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EEG EXTRACTION FOR MEDITATION

JEN L. TEE*, WAI Y. LEONG

School of Engineering, Taylor's University, Taylor's Lakeside Campus,
No. 1 Jalan Taylor's, 47500, Subang Jaya, Selangor DE, Malaysia
*Corresponding Author: teejenlooi@gmail.com

Abstract

EEG is a convenient method to study the functional state of the brain and brain-body-mind connection. This study investigates the EEG signal during meditation; a mental activity described as being in a state of calmness and focused attention. The objective is to study and extract features present in the EEG signal during meditation. The approach taken to extract EEG features associated with meditation is done through time series analysis, using the normalised signal amplitude mean as the primary feature. EEG signal is recorded at point F3 and F4, during meditation and post-meditation. A significant difference in signal amplitude means between these two states of the mind was observed. A 82.4% classification accuracy was achieved when using a BLR model to automatically classify the signal amplitude mean.

Keywords: Amplitude mean, EEG, Feature extraction, Meditation, Time series analysis.

1. Introduction

In recent studies of meditation, many studies were focused upon the comparison of meditation group vs. non-meditation (control groups), with results showing certain positive traits, such as better emotional control, being displayed more strongly in the meditation group [1]. However, questions were raised whether the positive traits were a result of meditation activities, or people with certain traits are naturally drawn to engage in meditation activity. For the purpose of clearer study, the effects of meditation, a physiological marker of meditation must first be determined. Then, by using the physiological marker of meditation as an independent variable, quantitative studies of the effects of meditation be carried out with more clarity. Since meditation is primarily a mental exercise, the physiological investigation naturally starts with the brain.

The human brain is a biochemical and bioelectrical organ. The brain functions and communicates through neurotransmission, a phenomenon where signals are transmitted from one neuron to another via neurotransmitters. Neurons form an intricate network, and interaction among neurons gives rise to a dynamic ionic electrical fluctuation, commonly called 'brain waves', in the brain. 'Brainwaves' are not truly waves, which are produced by the brain but are thus called due to the observed rhythmic changes in neural activity that takes the form of sinusoidal waves. These rhythmic waveforms appeared to reflect certain mental functions of the brain. Through careful observation, it is possible to identify specific patterns associated with the different functional state of the brain and thus use the specific patterns, also known as EEG features, as classifiers of mental functions.

The research objective here is to investigate whether there are physiological differences in brain activity during meditation and during post-meditation. Extracted EEG features of each different state can in turn be used as a classifier. The specific activity being studied in this research is meditation vs. post-meditation (a mental activity of calm, focused attention).

Electroencephalogram (EEG), the recording of 'brain waves', is a term coined in 1924 by German psychiatrist Haas [2], who was the first to successfully describe changes in EEG recording associated with epilepsy.

Evolution in EEG equipment and measurement procedure has resulted in modern EEG measurements to be non-invasive. The measurement procedure is performed by placing a gold plated low impedance electrode on a person's scalp using a bit of adhesive conductive paste [3]. An EEG recording device has at least two electrodes, one placed at the reference point, often the ear mastoid, and the other electrode at a point of interest. Multiple electrodes can be simultaneously placed at the different point of interest. The EEG device compares the tiny fluctuating voltage at the measurement electrode with the reference electrode and registers the difference between them. It is common for EEG device to sample the measurements at a rate of 128 Hz, 256 Hz or higher, and changes in the difference between electrodes are recorded as a time series data set.

A standard electrode placement, the 10-20 electrode placement system shown in Fig. 1, was adopted by the International Federation in Electroencephalography and Clinical Neurophysiology in 1958 [4] and is a common configuration used in research [5].

An advanced EEG recording device with appropriate measurement procedures is required to reliably capture the desired signal, coupled with signal processing (filtering and feature extraction) steps to produce results that can be mapped to a various functional state of the brain.

In recent studies, numerous benefits have been associated with meditation [6-8], such as a reduction in stress level and reduced inflammatory responsiveness [6]; increased dopamine release in the limbic brain regions which is associated with motivation and feeling of joy; increased in blood plasma levels of melatonin and serotonin, both neuro-chemicals that play important roles in mood stabilisation, stress and aging prevention [9, 10]; superior control in selective and sustained attention and inhibitory control [11, 12]; scoring lower in personality features of anxiety, neuroticism, psychoticism, and depression, and scoring higher in emotion recognition and expression [13], which suggested better emotion management skills; and reduction in stress, anxiety, and rumination [14].

