An EEG based Quantitative Analysis of Absorbed Meditative State

Gaurav G[1], Ashish Kumar Sahani[2], and Abhijit Sahoo[3]
[1]Department of Electrical Engineering, IIT Roorkee
[2]Center for Biomedical Engineering, IIT Ropar
[3]Department of Computer Science, IIT Madras

***Abstract*—Meditation is a mental practice to achieve focus of mind and emotional clarity. Meditation has been used for cognitive enhancement, rehabilitation and reducing stress and anxiety. In the present study, we are doing a comparative analysis between various levels of meditators based on EEG as psychophysiological indicator; and possibility of EEG as a neurofeedback for meditators. An analytical experiment on three categories of subjects (A: an expert meditator, B: five moderate meditators and C: five non-meditators) was done. Each subject was guided to perform two visual tasks; first to sit relaxed with eyes closed (REC) and second to gaze on a dot on screen (RDOT); supplied, EEG being recorded in parallel. The first subject was recorded with absorbed state of meditation (*Samādhi*). For psychophysiological analysis, wavelet transform based features from each recording of EEG was evaluated. Topographical mapping of brain functioning based on features were plotted and analyzed. It was observed that theta, alpha and beta were comparatively higher for expert meditator in frontal and central region during REC and RDOT. Also, during absorbed meditative state, the alpha and beta are higher at midline central region (Cz) and theta is higher at C3 and C4.**

Keywords- EEG, Meditation, Neurofeedback

I. Introduction

Neurofeedback is a tool for conditioning the psychophysiological functioning such as brain functioning into measurable quantities which can act as a feedback for clinical assessment. It is a fast growing field of study in the areas of neuroscience, brain machine interface (BMI) and cognitive psychology. In last few decades, neurofeedback has grown into a wide field with variety of applications due to advancement in neuronal monitoring systems. Tools like fMRI, PET, EEG, etc. have created advancement in neuronal monitoring, due to growth in generic use and with widely developing methods of analysis. Neurofeedback has been very helpful in various application such as cognitive disorder diagnoses [1]; attention, anxiety and sleep study [2]; cognitive enhancement and therapies; and in non-clinical applications such as emotion and mood indicators while performing activities such as listening music, videos, dance, Yoga, meditations and mindfulness, etc. [3] [4].

Electroencephalography (EEG) is the monitoring of electrophysiological signal generated due to brain cortical activity. Based on EEG rhythmic activity, viz. delta, theta, alpha, beta and gamma; physiological and mental state of a subject can be determined [5]. EEG has been widely used in clinical, cognitive neuroscience and in neurofeedback applications [6]. There have been a wide range of study done to characterize neuronal effects of meditation using EEG and event related potential. Meditation is a mental and consciousness based practice, to focus on particular representation and achieve high level of attention, focus and emotional clarity. There have been a wide range of study done to study neuronal effects of meditation using EEG and event related potential [7]. EEG studies on meditation practitioners has observed prominent increase in theta and alpha activity during meditation [8]. Other studies have reported an increase in the specific frequencies expressed in the alpha range and reduction in frequency of EEG activity in experienced meditators versus less experienced meditators while meditating [9].

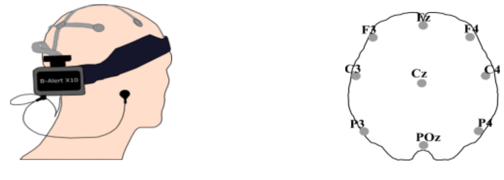
In the Buddhist and the Yogic literatures, various states of minds are discussed while going deep into the meditative or mindful states, termed in Sanskrit as *dhyana* or in Pali as *jhāna*. The mind reaches such a trance absorbed state where a high level of attended representation is activated to a highly sustained degree and all other representations of perceptions are deactivated. This state of high sustained attention and pure mindfulness is termed as *'samādhi'* in Sanskrit or '*Samāpatti'* in Pali [10]. A study done on transcendental meditation (TM) indicates slowing of alpha frequency and increase in alpha amplitude during deep state of TM (presumably the same as *Samādhi*), signaled by the subject through pressing a push button [11]. Progressing to deepness in meditation, first the alpha frequency decreases and amplitude increases, then theta rhythm occurs intermixing with alpha and then transcendence burst to higher beta frequencies (20-30 Hz) [12].

