Spectral Analysis of EEG Brainwave Frequencies on Yogic Practices

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Abstract: Spectral analysis is a fundamental part of EEG data analysis. The standard ranges of frequency bands are gamma, beta, alpha, theta and delta. Computer and information technology have advanced the study of the human brain with the development of EEG machines allowing for the measurement of brainwave activity. Data collected using these machines must be scientifically analysed to produce meaningful results thus the use of statistical software such as MATLAB with its toolbox EEGLAB are used to test and evaluate the data. In recent decades, researchers have explored the use of these technologies in relation to human health benefits. In this paper, the benefits of yogic practices on brainwave frequencies, and mental, physical, spiritual, and emotional health have been investigated. Studies explored have all shown positive changes in human health after the implementation of yogic practices by analysing the changes in alpha, theta, delta, gamma and beta brainwave frequencies.

IndexTerms – spectral analysis, EEG, yogic practices, meditation, brainwaves

INTRODUCTION

Spectral analysis of an EEG signal is core in EEG data analysis. In human EEG spectral analysis, there is a standard range for frequencies that has been given specific names, for example, gamma, beta, alpha, theta, and delta. Neurologists, psychotherapists, and researchers, together with other health care professionals have used computer and information technology (IT) to study the human brain with the use of spectral analysis of brainwave frequencies. It makes spectral analysis of the complex brain possible, thus unlocking a high point to study the science of the brain.

Brain activity in terms of chemical secretion and brainwave frequencies were once believed by scientists to be beyond one's ability to control, however, Swami Rama of the Himalayas was one of the first yogis to subject himself to experimentation which changed that belief by demonstrating on biofeedback. Swami Rama proved that one can control their brainwaves and other involuntary systems in the body consciously.

Zhuang et.al., (2009) states that the utilization of the EEG machine on the scalp can be used to detect Shen's electro-chemical activity in the brain which is continuously happening. The shapes and forms of the frequencies recorded have been categorized by scientists and it has been found that the wave shape, rhythm, and various electrical wave forms are associated with different types of mental activity. The EEG machine is used to measure brainwaves "by placing electrodes on the scalp to detect and measure electrical activity over a given period which have been studied to determine the relationships between frequencies of electrical activity or neural discharge patterns of the brain and its corresponding mental, emotional, and cognitive states" (Zhuang, et al., 2009).

Some scientists believe that almost all sickness relates to stress, which affects the whole body. Brainwave entrainment is highly recommended to change the state of one's brain to the alpha state to induce a positive effect on one's health, thereby reducing stress levels and changing one's perception of life. Along with this change, diet and exercise aid in reducing stress.

MATLAB SOFTWARE

Spectral analysis of EEG data, using the EEGLAB toolbox in the software MATLAB, produces the power spectrum of brainwave frequency. Spectral analysis aims to filter the various frequency components of an entire RR interval ("RR interval is the time elapsed between two successive R waves of QRS signal in electrocardiogram") and is the most popular approach to computing spectral indices based on Fast Fourier Transformation (FFT) (Cygankiewicz and Zareba, 2013).

MATLAB was invented by Cleve Moler, a mathematician and computer programmer, which he based on an idea he had during his PhD thesis in the 1960s. He became a mathematics professor at the University of New Mexico, then started to develop the MATLAB program for his students as a hobby. He initially developed MATLAB linear algebra programming followed by Fortran code for linear equations. His software was publicly disclosed in 1979 and in the 1980s, Cleve Moler and John N. Little reprogrammed MATLAB for IBM desktop. Then MATLAB C was created by John Little and Steve Bangert.

This software has MATLAB language ("a matrix-based language") embedded in its foundation, which allows the most natural expression of mathematical computation. The functions of MATLAB include data analysis, algorithm development, model development and application development which assists researchers with their projects from start to finish. It is used by millions of students, scientists, and engineers worldwide. MATLAB offers a "range of applications in industry, academia, deep learning, machine learning, signal processing, communications, image, video processing, control systems testing, measurement, computational finance, and computational biology". MATLAB toolboxes are designed by professionals, well-tested, and fully documented. The MATLAB software allows one to use various algorithms to work with their data, until one gets the desired results.

