic	Cingulate Gyrus	24 ,32
Right	Limbic	Anterior Cingulate Gyrus	24
Left	Limbic	Parahippocampal Gyrus	19, 37
Right	Brainstem	Mammillary Body	—
Left	Parietal	Inferior Parietal Lobule	40
Decreased Activity			
Left	Frontal	Inferior Frontal Gyrus	47
Left	Frontal	Precentral Gyrus	6
Left	Temporal	Supramarginal Gyrus	40

For beta1 activity, the Self-Generation condition produced increased right-sided activity (see Table XI and Figure 11), particularly in frontal, parietal and temporal regions. Decreased beta1 was generally more posterior, and primarily left-sided. Nevertheless, there were isolated areas of decreased beta1 activity in the right temporal area. For beta2, there was increased activation in frontal, limbic and parietal areas in both hemispheres (see Table XII and Figure 12). Left hemisphere activation involved temporal and parietal regions as well as the orbital frontal area. Decreased beta2 activity seemed to be limited primarily to the left and right temporal regions.

Statistically Significant Differences Between Conditions: For the Baseline versus Visualization condition, significantly increased alpha activity ($p < 0.01$)

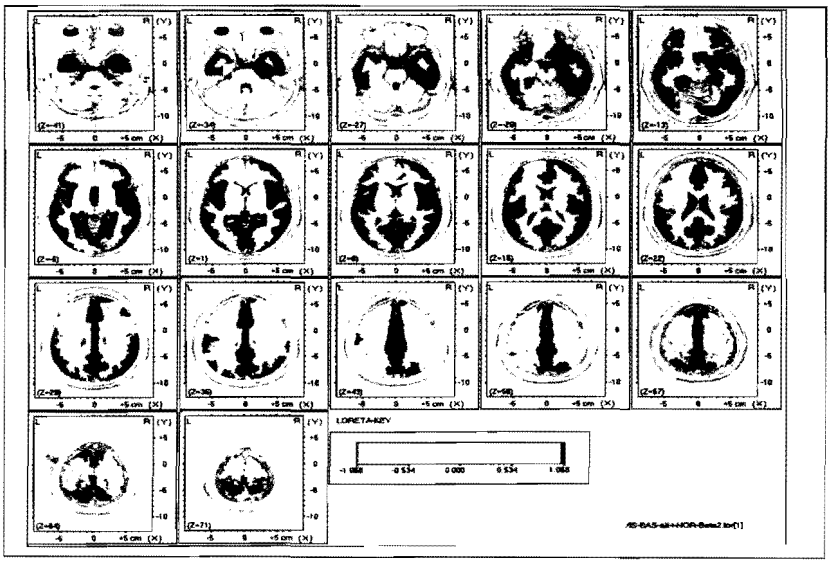

Figure 7. *LORETA beta2 absolute average power: areas of increased and decreased activity between Baseline and Visualization meditation conditions.*

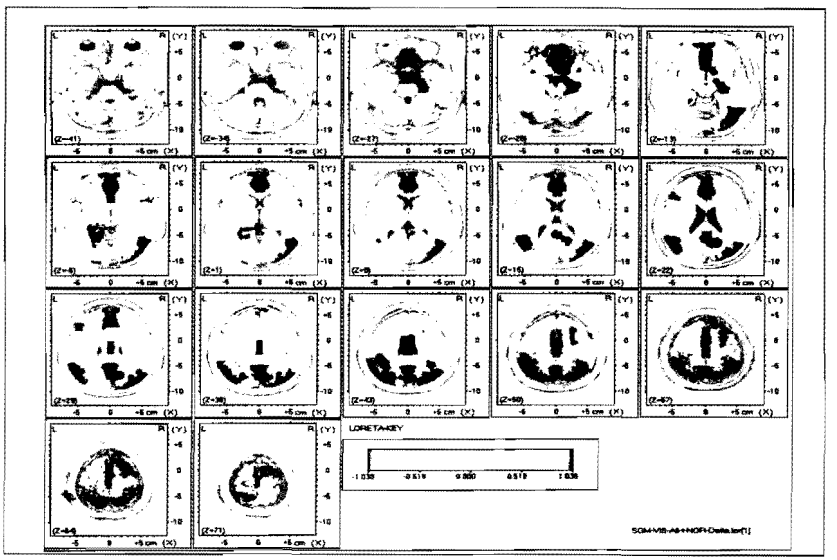

Figure 8. *LORETA delta absolute average power: areas of increased and decreased activity between Visualization and Self-Generation meditation conditions.*

Table VIII

LORETA Delta Absolute Power: Areas of Increased and Decreased Activity Between Visualization and Self-Generation Meditation Conditions

Hemisphere	Lobe	Location	Broadman Area
Increased Activity			
Right	Parietal	Precuneus	7
Left	Parietal	Superior Parietal Lobule	7
Right	Limbic	Anterior Cingulate Gyrus	32
Right	Frontal	Medial Frontal Gyrus	9, 10
Left	Frontal	Medial Frontal Gyrus	9
Left	Limbic	Anterior Cingulate Gyrus	32
Right	Limbic	Parahippocampal Gyrus	28
Left	Occipital	Lingual Gyrus	18
Right	Limbic	Uncus	38
Decreased Activity			
Left	Frontal	Middle Frontal Gyrus	9, 46
Left	Limbic	Parahippocampal Gyrus	19
Right	Frontal	Medial Frontal Gyrus	6
Right	Frontal	Paracentral Lobule	6
Left	Frontal	Paracentral Lobule	6
Right	Frontal	Superior Frontal Gyrus	6

was evident in bilateral limbic (i.e., posterior cingulate and cingulate) as well as right occipital (i.e., precuneus) and left temporal regions (see Table XIII and Figure 13). On the other hand, significantly decreased alpha ($p < 0.01$) was evident in right frontal and temporal areas.

For the Visualization versus Self-Generation meditation conditions, there were significant increases in beta1 and beta2 ($p < 0.01$) in right frontal and parietal regions (see Tables XIV and XV and Figures 14 and 15, respectively). For beta1, the most significant areas was the middle frontal gyrus ($p < 0.01$). However, several other regions of significantly increased were also identified including precentral gyrus, inferior parietal lobule, postcentral gyrus and fusiform gyrus. For beta2, significantly increased activity was found in the inferior frontal gyrus ($p < 0.01$). The other right frontal and limbic regions were also identified as evidencing significantly increased activity ($p < 0.01$). For both beta1 and beta2, there were no significantly decreased areas of activity.

