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A Quantitative Electroencephalographic Study of Meditation and Binaural Beat Entrainment

Christina F. Lavallee, MA,[1] Stanley A. Koren,[1] and Michael A. Persinger, PhD[1,2]

Abstract

Objectives: The study objective was to determine the quantitative electroencephalographic correlates of meditation, as well as the effects of hindering (15 Hz) and facilitative (7 Hz) binaural beats on the meditative process.
Design: The study was a mixed design, with experience of the subject as the primary between-subject measure and power of the six classic frequency bands (δ, θ, low α, high α, β, γ), neocortical lobe (frontal, temporal, parietal, occipital), hemisphere (left, right), and condition (meditation only, meditation with 7-Hz beats, meditation with 15-Hz beats) as the within-subject measures.
Location: The study was conducted at Laurentian University in Sudbury, Ontario, Canada.
Subjects: The subjects comprised novice (mean of 8 months experience) and experienced (mean of 18 years experience) meditators recruited from local meditation groups.
Intervention: Experimental manipulation included application of hindering and facilitative binaural beats to the meditative process.
Results: Experienced meditators displayed increased left temporal lobe δ power when the facilitative binaural beats were applied, whereas the effect was not observed for the novice subjects in this condition. When the hindering binaural beats were introduced, the novice subjects consistently displayed more γ power than the experienced subjects over the course of their meditation, relative to baseline.
Conclusions: Based on the results of this study, novice meditators were not able to maintain certain levels of θ power in the occipital regions when hindering binaural beats were presented, whereas when the facilitative binaural beats were presented, the experienced meditators displayed increased θ power in the left temporal lobe. These results suggest that the experienced meditators have developed techniques over the course of their meditation practice to counter hindering environmental stimuli, whereas the novice meditators have not yet developed those techniques.

Introduction

The term "meditation" has been used to describe a variety of techniques or mental strategies that are used to reach transcendent or altered states of consciousness, develop attentional or perceptual skills, as well as reduce stress and increase positive affect.[1–3] Scientific research, applying the tools of electroencephalography (EEG), has uncovered differences in the electrocortical activity of meditators, when compared to nonmeditators, as well as when comparing the meditative state to a resting baseline.[4,5]

In general, meditation has been associated with increased power in the α frequency band (8–12 Hz).[2] The EEG signal generated by α activity was first described by Hans Berger, who observed that α increased over the occipital scalp when the eyes were closed and sensory input decreased. Although the neuroelectric correlates of meditation are not completely established in the literature,[6] the majority of studies report an increase in α, then θ activity,[2,6] followed by decreases in overall frequency.[7] Increased α power has been related to attentional focus[8] and often observed when meditators are evaluated during meditation as compared to control conditions; the α band is stronger at rest in meditators than in nonmeditating controls.[9]

Some reports suggest that an observed increase in θ (4–8 Hz) power, rather than an increase in α, may be a specific state effect of one's experience with the meditative practice.[9,10] Aftanas and Golocheikine found increases in θ power to be associated with proficiency in technique when investigating yogic meditators; long-term meditators relative to nonmeditator controls display higher θ and α power as well as a slower baseline EEG frequency, which could be related

[1]Psychology Department and [2]Behavioural Neuroscience Department, Laurentian University Sudbury, Ontario, Canada.

to the specific meditative technique.[9,11] Thus, the increase in activity in the α band is commonly observed when one reaches a meditative state; however, θ may only be experienced by some advanced meditators. Subjects' years (or months) of experience was recorded and used for analysis in the study.

A variety of meditation techniques have surfaced throughout the years; however, the literature has not been able to reconcile specific neuroelectric correlates of each meditation practice, as only recent studies are being designed to accommodate for the different techniques.[6] During a comparison of mindfulness and concentrative meditation techniques, the results suggested that concentrative and mindfulness techniques may be unique states of consciousness. The mindfulness condition produced more δ, θ, α, and $\beta 1$ activity than the concentrative condition at certain electrode recording sites.[12] In addition, the mindfulness meditation condition produced greater frontal θ than concentrative meditation.[12] The current study focused on the experience of mindfulness meditators (novice versus experienced) under meditation conditions with and without binaural beats.