In the present study, we are experimentally analyzing the effect of meditation on brain activation. Quantitative and comparative analysis of EEG recorded for different groups of subjects was done. First group is of expert meditator (with self-assessment of *Samādhi*), second group is of moderate meditation practitioners and third group (control group), having no exposure, was done. Based on task oriented EEG evaluation and topographical mapping, the difference in cortical activity of advanced meditator, moderate meditation practitioners and non-practitioners was established. This study may be used as a neurofeedback indicator for meditation practitioner to self-assess the growth and deepness of meditative focus reached.

II. Experiment and Data

A. Hardware set up and preprocessing

In the present work, EEG signal is recorded using B-Alert X10 device. B-Alert X10 (Advanced Brain Monitoring, Inc., Carlsbad, CA) is a wireless acquisition system equipped with headset to get connected with one lead ECG and nine channel EEG visually – Poz, Fz, Cz, C3, C4,



(a) (b)

Fig. 1. (a) B-Alert X10 system scalp placement schematic and (b) 10/20 standard of electrode placement for nine channel EEG.

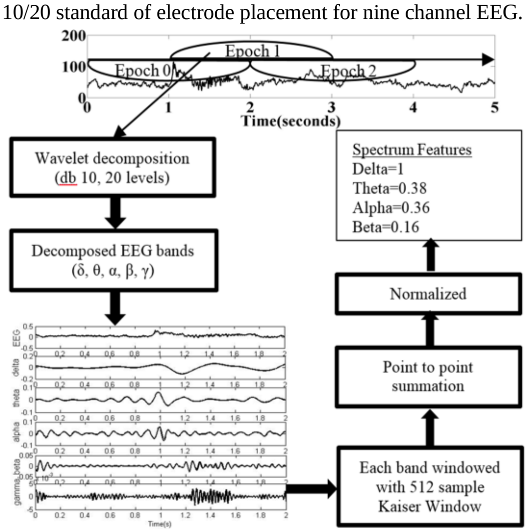


Fig. 2. Steps involved in generating wavelet decomposition based EEG frequency band features.

F3, F4, P3 and P4, following 10/20 electrode system. The headset is responsible for analog to digital conversion, which generally operates at 256 samples per second, and digital encoding at 16 bit resolution. Before recording electrical impedance between the scalp and the electrodes is checked to remain below 30KΩ. The signal is formatted and transmitted using a USB host device between 2.4 to 2.48 GHz radio transmitters. For recording and analysis, Acknowledge 4.2 software of Biopac™ is used. The recording was conducted in a silent and disturbance free environment.

The signal while recording is prone to motion artifact and powerline interference. A pair of electrode fixed at mastoid position records EMG along with EEG to remove motion artifact due to skull and scalp movement using adaptive filtering technique. Fig. 1 depicts the schematic of B-Alert X10 placement following 10/20 standard electrode positions. Those segments of signal which are majorly corrupted with motion artifact were removed. Signal was filtered using IIR Butterworth filter of order 4 between cut-off frequencies 0.5 Hz and 40 Hz.

B. *Experimental task and subject*

For this study, we took three category of subjects based on their meditation practice and level of experience. First group (A) has only one person, Om Swami (male, age 38 years), a Himalayan mystic with broad training and experience of Yoga (25 years of practice in meditation and mantras) [13]. During the experiment subject went into Samādhi sate, which was recorded and studied in this paper. Second group (B) have five meditative practitioners with more than 3 years of meditation practice (all male, age: 21-30 years). Third group (C) is control group of five subjects (all male, age: 21-30 years) without any practice or exposure to meditation. Written consent of each participant was taken and prior guidance about the experiment was provided.