Table IX
LORETA Theta Absolute Power: Areas of Increased and Decreased Activity Between Visualization and Self-Generation Meditation Conditions

Hemisphere	Lobe	Location	Broadman Area
Increased Activity			
Left	Limbic	Parahippocampal Gyrus	36
Right	Frontal	Superior Frontal Gyrus	9
Left	Limbic	Anterior Cingulate Gyrus	24
Left	Frontal	Rectal Gyrus	11
Left	Frontal	Medial Frontal Gyrus	11
Right	Brain Stem	Mamillary Body	—
Left	Brain Stem	Mamillary Body	—
Right	Parietal	Postcentral Gyrus	2, 5
Right	Parietal	Inferior Parietal Lobule	40
Right	Frontal	Precentral Gyrus	4, 6
Right	Sub-lobar	Insula	13
Right	Temporal	Fusiform Gyrus	20
Right	Limbic	Parahippocampal Gyrus	27, 35, 36
Decreased Activity			
Right	Frontal	Precentral Gyrus	44
Right	Frontal	Inferior Frontal Gyrus	47
Right	Frontal	Middle Frontal Gyrus	11
Right	Occipital	Inferior Occipital Gyrus	18
Left	Frontal	Postcentral Gyrus	4
Left	Frontal	Precentral Gyrus	4
Left	Frontal	Middle Frontal Gyrus	6
Left	Parietal	Inferior Parietal Lobule	40
Left	Parietal	Superior Parietal Lobule	7
Right	Parietal	Precuneus	7

DISCUSSION

In this study we investigated advanced Buddhist tantric meditation in a Tibetan ex-monk. Although this style of meditation utilizes concentration meditation as a base, it also adds complex visualizations and feeling states through a verbal scripted guided meditation process. As such, we hypothesized some differences we expected to see as compared to previous studies. Besides eyes open and eyes closed Baseline conditions, the two main meditation conditions were

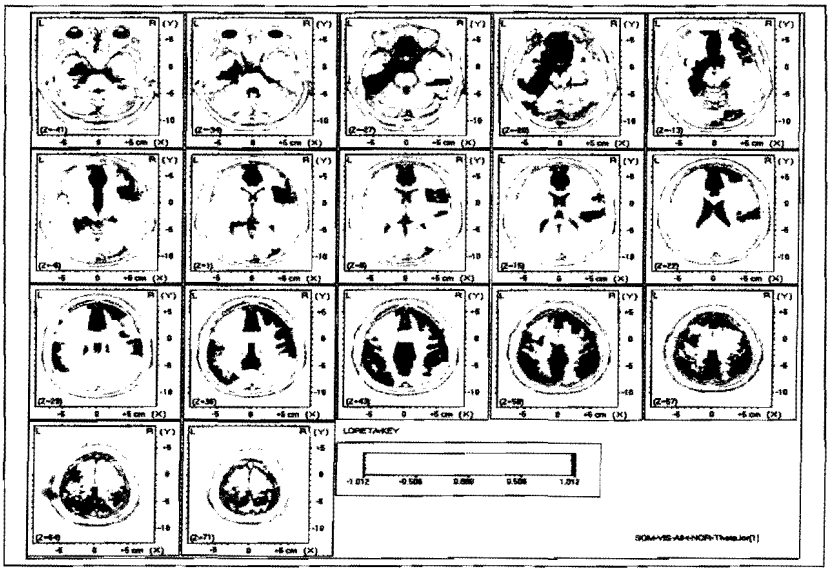

Figure 9. *LORETA theta absolute average power: areas of increased and decreased activity between Visualization and Self-Generation meditation conditions.*

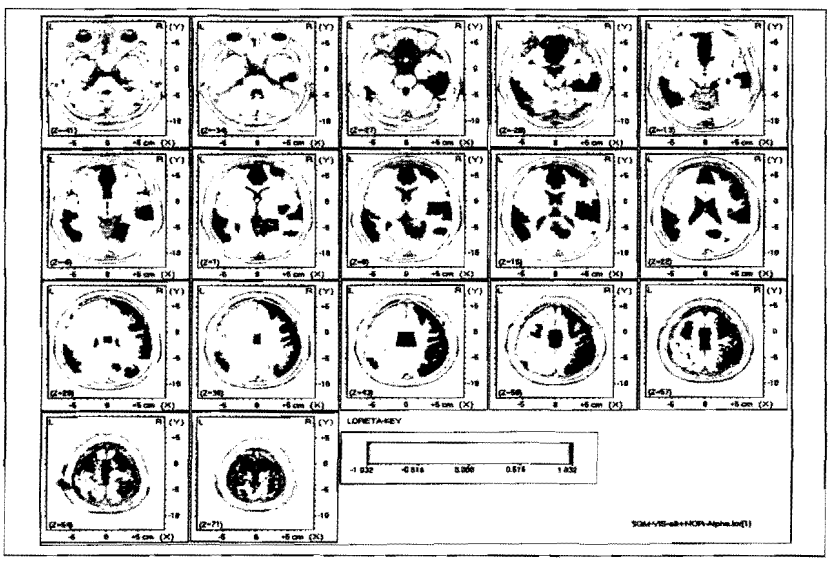

Figure 10. *LORETA alpha absolute average power: areas of increased and decreased activity between Visualization and Self-Generation meditation conditions.*

Table X

LORETA Alpha Absolute Power: Areas of Increased and Decreased Activity Between Visualization and Self-Generation Meditation Conditions

Hemisphere	Lobe	Location	Broadman Area
Increased Activity			
Right	Frontal	Middle Frontal Gyrus	6
Right	Parietal	Inferior Parietal Lobule	40
Right	Frontal	Precentral Gyrus	4, 6
Right	Parietal	Postcentral Gyrus	5
Right	Sub-lobar	Insula	13
Right	Temporal	Fusiform Gyrus	20
Left	Limbic	Anterior Cingulate Gyrus	24
Right	Limbic	Anterior Cingulate Gyrus	24
Left	Frontal	Medial Frontal Gyrus	6
Right	Frontal	Medial Frontal Gyrus	6
Left	Parietal	Superior Parietal Lobule	7
Decreased Activity			
Right	Temporal	Middle Temporal Gyrus	21
Right	Limbic	Parahippocampal Gyrus	19
Left	Temporal	Superior Temporal Gyrus	22
Left	Temporal	Middle Temporal Gyrus	21

studied: Eyes Closed Visualization and Self-Generation. In addition, we compared conditions (i.e., Visualization versus Baseline and Self-Generation versus Visualization) and identified statistically significant areas of activation and de-activation using LORETA.