In response to the increasing popularity of meditation,[2] certain technologies have been developed to enhance the meditative process. Specifically, binaural beats have been used to entrain the brain toward a desired frequency. When two tones of a slightly different frequency are presented separately to each auditory channel, the listener perceives a third tone, which is the difference between the initial two tones and is known as the binaural beat.[13] Electroencephalographic activity demonstrates synchrony with the frequency difference, which is known as the frequency following response.[14] Thus, this purportedly gives the novice meditator the ability to replicate the EEG patterns achieved by advanced meditators, such as θ waves.[4,5] It was the goal of the present study to determine the electroencephalographic effects that two different binaural beats have on the meditative process. A 7-Hz binaural beat was used to facilitate the meditation process, based on the results observed with the advanced meditators.[4,5] A 15-Hz binaural beat was utilized to hinder the meditation process due to its associated β properties of increased alertness[15] and excitation.[16]

Materials and Methods

A Grass Technologies EEG was used in this study; it consisted of eight channels and electrode sensors. For the purpose of this study, a monopolar montage was executed with electrodes placed on O1, O2, P3, P4, T3, T4, F7, and F8, references to the earlobe, based on the 10–20 International electrode mapping. Grass Technologies EC2 Electrode Cream was placed on each electrode. Spectral analysis of the raw EEG data was completed by Fast Fourier Transform for the following frequency bands: δ (1–4 Hz), θ (4–8 Hz), low α (8–10.5 Hz), high α (10.5–12 Hz), β (13–18 Hz), and γ (35+ Hz).

All binaural beats were created with Gnaural Binaural Beat Audio Generator 2.0. The binaural beats were played with a SanDisk MP3 Digital Audio Player (Model: SDMX1-512R v2) with NexxTech stereo headphones.

Participants ($N = 8$; 4 male, 4 female) were recruited from potentially interested groups, such as yoga, Buddhist, and meditation classes. All meditators employed mindfulness meditation techniques and self-reported regular meditation, practicing the technique approximately 1 hour per week, on average. Subjects' classification as either "novice" ($n = 4$) or "experienced" ($n = 4$) was based on previous research[10]; however, the specific criterion was modified to accommodate the population sampled from. The experienced meditators, in the current study, ranged from 5 to 39 years of experience, with a mean of 18 years of experience. The novice meditators ranged from 5 months to 12 months of meditation experience, with an average of 8 months of experience.

Each participant attended three counterbalanced sessions as part of the study, at the same time of day on 3 successive days as separate sessions were scheduled for meditation, facilitative, and hindering conditions. Subjects were not aware of the purpose of the study and were blind as to which conditions they were completing. Subjects completed informed consent; however, they were told that the purpose of the study was to determine how sounds presented during meditation affected ones' EEG over time. Subjects wore the headphones in all conditions as pink noise was presented in all conditions, in order to mask the binaural beats, making subjects blind to their condition. Electrode placement was completed, and a 30-second baseline resting rate was recorded.

For all conditions, the subjects were instructed to meditate as they regularly would, employing the mindfulness meditation technique once the track began, then quantitative EEG (QEEG) recordings were taken at four different time intervals within the 15-minute period of meditation. The four time intervals were the same for all participants, and the duration of each recording period was 30 seconds. After each of the three meditation sessions, the participants filled out a free-form exit questionnaire to assess the subjective experience of their meditation experience. The free-form exit questionnaire was assessed in terms of whether or not subjects had reported any anomalous or exceptional experiences that they would not normally have during a typical meditative session. At the end of the third session, subjects were debriefed as to the purpose of the experiment.

Statistical analyses involved the use of multivariate analysis of variance (MANOVA) to determine the effects of experience and experimental condition on cortical activation during meditation and meditation with binaural beat entrainment conditions. The MANOVA employed neocortical lobe (frontal, temporal, parietal, occipital), hemisphere (left, right), frequency band (δ, θ, $\alpha 1$, $\alpha 2$, β, γ) and recording time (baseline, four time intervals during meditation) as repeated factors with the between-subject measure being the experience of the participant (novice versus experienced). For the QEEG results, *post hoc* analyses involved using appropriate combinations of independent and paired t tests to determine the source of interactions between and within variables. χ^2 testing was used to analyze the participants' subjective report of their meditative experience with the experimental condition as these data were nominal.