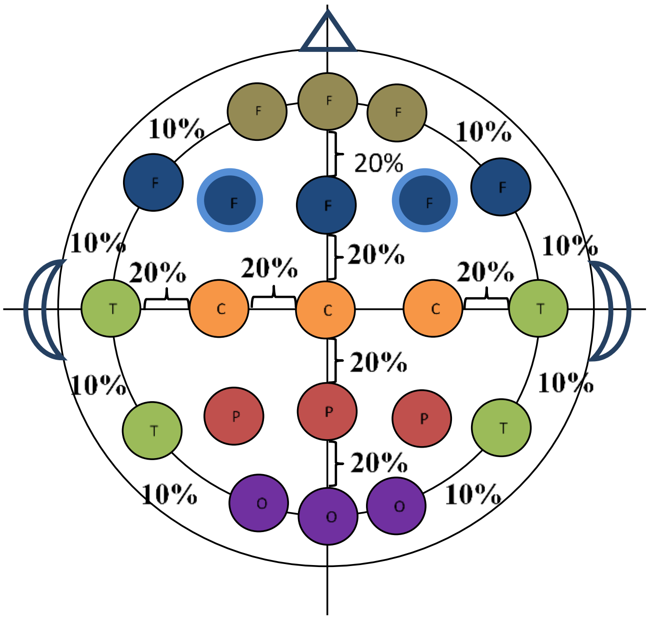

Fig. 1. Top view of subject's scalp showing a simplified 10-20 standard electrodes placement system for EEG electrodes.

However, meditation as a formal practice suitable as the clinical application was not widely established. While many studies were able to demonstrate positive traits associated with meditation, conclusions that were drawn from a comparison between long-term practitioners vs. control group raised questions toward whether the observed positive traits were causal effects of meditation practice or were naturally inherent between different demographic groups. A clearer understanding of meditation activity and any association to benefits must be reviewed before meditation could be adopted as a recommendable practice for a clinical purpose.

According to a review by Cahn and Polich [15], sixty-four EEG studies on meditation from 1957 until 2005 processed the EEG data using Power Spectrum

Density (PSD). The conclusion drawn by Cahn and Polich was while theta and alpha PSD activities appeared to be affected by meditation, no other inferences were notable. Contrary to this, more recent studies [16-18] (2010-2015) in meditation EEG still appeared to research within the area of PSD. This study proposes to leave the comfort zone of PSD and further explore alternative EEG features using variously available and more modern extraction methods.

2. Methodology

This study is based on an experimental setup. Equipment requirement for this study centralises around the Electroencephalogram. The device used is manufactured by CamNTech, named the CamNTech Actiwave Multichannel Recorder, a class 2a (EU) medical device. It includes the EEG recording device, electrode leads, conductive adhesive paste (for the interface between electrode and subject's scalp surface), and a docking interface which links the EEG recorder to a PC. The device comes with a user guide and the operational procedures were clearly described in the Actiwave User Guide [3].

One criterion in signal recording (sampling) lies with satisfying the Nyquist criterion. The Nyquist principle states that the sampling rate of the signal, *fs*, must exceed twice the maximum frequency, *BL* (band-limit), for the signal to be reconstructed from the sample, as shown in Eq. (1).

$$f_s > 2BL \tag{1}$$

This is a criterion that must be met in order to avoid signal aliasing, where two different sine waves can give the same samples if one of the sine wave has a frequency higher than half of the sampling frequency, rendering the actual (high frequency) data undetectable. Given that $x(t)$ is the original signal, and the Fourier transform of $x(t)$ is $X(f)$ as written in Eq. (2):

$$X(f) = \int_{-\infty}^{\infty} x(t)e^{-i2\pi ft}\,\mathrm{d}t \tag{2}$$

The Poisson summation formula is shown in Eq. (3):

$$X_s(f) = \sum_{k=-\infty}^{\infty} X(f - kf_s) \tag{3}$$

Poisson summation formula states that for $f > f_s/2$, the higher frequency component cannot be distinguished from a lower frequency component.