The absolute power of broad band activity in the Baseline condition was characterized by increased theta centrally (i.e., Cz), minimal alpha activation in occipital regions, and increased beta and gamma in the temporal regions bilaterally (see Figure 1). On the other hand, the Visualization condition was characterized by increased delta activity centrally (i.e., Cz - Pz), increased alpha in occipital regions, and increased beta2 activity in the temporal lobes and occipital areas. This was accompanied by decreased delta, theta and alpha absolute power in the temporal regions, bilaterally. Also, there was a decrease in frontal beta which was more prominent on the left side (i.e., F7, C3 and between Fp2 and F8). For the Self-Generation condition, the patterns of increased and decreased delta, theta and alpha were essentially identical to the Visualization condition

Table XI

LORETA Beta1 Absolute Power: Areas of Increased and Decreased Activity Between Visualization and Self-Generation Meditation Conditions

Hemisphere	Lobe	Location	Broadman Area
Increased Activity			
Right	Frontal	Middle Frontal Gyrus	6, 8, 9
Right	Frontal	Precentral Gyrus	6, 9
Right	Frontal	Inferior Frontal Gyrus	9
Right	Parietal	Postcentral Gyrus	2
Right	Parietal	Inferior Parietal Lobule	40
Right	Temporal	Fusiform Gyrus	20
Right	Frontal	Superior Frontal Gyrus	9
Right	Frontal	Medial Frontal Gyrus	6
Left	Frontal	Medial Frontal Gyrus	6
Left	Frontal	Superior Frontal Gyrus	6
Right	Sub-lobar	Insula	13
Left	Limbic	Parahippocampal Gyrus	35
Right	Frontal	Inferior Frontal Gyrus	11
Left	Parietal	Postcentral Gyrus	7
Left	Brainstem	Mamillary Body	—
Left	Parietal	Inferior Parietal Lobule	40
Decreased Activity			
Right	Occipital	Inferior Occipital Gyrus	18
Left	Frontal	Inferior Frontal Gyrus	47
Left	Parietal	Postcentral Gyrus	43
Left	—	Inferior Temporal Gyrus	37
Left	Occipital	Middle Occipital Gyrus	19
Left	Temporal	Middle Temporal Gyrus	21
Right	Temporal	Superior Temporal Gyrus	22
Right	—	Middle Temporal Gyrus	21

although somewhat attenuated. The major difference between the two meditation conditions was a rather strong increase in beta1 and gamma activity in the fronto-temporal region of the right hemisphere (i.e., C4). The latter was accompanied by decreased left frontal beta (as for the Visualization condition) along with decreased beta and gamma in frontal (i.e., between Fp2 and F8) and posterior (i.e., between O1 and T6) regions of the right hemisphere. Thus, these three conditions, baseline and two meditation states, appear to produce unique mental states as evidenced by differences in patterns of broad band EEG activity.

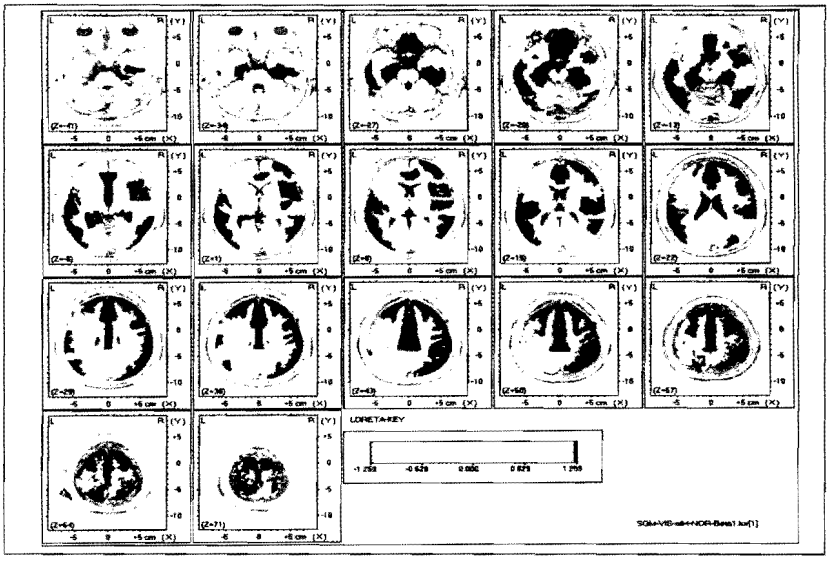

Figure 11. *LORETA beta1 absolute average power: areas of increased and decreased activity between Visualization and Self-Generation meditation conditions.*

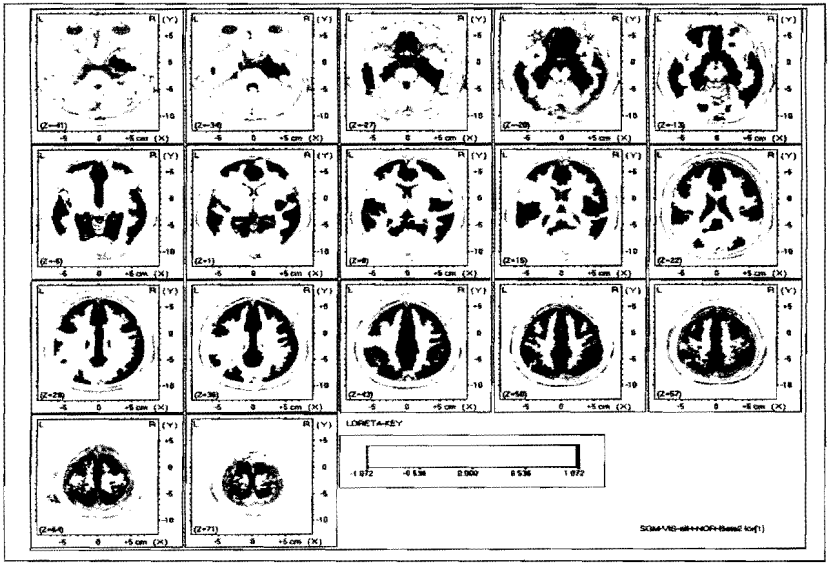

Figure 12. *LORETA beta2 absolute average power: areas of increased and decreased activity between Visualization and Self-Generation meditation conditions.*

Table XII

LORETA Beta2 Absolute Power: Areas of Increased and Decreased Activity Between Visualization and Self-Generation Meditation Conditions

Hemisphere	Lobe	Location	Broadman Area
Increased Activity			
Right	Frontal	Inferior Frontal Gyrus	9
Right	Limbic	Cingulate Gyrus	24
Right	Frontal	Superior Frontal Gyrus	6,11
Right	Frontal	Middle Frontal Gyrus	6, 8
Right	Parietal	Inferior Parietal Lobule	40
Right	Parietal	Superior Parietal Lobule	7
Right	Parietal	Postcentral Gyrus	2
Right	Limbic	Parahippocampal Gyrus	36
Right	Sub-lobar	Insula	13
Right	Brainstem	Mamillary Body	—
Left	Brainstem	Mamillary Body	—
Left	Limbic	Parahippocampal Gyrus	27, 30, 35, 36, 37
Left	Temporal	Sub-gyral	—
Left	Temporal	Fusiform Gyrus	37
Left	Parietal	Inferior Parietal Lobule	40
Left	Frontal	Precentral Gyrus	6
Right	Occipital	Lingual Gyrus	18
Left	Frontal	Superior Frontal Gyrus	10, 11
Left	Frontal	Orbital Gyrus	11
Left	Occipital	Fusiform Gyrus	19
Decreased Activity			
Left	Temporal	Middle Temporal Gyrus	21, 37
Left	—	Superior Temporal Gyrus	22
Left	Temporal	Inferior Temporal Gyrus	20
Right	Temporal	Superior Temporal Gyrus	22
Right	—	Middle Temporal Gyrus	21