Each participant was asked to perform two tasks, each of five minutes approximately. In first session, the subject has to keep their eyes closed and sit with relaxed state on a chair (rest eyes closed, REC). In the second session, each subject is guided to perform a task to continuously focus their visual attention on a red colored dot shown on a dark computer screen (restfully gazing at a dot on screen, RDOT). Each task was performed in dark and noiseless environment. While performing the tasks for each participants nine channel EEG was recorded.

III. METHOD AND DATA ANALYSIS

A. *Wavelet decomposition and features*

For EEG analysis, frequency band features of the recorded signal has to be evaluated. The corresponding bands in EEG are delta (δ) between 0.1 to 4 Hz, theta (θ) between 4 to 8 Hz, alpha (α) between 8 to 13Hz, beta (β) between 13 to 30 Hz and gamma (γ) beyond 30 Hz, consecutively. EEG being non-stationary and rhythmic, discrete wavelet decomposition has been widely used for feature extraction [14].

For the feature extraction, we use an observation window of 2s (512 samples) to select segments pf the full sequence. Every next segment is selected by shifting the observation window by 256 samples (one second). Thus, each segment has an overlap of 50% (256 samples from both sides) shown in fig. 2. On each segment, a discrete wavelet decomposition is performed using Daubechies 10 and 20 levels decomposition. The first five levels are selected for time-localized EEG frequency band features (first level: delta, second level: theta, third level: alpha, fourth level: beta and fifth level: gamma). All these decomposed bands are windowed with a 512 sample Kaiser window and then point to point summed together to get absolute value of band feature. The absolute value is normalized by subtracting minimum value from each feature and dividing by maximum value. This step is repeated for each segment of the EEG sample for all nine channels.

IV. RESULT

A. *Topographic mapping of wavelet features*

The wavelet based EEG band features are evaluated for all the subjects for both experimental sessions (REC and RDOT). Taking these band features, topographical mapping of EEG power spectrum is developed using interpolated pixel values on a head image. These topographical projections are analyzed to compare the cortical activity in different bands for all subjects and both sessions. Similarity in topographical pattern of each subject of same group was observed and listed. Fig. 3 shows the topographical mapping of features for task REC for one member of each group A, B and C. Fig. 4 shows the topographical mapping of features for task RDOT for one member of each group A, B and C.

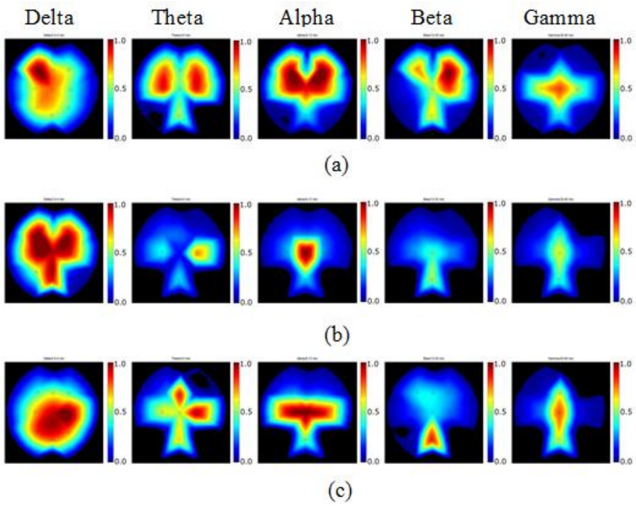


Fig. 3. Topographical map of the features during REC session for on member of (a) group A, (b) group B and (c) group C

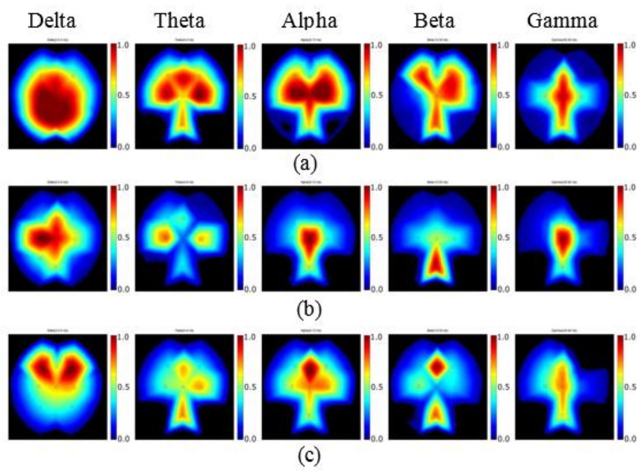


Fig. 4. Topographical map of the during RDOT session for on member of (a) group A, (b) group B and (c) group C