The Actiwave device sample signals at a rate of at least 128 Hz, and capable of scaling upwards to over 1024 Hz. Since most EEG signal of interest lies between 0.5 Hz-50 Hz range, which has been widely accepted and segregated into delta waves (0.5 Hz-4 Hz), theta waves (4 Hz-7 Hz), alpha waves (7 Hz-14 Hz), beta waves (14-30 Hz), gamma waves (31-50 Hz), these signals lie well within the measurement range of this measurement devices. Given the maximum frequencies of interest is 50 Hz, from Eq. (1) to Eq. (3), we calculated the minimum sampling frequency was 100 Hz. The device preset sampling frequency of 128 Hz was selected, as 100 Hz was not a selectable option.

Studies by [8, 15, 19, 20] have observed an increase in EEG theta band frequencies associated with meditation. The primary definition of meditation in this study is reliant upon the observation of increased theta band frequencies during the meditation process.

Theta Healing® [21], a meditation practice founded by Stibal, who authored a book titled under the same name, stated that the Theta Healing® technique is a meditation process, when performed accordingly to the instructions, stimulates the brain to produce observable signals in the EEG theta band frequencies. The sampling frame for this study is drawn from Theta Healing® practitioners from Malaysia, Singapore, and Australia. Data collections were conducted at Theta Healing® seminars, at the respective venue, with permission and prior mutual agreement. Data collection takes place in the late afternoon, after the conclusion of regular seminar activities.

This study took live EEG measurement of the participants under the direct supervision of a medical officer from Hospital Sungai Buloh. Collaboration with Hospital Sungai Buloh was undertaken to ensure that the EEG measurement procedure conforms to the best medical practice and to validate the accuracy of the result. Participation was strictly on a volunteer basis and recruitment was challenging. At the time of this study, only nine participants volunteered for the study.

Nine subjects, aged between 18-55, were tasked with performing focused attention meditation guided by an audio recording [22] according to the standard practice of Theta Healing®. The subjects were briefed with the procedure and remained seated comfortably during the measurement. EEG electrodes were placed on the F3 and F4 according to the EEG 10-20 standard placements of electrodes (corresponding to the brain's frontal lobe) of the subject. The F3 and F4 points are selected based on previous studies [16, 17], where F3 and F4 were some of the points where an increase in theta band frequencies during meditation are more observable.

EEG measurements of these two points will be recorded during meditation and after the mediation process stops. The audio recording guides participants through approximately eleven-minute visualisation meditation process. At the end of the audio recording, the subject is instructed to stop meditation activity. The EEG recording continues for another three minutes, recording post-meditation signal. EEG data were then extracted and evaluated. The collected data goes through a data processing flow as shown in Fig. 2.

3. Results and Discussion

EEG signal from nine subjects is recorded. Each recording yielded results from two channels (F3 and F4). Data from each channel were sampled twice; each sample segment is eight seconds in duration. A total of 34 meditation data and 34 post-meditation data were recorded. Figure 3 shows an example of an EEG recording.

Two 8 seconds segment of meditation data were extracted from between the 100-700 seconds time frame, with an example shown in Fig. 4. Two 8 seconds segment of post-meditation data were extracted from between the 850-950 seconds time frame, with an example shown in Fig. 5.

A segmented meditation signal, as shown in Fig. 4. depicted a relatively rhythmic brain activity with balanced positive and negative voltage spikes. Whereas in Fig. 5., the post-meditation signal shows voltage spikes that are much more lopsided on the positive voltage end. In order to quantify this qualitative observation, the instantaneous statistics of the signal, such as the signal mean was investigated.

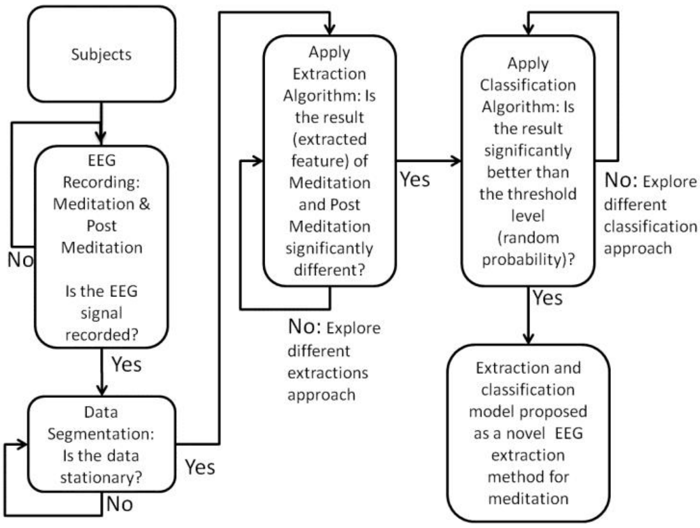

Fig. 2. Process flow diagram.