HYPOTHESES

Consistent with previous studies of concentration meditation, we did find increased alpha activity in the Visualization meditation condition. However, contrary to the often reported increase in frontal-central alpha, alpha absolute power was increased in the posterior regions (e.g., O1, O2, Pz, Cz) at 9 to 11 Hz. Increases in central or midline (e.g., Cz, Pz) delta activity were also identified in the 2 to 4 Hz range. There were no increases in either theta activity

Table XIII

LORETA Alpha Absolute Power: Significant Differences Between Baseline and Visualization Meditation Conditions

Talaraich Coordinates (x, y, z)	Hemisphere	Lobe	Location	Broadman Area	*t* Value
Increased Activity					
-59 -60 29	Left	Temporal	Superior Temporal Gyrus	39	5.5311*
4 -53 22	Right	Limbic	Posterior Cingulate Gyrus	31	5.2181*
-3 -60 29	Left	Limbic	Cingulate Gyrus	31	5.2181*
4 -60 29	Right	Limbic	Cingulate Gyrus	31	5.2181*
-3 -53 22	Left	Limbic	Posterior Cingulate Gyrus	31	5.2181*
11 -60 29	Right	Occipital	Precuneus	31	5.2181*
-3 -46 15	Left	Limbic	Posterior Cingulate Gyrus	29	5.2181*
Decreased Activity					
67 -18 -20	Right	Temporal	Inferior Temporal Gyrus	20	-5.4790*
67 -4 22	Right	Frontal	Precentral Gyrus	6	-6.2617*
25 31 36	Right	Frontal	Middle Frontal Gyrus	8	-6.3139*
39 52 15	Right	Frontal	Superior Frontal Gyrus	10	-6.6270*

* $p < 0.01$, two-tailed.[58,59]

or alpha coherence. Activity in the temporal lobes was decreased in the delta, theta and alpha broad bands for both meditation conditions. However, for the Visualization condition, there was an increase in beta2 in both temporal areas as well as in the occipital region. Increased beta activity was previously reported during gTum-mo meditation and in particular, in both temporal lobes during concentrative meditation.[26,29,30] For both meditation conditions, there was a decrease in beta activity in the left frontal area (i.e., F7 - C3). We had expected an increase in activity in this area based on task demands of internal speech. With respect to feeling states and subjective sense of self, there was an increase in beta and gamma activity in the right fronto-temporal region for the Self-Generation meditation condition.

Comparison of Highest Yoga Tantra and Concentration Meditations

At this point, the failure to show increased theta and alpha coherence in either tantric meditation conditions suggests that the two procedures emphasize

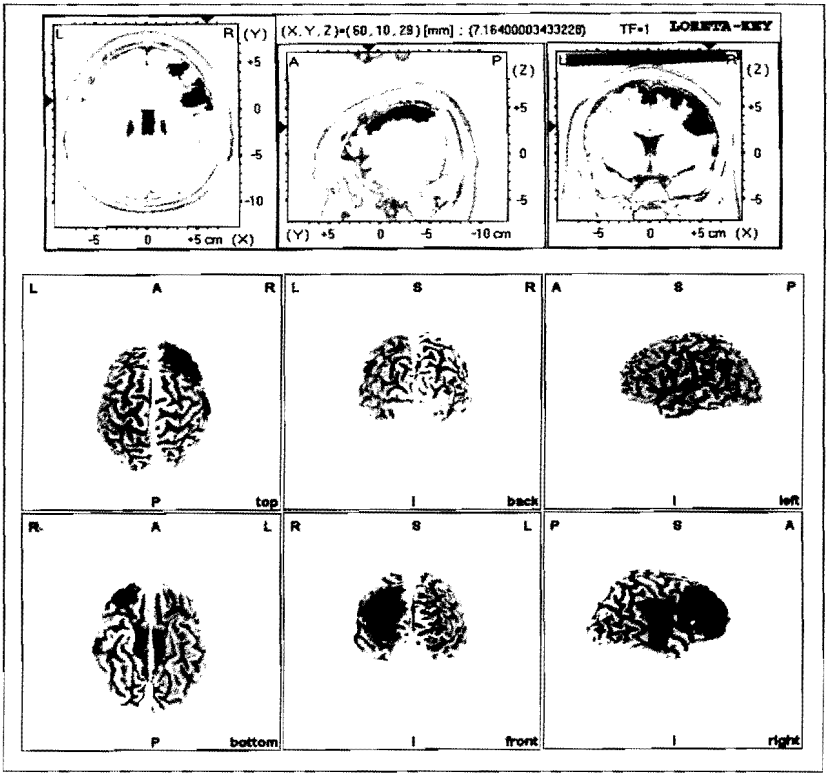

Figure 13. *LORETA alpha absolute average power: areas of statistically significant difference between Baseline and Visualization meditation conditions. LORETA key: left (L), right (R), anterior (A), posterior (P), superior (S), inferior (I).*

different goals, and therefore employ different underlying processes. That is, the goals of concentration meditation, continual repetition of a single pointed activity (i.e, watching the breath, mantra repetition) has as its effect the quieting of the mind, the release of stress and unconscious material in the form of emerging thoughts that one simply observes but does not follow. The development of this skill can lead to specific states of attainment or samadhi in addition to a host of other positive mental and physical benefits.[61] The development of one-pointed focus and quieting of the mind are presumably characterized by increased theta (i.e., frontal midline theta generated by the anterior cingulate gyrus) and alpha coherence.[11,14,15,20]

Table XIV

LORETA Beta1 Absolute Power: Significant Differences Between Visualization and Self-Generation Meditation Conditions

Talaraich Coordinates (x, y, z)	Hemisphere	Lobe	Location	Broadman Area	*t* Value
Increased Activity					
25 24 57	Right	Frontal	Middle Frontal Gyrus	6	5.5123*
46 10 43	Right	Frontal	Middle Frontal Gyrus	8	4.9935*
39 3 36	Right	Frontal	Precentral Gyrus	6	4.9935*
39 10 36	Right	Frontal	Precentral Gyrus	9	4.9935*
53 3 43	Right	Frontal	Middle Frontal Gyrus	6	4.9935*
53 3 36	Right	Frontal	Precentral Gyrus	6	4.9935*
53 10 43	Right	Frontal	Middle Frontal Gyrus	6	4.9935*
46 3 36	Right	Frontal	Precentral Gyrus	6	4.9935*
46 3 43	Right	Frontal	Middle Frontal Gyrus	6	4.9935*
39 3 29	Right	Frontal	Precentral Gyrus	6	4.9935*
46 17 43	Right	Frontal	Middle Frontal Gyrus	8	4.9935*
60 -32 43	Right	Parietal	Inferior Parietal Lobule	40	4.8638*
53 -25 57	Right	Parietal	Postcentral Gyrus	2	4.8638*
53 -25 50	Right	Parietal	Postcentral Gyrus	2	4.8638*
60 -25 50	Right	Parietal	Postcentral Gyrus	2	4.8638*
60 -32 50	Right	Parietal	Inferior Parietal Lobule	40	4.8638*
53 -25 43	Right	Parietal	Postcentral Gyrus	40	4.8368*
39 -25 -27	Right	Temporal	Fusiform Gyrus	20	4.8422*