Results

A significant interaction [$F(3,18) = 5.21$, $p < 0.01$, partial $\eta^2 = 0.465$] was observed between lobe, hemisphere, and experience of the subject in the meditation and facilitative

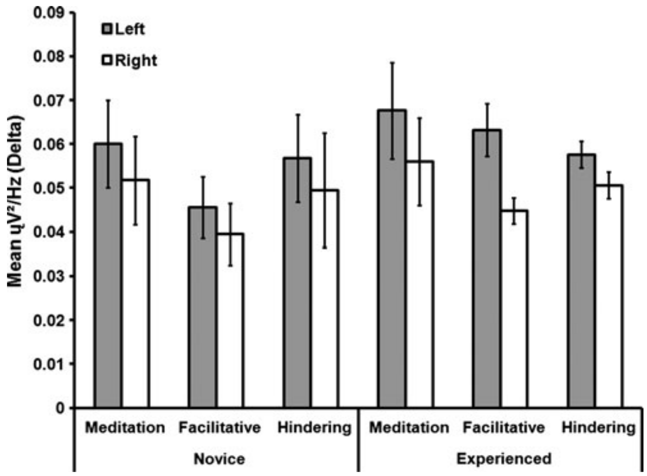

FIG. 1. Mean δ band spectral power for novice and experienced meditators in all conditions for the right and left temporal lobes.

binaural beats condition when the δ (0.5–4 Hz) clinical band was examined. *Post hoc* analysis revealed that the primary source of this interaction occurred within the left and right temporal lobes during the facilitative binaural beats condition for the experienced meditators. There was more mean power ($\mu V^2/Hz$) in the left temporal lobe compared to the right (Fig. 1).

A statistically significant interaction between experience of the subject, lobe, and hemisphere in the meditation and hindering binaural beats condition was found [$F(3,18) = 4.82$, $p < 0.05$, partial $\eta^2 = 0.446$] in the θ (4–8 Hz) band. *Post hoc* analysis revealed that the primary source of the interaction occurred within the occipital lobes. This is shown in Figure 2, where the greater power in the right hemisphere during the hindering treatment for the experienced meditators is clearly evident. The differences between the frontal, temporal, and parietal lobes were not statistically significant.

A significant interaction [$F(6,36) = 2.64$, $p < 0.05$, partial $\eta^2 = 0.305$] was observed between experience of the subject, experimental condition, and lobe in the γ band (35+ Hz). The

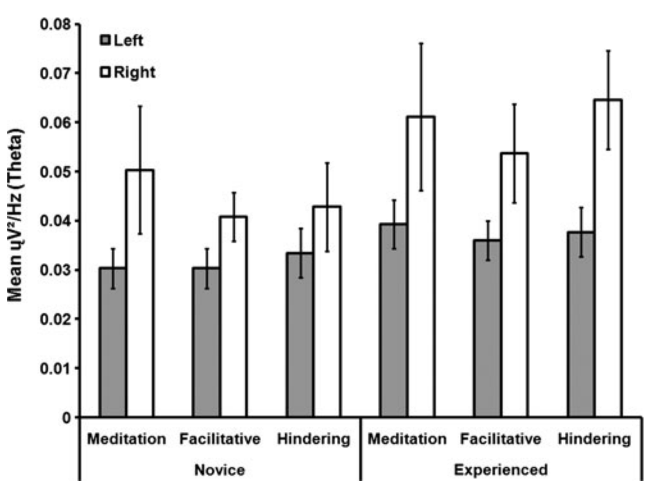

FIG. 2. Mean θ band spectral power for novice and experienced meditators in all conditions for the right and left occipital lobes.