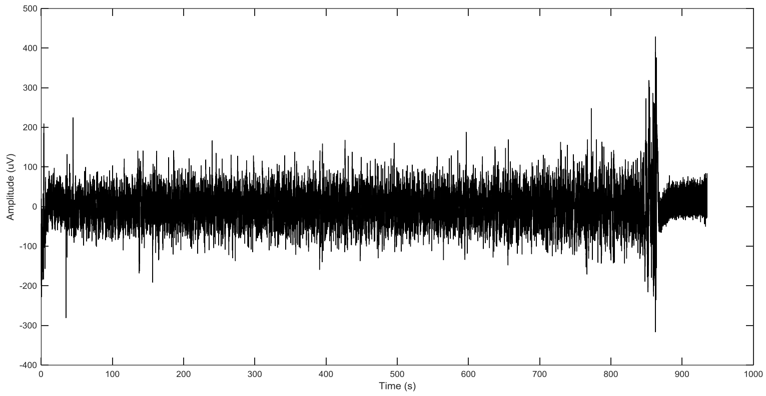

Fig. 3. EEG recording of F3 point of subject who began meditation at 0 second mark and stopped at 850 seconds mark.

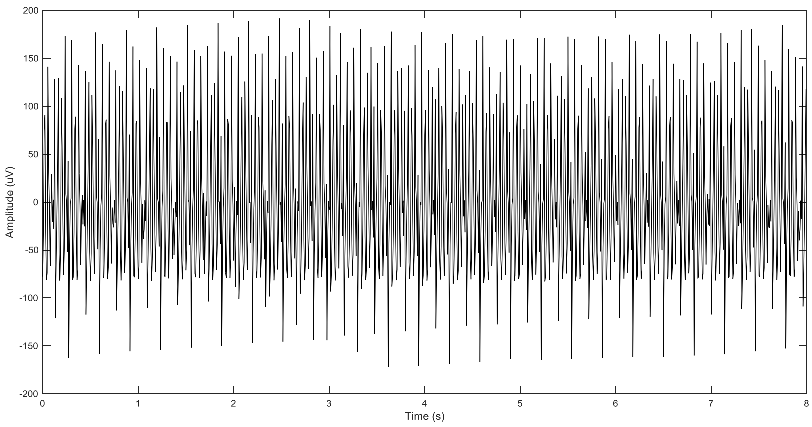

Fig. 4. Sample data of 8 seconds segment extracted from meditation period.

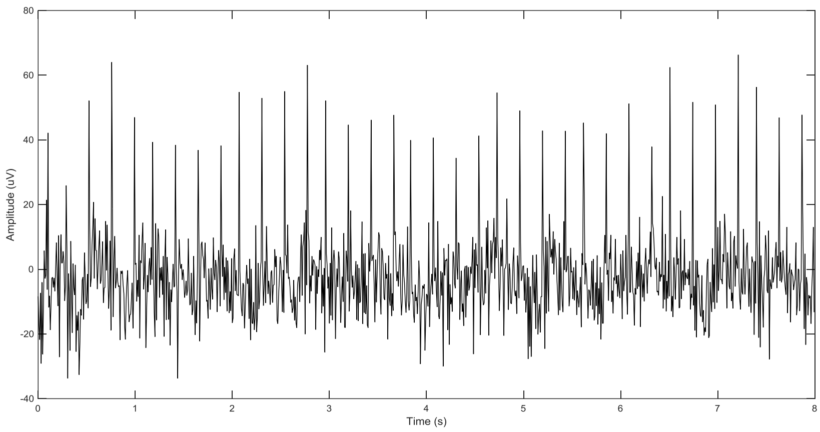

Fig. 5. Sample data of 8 seconds segment extracted from post-meditation period.

The time domain signal was first normalised and the amplitude means, median, standard deviation, maximum, minimum, and range were quantified and compared. Among these statistical data collected, the amplitude mean data presented the most significant difference.

By taking the average of the amplitude mean of each subject, the average meditation signal's amplitude mean is significantly lower as seen in Table 1.