It has been evident from the fig. 3 that theta, alpha and beta are consistently higher in frontal region (F3 and F4) for the case of group A in comparison to group B and group C, while performing task REC. Also in the central region (C3, C4 and Cz) theta and alpha are relatively higher while performing REC for group A. Similarly, it has been observed that the frontal region (F3, F4 and Fz) and central region (C3, C4 and Cz) has consistently high intensity theta, alpha and beta for group A in comparison to group B and group C, while performing RDOT, as shown in fig. 4.

In case of absorbed meditative state for group A, it has been observed that the whole cortical activity is intense at central region. C3 and C4 entertain high theta, whereas alpha, beta and delta are concentrated high Cz position, as shown in fig. 5. This represents a very high adaptive attention level [15].

Along with the topographical mapping, a boxplot distribution of the features generated from both the tasks show the contrast between their cortical activities. Fig. 6 represents the boxplot of features for task REC. Fig. 7 represents the boxplot of features for task RDOT.

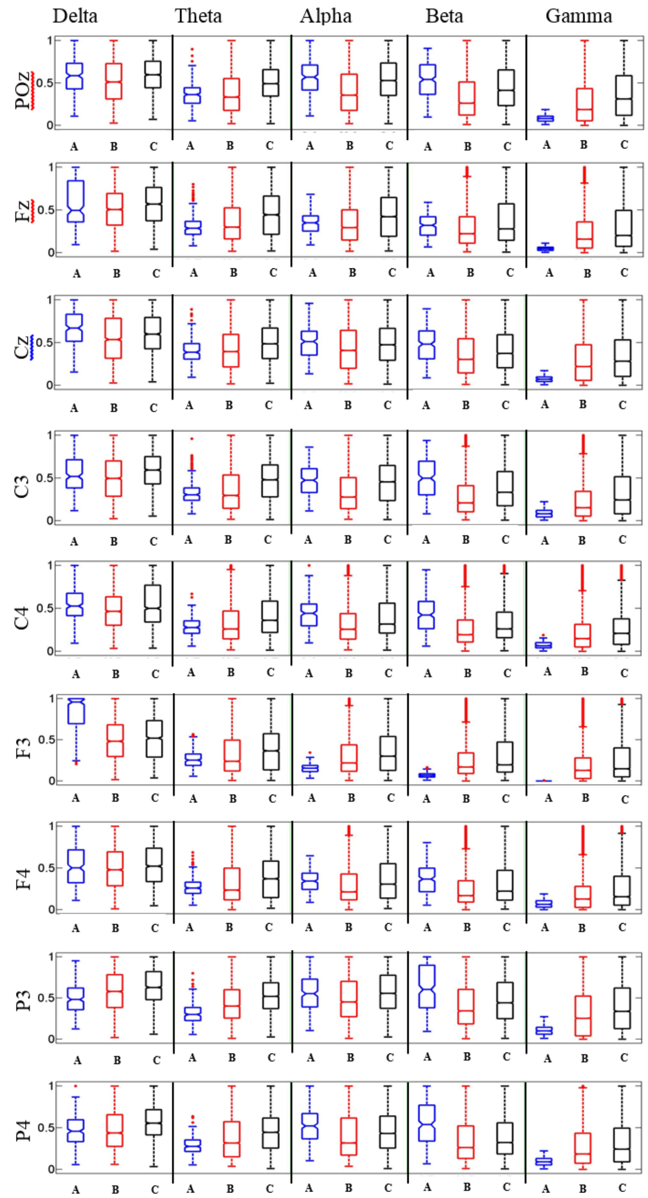


Fig. 6. Boxplot of wavelet EEG band features for group A, B and C while performing REC for all nine channels.