* $p < 0.01$, two-tailed.[58,59]

On the other hand, the form of tantric meditation studied herein emphasizes a scripted complex visualization process and has an altogether different goal. In this form of meditation, the process is to engender projection and re-collection of specific qualities, and ultimately, of the divine itself. While this form of meditation does rest on the basis of concentration meditation, it does primarily for the purpose of sustained focus. Thus, it may be the activity of following a scripted meditation that accounts for the absence of increased frontal alpha activity. Moreover, for such deeper meditation practices employing the process of projection and re-collection, the brain reaches deep to engage the very slow delta waves that may ultimately be found to be related to the collective unconscious and/or non-local mind.[62]

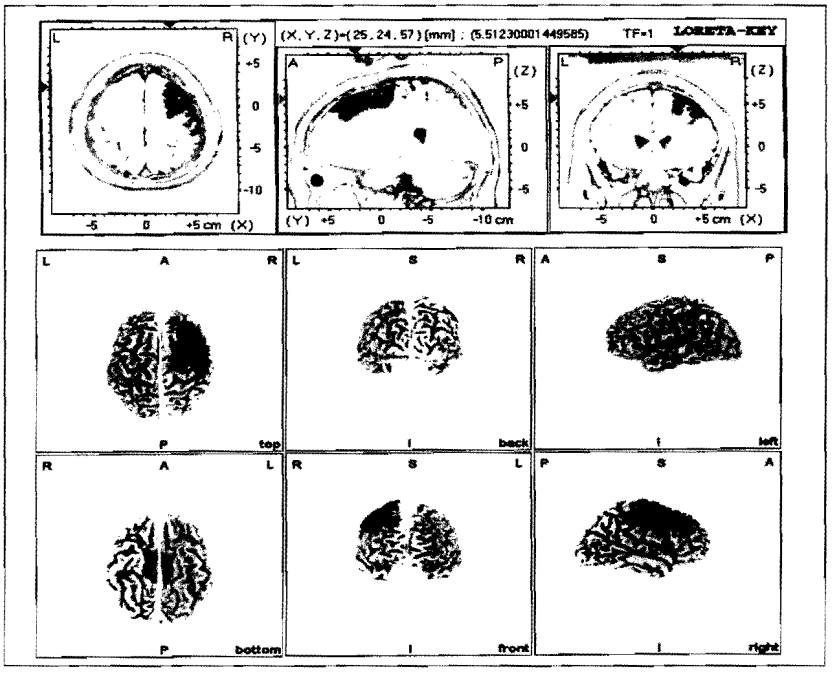

Figure 14. *LORETA beta1 absolute average power: areas of statistically significant difference between Visualization and Self-Generation meditation conditions. LORETA key: left (L), right (R), anterior (A), posterior (P), superior (S), inferior (I).*

BASELINE VERSUS VISUALIZATION MEDITATION

Compared to the Baseline condition, the Visualization meditation was characterized by an increase in delta absolute power centrally (i.e., Cz - Pz), increased alpha and beta activity in the occipital region (O1, Pz, O2), increased beta2 (i.e., 18.0 - 25.0 Hz) activity in both temporal lobes (i.e., T3 and T4), decrease in central (i.e., Fz, Cz, Pz) theta, and decreased beta1 activity in the temporal lobes. However, the only significant differences ($p < 0.01$) between the conditions were as follows: increased alpha absolute power were in temporal (i.e., superior temporal gyrus), limbic (i.e., posterior cingulate and cingulate) and occipital (i.e., precuneus) regions of both hemispheres. Significant decreases in alpha absolute power were found in the right frontal (i.e., precentral gyrus, middle frontal gyrus, and superior frontal gyrus) and temporal (i.e., inferior temporal gyrus) regions. Increased occipital alpha may reflect greater cerebral

Table XV

LORETA Beta2 Absolute Power: Significant Differences Between Visualization and Self-Generation Meditation Conditions

Talaraich Coordinates (x, y, z)	Hemisphere	Lobe	Location	Broadman Area	*t* Value
Increased Activity					
60 10 29	Right	Fontal	Inferior Frontal Gyrus	9	7.1640*
46 10 22	Right	Frontal	Inferior Frontal Gyrus	9	7.1359*
11 -18 43	Right	Limbic	Cingulate Gyrus	24	6.7145*
18 10 64	Right	Frontal	Superior Frontal Gyrus	6	6.3212*
25 17 50	Right	Frontal	Middle Frontal Gyrus	6	6.2369*
25 17 43	Right	Frontal	Middle Frontal Gyrus	8	6.2369*
60 -39 43	Right	Parietal	Inferior Parietal Lobule	40	6.1526*
25 -53 64	Right	Parietal	Superior Parietal Lobule	7	6.0121*
25 -11 57	Right	Frontal	Middle Frontal Gyrus	6	5.9560*
25 -11 64	Right	Frontal	Precentral Gyrus	6	5.9560*
32 -32 -27	Right	Limbic	Parahippocampal Gyrus	36	5.5345*

* $p < 0.01$, two-tailed.[58,59]

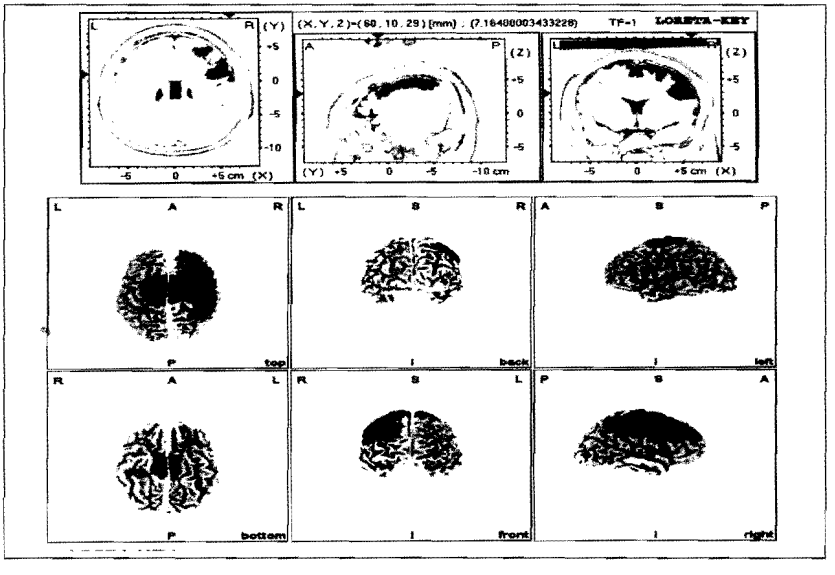

Figure 15. *LORETA beta2 absolute average power: areas of statistically significant difference between Visualization and Self-Generation meditation conditions. LORETA key: left (L), right (R), anterior (A), posterior (P), superior (S), inferior (I).*