The hypothesis of this study is there are differences between the EEG signals recorded during meditation compared to post-meditation. In order to test and confirm the hypothesis, a paired sample test was used to analyse the data. Log values of the signal amplitude mean were used in the test. Results are shown in Fig 6. The t value was -7.619, and the p-value was 0.000. Since the p-value is less than 0.05, it was concluded the average differences between meditation signal amplitude mean and post-meditation signal amplitude mean was significantly different by a mean of 1.240 (log scale).

A long whisker was observed in post-meditation signal data as can be seen in Fig. 6. These data specifically were recorded from subject #7 and #8. These data were observed to have low amplitude mean, similar to meditation data. It is likely these practitioners are still in meditation (state of a calm focused attention) during post-meditation, and these data collected during post-meditation still reflected a physical state of meditation, possibly causing a negative impact on the accuracy of this study. The larger standard deviation in the post-meditation data also supports the likelihood of this observation.

In order to classify, or predict, a person's mental state is in a state of 'meditation' or 'post-meditation' from EEG data, analysis using Binomial Logistic Regression was performed. Binomial Logistic Regression was chosen as the classification model because the independent variables were scalar and dependent variables were nominal values (i.e., meditation or post-meditation), and there were only two categories. There were 34 meditation samples and 34 post-meditation samples. The ratio of the samples was 50-50. As such, the classification threshold value is 50%.

Table 1. Signal amplitude mean and standard deviation comparison between meditation and post-meditation.

Signal Amplitude Mean		Standard Deviation	
Meditation	**Post Meditation**	**Meditation**	**Post Meditation**
4.44E-03	6.40E-02	1.17E-02	8.11E-02

Fig. 6. Logged signal amplitude mean comparison between meditation signal and post meditation signal.

The data were processed using SPSS Binomial Logistic Regression model. The resulting regression model was the best fit model for the data set that were inputted.

From the result of the analysis, the prediction accuracy achieved was 82.4%. Detailed results are shown in Table 2.

Table 2. Classification table using binomial logical regression.

			Predicted		
			State		Percentage
Observed			Post-Medi	Meditation	Correct
Step 1	State	Post-Medi	27	7	79.4
		Meditation	5	29	85.3
	Overall Percentage				82.4

The Nagelkerke R^2 was 0.405, and the Cox & Snell R^2 was 0.540. The Hosmer and Lemeshow Test results showed the Chi-square/*df* = 8.242/8 = 1.030.

The *B*-value of the constant was -4.959 and *B*-value of the independent variable Logged Signal Mean (LSM) was -2.146.

The resulted prediction equation was formulated as follow in Eq. (4):

$$P_R\left(\frac{Y}{X}\right) = \frac{e^{(-4.959+(--4.95)*-4.9}}{1+e^{(-4.959+(--4.95)*-4.9}} \quad (4)$$

When the output of the equation is greater than 0.5 based on the input value of LSM, the subject is classified as in a state of meditation.

4. Conclusion

EEG signal analysis has been widely applied in research of various areas, including but not limited to the study of human psychological responses, sleep, neurological disorder, and mental activities such as meditation. When exploring the literature of these research areas, noticeable differences among the advancement in EEG signal analysis techniques achieved in each area were obvious. EEG signal analysis in meditation is an area with room for improvement. The finding in this research, as intended, successfully offers an additional feature - the logged amplitude mean, to be used as a feature for classification in the study of meditation EEG.

A meditation activity classifier with 82.4% accuracy was achieved using binomial logical regression as a classifier, and the normalised EEG logged amplitude mean value as a feature. The classifier's accuracy leaves room for improvement. In order to improve upon this issue, it is suggested for further studies to have a larger sample size. It is also suggested to improve upon the data collection process, so as to maximise the distinction between the meditation state and post-meditation state by including EEG data from states of pre-meditation and to also benchmark results with participants that have totally no history of meditation practice.

Nomenclatures

B	Classifier constant
BL	Target signal frequency band limit
f	Variable in frequency, Hz
fs	Sampling frequency, Hz
k	Constant
P_R	Probability of classifier result
t	Variable in time, s
X(*f*)	Variable in (frequency domain), Hz
x(*t*)	Variable (time domain), uV

Abbreviations

BLR	Binomial Logistic Regression
EEG	Electroencephalography
EU	European Union
F3/F4	EEG measurement points on the frontal lobe
LSM	Logged Signal Mean
PSD	Power Spectral Density

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