In both fig. 6 and fig. 7, the distribution of all the features of delta, theta, alpha, beta and gamma of all nine channels(POz, Fz, Cz, C3, C4, F3, F4, P3 and P4) are plotted for group A, B and C and compared with each other. It is observed that group A has most of the cortical region very stable through-out the session REC and RDOT and deviation from central tendency is very less. Alpha and beta is overall higher for group A, whereas, for symmetric region, central region and F4 region central tendency of theta, alpha and beta are higher for group A than group B and C.

Similarly, in case of RDOT, alpha and beta in midline region (POz, Cz and Fz) are significantly higher for group A. Also in central (Cz, C3 and C4) and frontal (F4) region; alpha and beta are higher. A high alpha to theta ratio is an indicator of higher auditory and visual working memory [16].

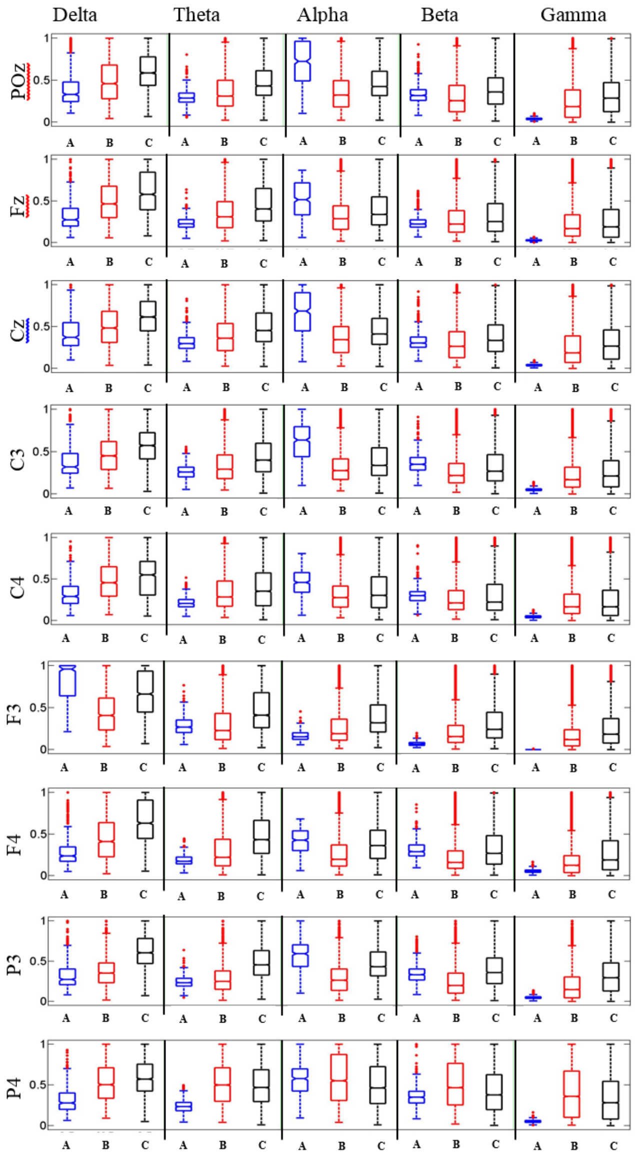


Fig. 7. Boxplot of wavelet EEG band features for group A, B and C while performing RDOT for all nine channels.

V. Conclusion

A quantitative comparative study and analysis of meditation practitioners and non-practitioners was done using EEG as a psychophysiological indicator. Wavelet decomposition based features from nine channel EEG was taken for the analysis. Topographical mappings of the features were done to observe the neuronal activation of different EEG bands during eyes closed at rest state and then focused gazing on a dot on screen. The activation of brain cortex during REC and RDOT task performed by three groups was evaluated and a comparative analysis was made about the positions and EEG frequency bands. The absorbed meditative state was separately analyzed and various position of brain cortex activation during absorbed state was reported. Overall, the wavelet feature based method adopted to evaluate the brain rhythmic activities was successfully used in creating discrimination as per the experience of and level of meditation of subject groups. The efficacy of the quantitative results may be utilized as neurofeedback for self-assessment of meditation.