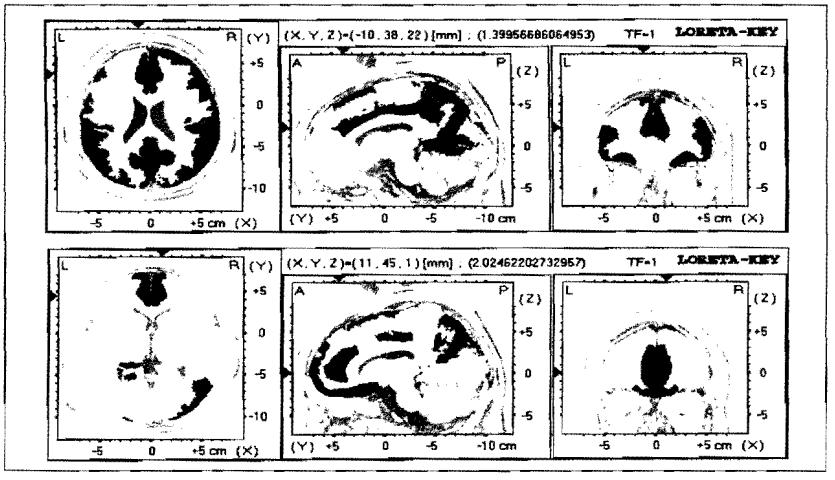

Figure 16. *Cognitive (top) and affective (bottom) divisions of the anterior cingulate gyrus: increased beta2 in the Baseline-Visualization comparison (top) and increased delta activity in the Visualization-Self-Generation comparison (bottom).*

"idling" as the meditator is, for the most part, fixated on a static internally generated visual image. Changes in the visualization may be reflected in the non-significant increase in beta activity in that region, particularly in the beta2 range. Decreases in right frontal alpha absolute power, albeit without significant increased beta activity, may reflect those systems being "on-line" and active. Frontal alpha (i.e., areas 6, 8) was decreased in dorsolateral cortex of both hemispheres, although only significantly so in the right hemisphere. Recent neuroimaging studies have reported involvement of the right dorsolateral prefrontal cortex in addition to right parietal areas in complex visuospatial matrix rotation.[63] Newberg *et al.* reported increased SPECT glucose metabolism for the inferior frontal and orbital frontal cortex as well as in the dorsolateral prefrontal cortex.[34] Although he attributed this activity as being related to concentration skills, the greatest percent change from baseline to meditation condition reported in his study was for the orbital frontal and cingulate cortices at 25.8% and 25.3%, respectively. Thus, while activity in the anterior cingulate was considered by Newberg *et al.* to reflect increased concentration and involvement of the frontal attentional system, it may be that involvement of orbital frontal areas reflect feelings of empathy or the generation of compassion.[14,15] The latter is consistent with the process involved in this form of Indo-Tibetan Buddhist meditation practice.

With respect to the posterior alpha activation in the Visualization condition, this would presumably be related to visualization and verbal repetition of the sadhana or meditational liturgy. The latter may also correspond to decreases in left frontal beta activity. These findings seem to be consistent with the finding of Lehman *et al.*[35] They reported increased gamma activity in the right parietal (posterior, inferior) for visualization and left central (medial) areas for verbalization meditation (i.e., mantra repetition).

Visualization versus Self-Generation Meditations

Both the Visualization and Self-Generation meditation conditions evidenced relatively similar patterns of activity in the delta, theta and alpha ranges. However, activity in these broad band areas was attenuated in the Self-Generation compared to Visualization condition. The major difference between these two conditions was the increased beta and gamma absolute power in right frontal (i.e., middle frontal gyrus, precentral gyrus, superior frontal gyrus, and inferior frontal gyrus), parietal (i.e., inferior parietal lobule and postcentral gyrus), temporal (i.e., fusiform gyrus), limbic (i.e., parahippocampal gyrus) regions. Interestingly, the NeuroGuide results suggest that activity was in the beta1(i.e., 15.0 to 17.5 Hz) and gamma (i.e., 25.5 to 30.0 Hz) ranges, and not the beta2 (i.e., 18.0 to 25.0 Hz) range.

For the LORETA analysis, areas of statistically significant change ($p < 0.01$) were limited to increased beta1 the right middle frontal gyrus and precentral gyrus. There were also significantly increased levels of beta2 activity in the frontal (i.e., inferior frontal gyrus, middle frontal gyrus, superior frontal gyrus, and precentral gyrus), limbic (i.e., cingulate gyrus and parahippocampal gyrus), and parietal (i.e., inferior and superior parietal lobule) regions of the right hemisphere. Areas of non-significant increased beta2 absolute power included the sub-lobar (i.e., right insula), brainstem (i.e., right and left mamillary bodies), temporal (i.e., left fusiform gyrus), occipital (i.e., lingual gyrus and fusiform gyrus), and frontal (i.e., orbital gyrus) regions. Non-significant areas of decreased beta2 absolute power included the left and right temporal areas (i.e., middle and superior temporal gyri). Isotani *et al.* report that beta2 activity is involved in the experience and/or processing of emotional states.[64]

The primary area of increased beta activation was the dorsolateral prefrontal area (i.e., Broadman areas 6, 8, 9, 10) with some involvement of the orbito-frontal cortex (i.e., Broadman areas 11, 47). These findings are consistent with previous SPECT and LORETA studies of this form of meditation. More specifically, Newberg *et al.* reported increased glucose metabolism in the orbital frontal region while Lehmann *et al.* found increased gamma activity in the dorsolateral frontal area.[34,35] Both of these frontal areas are involved with executive and higher-order socio-emotional functioning. For instance, Grattan *et al.* found that the dorsolateral prefrontal cortex was related to both empathy and cognitive flexibility (i.e., the ability to shift perceptual set, to transition from one experience to another, or perspective-taking); lesions of the dorsolateral cortex may produce indifference and difficulty interpreting emotional cues.[65] On the other hand, lesions of the orbito-frontal regions often result in decreased empathy while sparing of cognitive flexibility skills. Grattan *et al.* suggest that the orbito-frontal region may involve the underlying ability to experience somatic states necessary for responding to socially meaningful stimuli and engaging in empathic relationships.[65] Alternately, Grattan *et al.* reported that lesions of the mesial frontal areas (e.g., anterior cingulate gyrus) had a negative effect on cognitive flexibility but not empathy.