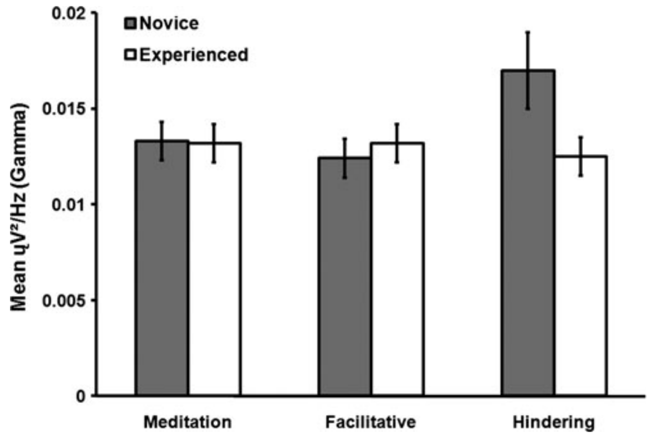

FIG. 3. Mean frontal γ spectral power for novice and experienced meditators.

primary source of the interaction occurred in the frontal lobe (no hemisphere effect). Figure 3 shows the increased γ power for novice subjects compared to experienced meditators during the hindering condition for the frontal lobe only. Further analysis in the γ band (Fig. 4) yielded a significant interaction [$F(4,24) = 3.29$, $p < 0.05$, partial $\eta^2 = 0.354$] between experience of subject and recording time in the meditation and hindering binaural beats condition. Compared to baseline, experienced meditators displayed less γ power than novices across all time measurements.

A significant interaction between meditation condition and subjective report of the experience was observed ($\chi^2 = 7.25$, $p < 0.05$), where participants in the meditation and facilitative binaural beats condition reported more anomalous experiences than in the meditation only or hindering conditions. On free-form exit questionnaires, subjects in the facilitative binaural beats condition had reported "feeling waves of energy," "blissful experiences," and "connections with the universe" that were otherwise not typically experienced during a normal meditation session.

Discussion

The results from the MANOVA indicated interactions in the temporal, frontal, and occipital regions. The temporal

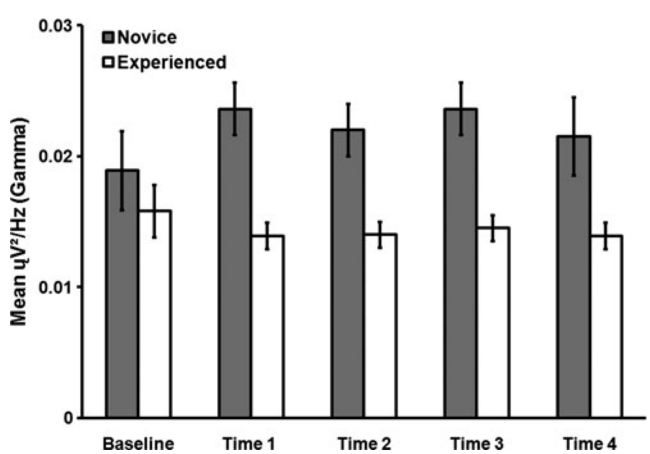

FIG. 4. Mean γ band spectral power over time for novice and experienced meditators.

lobe, by nature, is electrically more labile than other regions[17] and the temporal lobe, specifically the right, has also been implicated in a type of "cognitive kindling" process hypothesized to occur during meditation.[18] Implications are further discussed below. Since the frontal lobe typically demonstrates increased θ activity during mindfulness meditation, we did not hypothesize a frontal lobe γ interaction; however, these results are interpreted with respect to the participants' ability to maintain their meditative state. Furthermore, the occipital lobe generally demonstrates increased α activity[2,6] or γ coherence[19] during meditation, and the research outlining occipital θ is sparse.

The increase in left temporal lobe δ for experienced meditators in the meditation and facilitative binaural beats condition may be viewed with respect to religious or transcendent-like experiences. Research by Persinger has illustrated that transient electrical changes in the temporal lobe may be correlated with religious experiences. Temporal lobe δ was observed in the EEG investigation of an experienced Transcendental Meditation teacher during a routine peak experience, where a δ-wave-dominant electrical seizure was recorded in the temporal lobe for approximately 10 seconds.[20] Although the measurements taken in the current study did not yield results consistent with a δ-wave-dominant temporal lobe seizure, the previous research[20] on peak experiences may provide more insight into understanding the increased left temporal lobe δ activity.