References

[1] M. Arns, S. D. Ridder, U. Strehl, M. Breteler, A. Coenen, "Efficacy of neurofeedback treatment in ADHD: the effects on inattention, impulsivity and hyperactivity: a meta-analysis," *Clinical EEG and neuroscience*, vol. *40, no.* 3, pp.180-189, July 2009.

[2] D. C. Hammond, "Neurofeedback with anxiety and affective disorders," *Child and Adolescent Psychiatric Clinics*, vol. 14, no. 1, pp. 105-123, Jan. 2005.

[3] J. Gruzelier, "A theory of alpha/theta neurofeedback, creative performance enhancement, long distance functional connectivity and psychological integration," *Cognitive processing*, vo.10, no. 1, pp. 101-109, Feb, 2009.

[4] A. Chiesa, A. Serretti, "Mindfulness-based stress reduction for stress management in healthy people: a review and meta-analysis," *The journal of alternative and complementary medicine*, vol. *15*, no. 5, pp. 593-600, Nov. 2009.

[5] V. P. Perlo, "Fundamentals of Electroencephalography," *JAMA*, vol. *218*, no. 12, pp. 1833-1833, Dec. 1971

[6] J. R. Evans, A. Abarbanel, "Introduction to quantitative EEG and neurofeedback," Elsevier, May 1999 May.

[7] B. R. Cahn, J. Polich, "Meditation states and traits: EEG, ERP, and neuroimaging studies," *Psychology of Consciousness: Theory, Research, and Practice*, vol. 1, no. S, pp. 48-96, 2013.

[8] Chiesa, Alberto, and Alessandro Serretti. "A systematic review of neurobiological and clinical features of mindfulness meditations." *Psychological medicine*, vol. 40, no. 8, pp. 1239-1252, Aug. 2010.

[9] B. Stigsby, J. C. Rodenberg, H. B. Moth, "Electroencephalographic findings during mantra mediation (transcendental meditation). A controlled, quantitative study of experienced meditators," *Electroencephalography and Clinical Neurophysiology*, vol. 51, no. 4, pp. 434-442, Apr. 1981.

[10] R. Shankman, "The experience of Samadhi: An in-depth exploration of Buddhist meditation," Shambhala Publications; Dec. 2008.

[11] J. P. Banquet JP, "Spectral analysis of the EEG in meditation," *Electroencephalography and clinical neurophysiology*, vol. 35, no. 2, pp. 143-51, Aug. 1973.

[12] P. B. C. Fenwick, S. Donaldson, L. Gillis, J. Bushman, G. W. Fenton, I. Perry, C. Tilsley, H. Serafinowicz, "Metabolic and EEG changes during transcendental meditation: an explanation," *Biological Psychology*, vo. 5, no. 2, pp. 101-118, Jun. 1977.

[13] O. Swami, "Om Swami- A mystic's viewpoint," Internet: www.omswami.com [Sep. 21, 2018].

[14] W. Ting, Wu, Y. Guo-zheng, Y. Bang-hua, and S. Hong, "EEG feature extraction based on wavelet packet decomposition for brain computer interface," *Measurement* vol. 41, no. 6, pp. 618-625, Jul. 2008.

[15] S. Sadaghiani, R. Scheeringa, K. Lehongre, B. Morillon, A. L. Giraud, M. D'Esposito, A. Kleinschmidt, "Alpha-band phase synchrony is related to activity in the fronto-parietal adaptive control network," *Journal of Neuroscience*, vol. 32, no. 41, pp. 14305-14310, Oct. 2012.

[16] M. Kawasaki, K. Kitajo, and Y. Yamaguchi, "Dynamic links between theta executive functions and alpha storage buffers in auditory and visual working memory," *European Journal of Neuroscience*, vol. 31, no. 9, pp. 1683-1689, May 2010.