Lehmann *et al.* posited that increased activity in the dorsolateral prefrontal region was consistent with notions of the self.[35] That is, the right dorsolateral region was involved with self-consciousness, self-recognition, autobiographical retrieval, self evaluation, and, from studies of neuropsychiatric illness, experiences of detachment, depersonalization, and derealization.[36-40] The latter is also consistent with findings reported by Gusnard *et al.* implicating the dorsal portion of the medial prefrontal cortex in self-referential and/or introspectively oriented mental activity.[66] However, such "self-processing" may not be so discretely lateralized as Newberg *et al.* reported that changes in dorsolateral frontal activity levels were correlated with changes in left thalamic activity.[34] Moreover, others have reported activation of the left fusiform gyrus during self-reference processing regardless of the type of stimuli used.[67]

Nevertheless, most tasks are complex and represent a multidimensional array of cognitive sub-component skills. For instance, visual imagery of famous faces (e.g., familiar) and auditory imagery have both been shown to activate various brain areas that are also identified in the present study. The latter is not

surprising given that variations of both forms of imagery are clearly involved in the type of meditation practice under study. Auditory imagery has been shown to activate the medial and frontal inferior gyri, precuneus, middle frontal gyri, superior temporal gyri and anterior cingulate gyri.[68] While visual perception of famous faces activated the inferior occipital gyri, lateral fusiform gyri, superior temporal sulcus, and the amygdala, visual imagery activated a network of regions composed of the bilateral calcarine, hippocampus, precuneus, intraparietal sulcus, and inferior frontal gyrus.[69]

Other areas on non-significant change (i.e., increased or decreased absolute average power) identified in the Self-Generation meditation condition occurred in delta, theta and alpha bands. For delta, there was increased activity in parietal (i.e., precuneus and superior parietal lobule) and limbic (i.e., anterior cingulate gyrus, parahippocampal gyrus, and uncus) bilaterally, in addition to left-sided activation of the occipital region (i.e., lingual gyrus). Again, these areas have been found to be related to the production and manipulation of visual imagery (e.g., parietal) in conjunction with emotionally-toned content (e.g., limbic). In the theta range, there were non-significant increases in activity in left orbito-frontal and limbic regions as well as in portions of the right parietal and temporal lobes. Theta increases in the temporal and occipital regions may reflect activation of areas for imagery, retrieval or memory for visual imaginal and auditory scripted liturgy and, for the right temporal area, emotionally toned or possibly transcendent functions. There was also a corresponding decrease in theta activation in the right orbito-frontal cortex, left frontal and parietal areas. Non-significant alpha changes included activation of bilateral portions of the frontal, limbic and parietal lobes in addition to right temporal regions. Alpha decreases were associated with bilateral temporal and right parietal regions.

With respect to limbic involvement, Figure 16 shows increased beta2 activation in the cognitive division of the anterior cingulate gyrus (top) and increased delta activation in the affective portion (bottom); the latter were from the Baseline-Visualization and Visualization-Self-Generation comparisons, respectively.[70] According to Bush *et al.*, the affective subdivision is connected to the amygdala, periaquaductal grey, nucleus acumbens, hypothalamus, anterior insula, hippocampus and orbital frontal cortex. Functionally, it is involved in assessing the salience of emotional and motivational information as well as in

regulating emotional responses. The cognitive division of the anterior cingulate gyrus is part of a distributed attentional network; it is also involved in response selection, monitoring competition, complex motor control, motivation, novelty, error detection, working memory and the anticipation of cognitively demanding tasks.[14,15,70] The posterior cingulate gyrus has been associated with the retrieval of autobiographical memories.[71] Consistent with the current LORETA findings, Newberg *et al.* reported metabolic increases in the anterior and posterior regions of the cingulate gyrus during meditation.[34]

In summary, the overall pattern significantly increased beta1 and beta2 activity suggests relatively greater involvement of right hemispheral systems in the Self-Generation as compared to Visualization form of meditation. Self-Generation meditation involves the "becoming" the deity or enlightened being through complex imaginal processes that include feeling states as well as perceptual and conceptual changes. That is, the meditator embodying what the Buddhists call Bodhimind, the mind of wisdom and compassion.

Stages of Self-Generation Meditation Practice

At this level of Buddhist tantric practice, the preliminary or "generation" stage of practice involves the meditator imagining her or himself as emerging as the deity or enlightened being. That is, the meditator imagines "as if" this is actually taking place. The "completion" stage of practice is when this transformation actually occurs for real, through the power of meditation alone. However, does the brain process information in the same way for the imagined "as if" condition as it does for the real activity? In studying musicians, Lotze *et al.* compared professional versus non-professional string players and found that the professionals activated the same brain regions when imagining playing as they did when actually playing their instrument.[72] Non-professionals did not show the same pattern across conditions. The authors concluded that practice accounted for the difference.

Szechtman *et al.* measured glucose metabolism in a PET study comparing hearing an auditory stimulus, imagining an auditory stimulus and hallucinating (via hypnotic suggestion) an auditory stimulus.[73] Normal volunteers in the high-hypnotizable group evidenced increased activation in area 32 of the right

anterior cingulate gyrus when the auditory stimulus was real or hallucinated but not when it was merely imagined. Those unable to hallucinate under hypnosis did not evidence the similar results.

From another perspective, studies have shown the efficacy of cognitive behavioral therapy (CBT) in treating major depression and obsessive-compulsive disorders with concomitant changes in brain function utilizing PET. Most recently, CBT was used to treat spider phobia.[74] Prior to treatment, films of spiders activated areas in the right dorsolateral prefrontal cortex, parahippocampal gyrus, and bilateral visual association areas. The authors surmised that increased activity in the right frontal area may reflect the use of metacognitive strategies aimed at self-regulating the fear triggered by the noxious stimuli while the parahippocampal activation being related to an automatic reactivation of the contextual fear memory that lead to the phobic behavior. Following successful CBT treatment, there was no significant activation in the right prefrontal or parahippocampal areas. Paquette *et al.* concluded that changes made at the "mind level" in a therapeutic context, were able to functionally "rewire" the brain.[74]

When taken together, these findings are quite heartening. That is, in the latter case we find that cognitively re-structured thought patterns can lead to changes in brain activity. More importantly, the former two studies show that the human brain does indeed appear to be able to achieve a level or state of processing where the imagined acts like the real. As those great spiritual teachers who have gone before us, we have only to practice in a well-intentioned and diligent fashion to achieve similar results. In the words of my (J.W.D.) teacher Kyabje Gehlek Rinpoche, who is kind in three ways, "Practice!"