Some experienced meditators, in the present study, reported (in free-form exit questionnaires) seeing visions and feeling waves of energy overcome their bodies while meditating. However, the experimental procedure was not designed to discern when they and the concurrent QEEG changes were occurring. Future studies may consider employing a technique similar to Banquet's study,[21] where meditators were asked to make the experimenter aware of any relevant changes in their personal experience, including peak experiences, to ensure that recordings were taken at that time.

In the θ range (4–8 Hz), the primary source of the interaction was found to occur in the occipital lobes. The experienced meditators displayed a significant increase in the right occipital lobe compared to the left for all three conditions. In other words, the facilitative and hindering conditions did not interfere with their meditative profile. This was not the case for the novice meditators. For the novice meditators, there was a significant relative increase in right θ power displayed compared to the left lobe for the meditation only and in the meditation and facilitative binaural beats conditions. However, unlike the experienced meditators, the right hemispheric enhancement of θ over the occipital lobe was not displayed by novices.

Although most of the research on the θ band, with respect to meditation, is largely reported in the frontal midline region,[13] there is very little research on occipital θ in the meditation literature. One report of an experienced Zen master, who was tested via EEG after a 2-hour meditation session, revealed increased midline frontal θ bursts, with a small but significant increase in occipital θ.[22] One may infer that the novice subjects in the present study are not able to maintain certain levels of θ power in the hindering binaural beats condition. Whether or not this absence of a hindering beat/facilitative beat ratio could be employed to discern the "strength" or historical duration of meditation remains to be established.

In the γ band, the novice and experienced subjects did not differ in the amount of frontal γ power displayed in the meditation only condition and when facilitative binaural beats were presented. During the meditation and hindering binaural beats condition, the novice subjects display significantly more power than the experienced subjects. These results would provide evidence for the hypothesis that the experienced meditators are able to maintain their meditative states even when countering environmental stimuli are present. The novice meditators may not have developed such strategies yet and were displaying more power in the frequency band (i.e., γ) associated with the higher levels of arousal.

Further evidence that may support this hypothesis was reflected in the interaction between recording time and experience of the subject in the meditation and hindering binaural beats condition within the γ band. For this interaction, novice and experienced subjects did not differ in the amount of γ power displayed in the baseline condition; however, as meditation began and continued, the experienced meditators consistently displayed less γ power than the novice subjects when hindering binaural beats were applied.

Although the functional application of binaural beats has been of interest to mental health and alternative medicine practitioners for years, few studies have empirically demonstrated their efficacy. Furthermore, a recent comprehensive review of brainwave entrainment research concluded with the need for rigorous research trials.[23] By measuring the neuroelectric activity during these conditions, we suspect that these results would contribute significantly to the scientific literature surrounding binaural beat entrainment. Since the purpose of using binaural beats is to alter or in some way entrain the rhythmic activity of the brain, we believe that measuring the activity of the brain is a much more central way to deduce the effectiveness of binaural beat brainwave entrainment, rather than simply considering psychologic measures.[23] Although these measures are interesting and necessary, they may be peripheral to developing a concrete understanding of brainwave entrainment.

Conclusions

When the QEEG profiles were analyzed in terms of the six classic clinical frequency bands, experienced meditators in the facilitative binaural beats condition display power differences in the temporal lobes. The novice meditators display less θ power and more γ power in the hindering binaural beats condition. The results suggest that the experienced meditators have developed techniques during their years of practice to maintain deep meditative states while blocking out external stimuli, whereas the novices have not yet developed these techniques.

Disclosure Statement

No competing financial interests exist.

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Address correspondence to:
Christina F. Lavallee, MA
Psychology Department
Laurentian University
935 Ramsey Lake Road
Sudbury P3E 2C6
Ontario
Canada

E-mail: cx_lavallee@laurentian.ca