Delta Waves in Waking Consciousness

There is a substantial, albeit often ignored, literature relating delta activity to higher order mental functions. For example, increased delta has been found in adults performing mental calculations and abstract thought.[75-77] Fernandez *et al.* suggest that ". . . one possible explanation for increase in delta power during the performance of mental tasks is the activation of the cortico-fugal pathway that inhibits the thalamo-cortical cells,

producing a disconnection of the cortex from environmental stimuli," a state the authors referred to as "internal concentration."[75(p.180)] Interestingly, alpha was suppressed. In a study of EEG and cocaine sensitization in adults, Alper hypothesizes that awake state delta has a role in the process of interpolation of activity across the association cortex.[78] He states that ". . . delta in normal awake individuals can be a correlate of the process of allocating attention and limiting access to extraneous stimuli during states in which the cortex is processing its own input."[78(p.212)]

This sort of explanation would certainly seem consistent with the processes one undergoes during the advanced tantric meditation. In fact, the connection to non-local mind is supported in an indirect manner by a study of distant healing undertaken by Norman Shealy and colleagues. Shealy *et al.* conducted EEGs on 110 adults receiving healing at distances from 100 ft to 160 miles. The results reported the greatest power in delta.[79] There were varying degrees of theta and alpha, which were usually bilateral and symmetrical. In most instances, there was minimal beta activity.

The "Ear Muff" Effect

In our study of advanced tantric meditation, we evidenced decreased delta, theta and alpha activity at T3 and T4 with increased beta2 same area in the Visualization condition; this pattern was not evident in either the Baseline or Self-Generation meditation conditions. This higher frequency bilateral activity at T3 and T4 has been referred to as the "ear muff" effect. It has been reported in previous studies of a Hawaiian kahuna or shaman, a healer and a Qi Gong master. Working with a Hawaiian healer, Bearden found increased baseline alpha absolute power, particularly at T3 and T4, in addition to high alpha coherence.[80] Recording the brain activity of a healer during a meditation condition, Fahrion *et al.* reported high frequency (i.e., 80-90 Hz) activity over both temporal regions (i.e., T3 and T4).[81] In addition, an EEG recording of a Qi Gong master evidenced increased beta (16-32 Hz) at T3 - T4 during "lost mind" state.[82]

In the same article, Gilbert *et al.* also refer to the work of Dr. Edgar Wilson who, among other things, studied out of the body experiences in conjunction

with the Monroe Institute.[82,83] Apparently, these experiences were associated with increased beta at T3 - T4, being highest at 22 and 40 Hz in addition to increased delta. In working with the Australian healer Rod Campbell, Wilson summarized the effect as being a sudden shift from center of the skull (i.e., Cz or the crown chakra) to high frequency activity in the temporal lobes.[83] This was coupled with the loss of time awareness and space awareness in the context of increased experience of deep empathy or loss of separateness from ourselves and from the world. These fearless, transcendent moments were also accompanied by slow wave activity of 1 to 6 Hz at Cz. Wilson wrote that ". . . this seems to keep time/space at bay . . ."[83(p.175)] Wilson also refers to Penfield's work on brain stimulation. It seems that Penfield reported that stimulation of the right temporal lobe often led the brain surgery patient to talk about psychic phenomena, from things that weren't there, to out of the body experiences.[83(p.176)]

In his work with the Monroe Institute, Wilson also studied the effects of sound (i.e., binaural beats) on the brain, particularly with respect to transcendent experiences. Ultimately, he discovered that, as alpha activity decreased, delta and very high frequencies increased. When Wilson noticed that as alpha increased, the higher frequencies were attenuated, he concluded that alpha actually inhibits the shift into transcendent states.[83(p.178)] More importantly, Wilson surmised that the transcendent process began with delta activity at Cz, suddenly shifting as time/space is transcended. Acting like an energy pump, slow wave activity at Cz or the crown chakra pumps out high amplitude theta until a splitting occurs and the energy flows into the temporal lobes in increasing frequency and amplitude.[84] This process as described, actually connects the two interesting findings in the present study, those being central delta activity and the ear muff effect.

Interestingly, the latter pattern of activation was evident only in the Visualization condition and not the Self-Generation meditation. Does this mean that the Self-Generation meditation lacks a connection to the divine? Is it simply a practice in the "art of pretending?" Actually, the basis for the differential patterns of brain activation in the two meditation conditions may be simply a matter of intent or cultural mind set. A difference of "form," if you will. That is, in the Visualization condition, as well as in all of the other meditative conditions in which this pattern manifests (e.g., healing by a

Hawaiian Kahuna, lost mind state by a Qi Gong master, etc.), the meditator or healer acts as a channel or conduit for divine universal energy from an external source. Alternately, in the Self-Generation condition, the practitioner is embodying that divine energy from within. Thus, in the former case the meditator retrieves and distributes the divine energy while in the latter instance the practitioner becomes it.

Future Directions

We have followed up these current findings with additional EEG recordings of two more Tibetan Buddhist monks along with a second recording of our first participant (AT). At present, two analyses are under way. The first compares different "types" of meditation practice, such as concentration, visualization, and analytical meditation. The second compares the monks meditating on various "objects of meditation" such as "bodhicitta" (i.e., unconditional love and compassion) and "sunyata" (i.e., emptiness or the lack of inherent existence of things).[85]

Postscript

The findings presented by Edgar Wilson pertaining to increased delta at Cz and gamma activity bilaterally at T3 and T4 are quite pertinent to the results presented here. His hypothesis for the interaction of spirit and matter remains intriguing, although the exact mechanism responsible for such exchange remains elusive. While our current findings shed some additional light on neurophysiological and psychological processes supporting this particular meditative practice, it is not our intention to leave the reader with a reductionistic or mechanistic spin on these ancient and powerful healing practices. Rather, we encourage others to pioneer the way, bridging the gap in our understanding of the interface between the physical world and subtle body or spiritual dimensions. It would seem that our best bet would be to follow Dr. Edgar Wilson's extraordinary insight and continue our focus on the ancient models from the east. In fact, the Indo-Tibetan Buddhist model of the subtle body, consisting of channels, chakras and "winds," may be a helpful place to start as their sacred literature is rich in both detailed descriptions and

practices. But that is another discussion altogether. So at least for the moment, consider the fact that, for Buddhists, the mind resides in the heart (chakra), not in the head.

DEDICATION

May my venerable Lama's life be firm,
his white divine actions spread in the ten directions,
and the torch of Lozang Drakpa's teachings, dispelling
the three world's beings' darkness, always remain.

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ACKNOWLEDGMENTS: The authors would like to thank AT for participating in this study, he has the heart of a Buddha. We greatly appreciate the expert consultation and LORETA statistical analyses completed for this study by Marco Congedo. Also, grateful thanks and deep appreciation to Carol Schneider for ptoviding reference materials regarding Dt. Edgar Wilson, but also for her enthusiasm and support fot this study throughout its incarnations. Thanks also to Philip Nicholson and Russell Hebert for their stimulating discussions. Finally, we greatly appreciate Penny Hiernu and the ISSSEEM staff for their kindness and incredible display of patience.

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