EEGLAB TOOLBOX

MATLAB offers a toolbox, EEGLAB, which is "interactive, for processing continuous and event-related EEG, and other electrophysiological data, time and frequency analysis, artifact rejection, event related statistics and several modes of visualisations of the average and single-trial data" (SCCN, 2023). Swartz Center for Computational Neuroscience (SCCN) (2023) states that "MATLAB is an interactive graphical user interface (GUI), allowing flexibility to users, interaction to high- density EEG, and other brain related data using Independent Component Analysis (ICA) and/or Time and Frequency Analysis (TFA) as well as a standard averaging method. EEGLAB users can access structured programs for storing, accessing, measuring, manipulating, and visualising event related EEG (electroencephalography) data". It is multifaceted in its abilities which include, but are not limited to, "academic research, GUI, multiformat data importing, high-density data scrolling, interactive plotting functions, semi-automated artifact removal, ICA, TFA, event and channel location handling, forward/inverse head/source modelling, defined EEG and STUDY data structures, and more than 120 advanced extensions" (SCCN, 2023).

Spectral Analysis

Bose (2019) explains that "Spectral analysis or Spectrum analysis is a method of evaluating a range of frequencies or quantities such as energy, eigenvalues and more in specific areas such as spectral theory in mathematics, spectroscopy in hardware device, and spectroscopy in chemistry and physics". The explanation continues by stating that "Spectral analysis is an important research tool for deciphering information in various fields of science and technology. It is based on the FFT theorem, which states that any waveform can be decomposed into a sum of sine waves at different frequencies with different amplitudes and different phase relationships. In research, spectral analyzing techniques were linked with several other methods like proportional, interpolation, time space domain transformation and the time domain refinement into the sampling method" (Bose, 2019).

Azar, et al. (2001) states that "spectral analysis and spectral techniques are important for a range of applications". Some of these applications include "semantic analysis of documents which produce cluster documents in areas of interest, collaborative filtering to determine the importance of data based, citations or link structure". It provides a model framing data and solving the resulting data problems with spectral analysis. It gives a valuable, strong justification to use spectral techniques for a range of applications.

Spectral analysis is based on both non-parametric and parametric methods. Non-parametric is based on a method of dividing time domain data into segments, applying FFT on each segment, computing the squared-magnitude of the transform, and summing then averaging the transform. These methods do not depend on the population and there are no fixed set of parameters available as well as no normal distribution available for use. Non- parametric methods are referred to as distribution-free methods, e.g., the Spearman's correlation test, sign test for population means and U-test for two independent means. The parametric methods are a set of fixed parameters which are used to determine a probability model as well as to determine if the population is normal. If it is not normal, one can easily approximate using a normal distribution. Parameters for using a normal distribution are the mean, and standard deviation. Some parametric methods use confidence intervals to determine population means for both known and unknown standard deviations, population variance, and to determine the difference of two means with unknown standard deviation. In the parametric method, "the model for generating the signal can be constructed with several parameters that can be estimated from the observed data. From the model and estimated parameters, the algorithm computes the power spectrum implied by the model" (Rajner, 2001).

EVALUATION OF MENTAL AND PHYSICAL HEALTH USING EEG

Saidatul et. al., (2011) believes that to study the behaviors of the brain, EEG analysis is very important. In this study, they show an integrated system to detect brain changes in conditions of mental stress and relaxation. Quantitative analysis of an EEG was carried out and the measured EEG properties were computed through power spectral density (PSD). PDS uses FFT Welch's method to calculate spectra and a neural network classifier was used to classify relaxation and mental stress conditions.

Ahani et.al., (2013) used spectral analysis to analyze data collected for EEG and respiration which were viable for meditation. They hypothesized that mindful meditation practiced on older people can reduce high stress levels. Signal process methodology was assessed using the EEG and respiration signals in meditation, under controlled conditions. Thirty-four (34) subjects were analyzed after six (6) weeks of meditation intervention and EEG was used for collecting respiration signals, with higher accuracy. Spectral analysis was used for the evaluation of the EEG data collected which resulted in differences in brainwave frequencies of alpha, beta and theta brainwave frequencies which proved that utilizing EEG and respiration were viable for meditation analysis. Kora et. al. (2021), examined the effects of yoga and meditation on brainwave frequencies with respect to physical and mental health and concluded that yoga and meditation improved the physical and mental health of those in the experiment. They used an EEG machine to measure brainwave frequencies of those involved in their experiment and classified brainwaves frequencies obtained into three main categories: preprocessing, feature extraction, and classification.

Huang and Lo (2009) conducted research by using an EEG machine to obtain measurements to aid in the comparison of twenty (20) Zen meditators for forty (40) minutes in their experimental group and twenty-three (23) subjects in the controlled group at rest (relax) for forty (40) minutes. The brainwave frequencies of the meditators were subjected to spectral analysis for the initial, middle, and final five (5) minutes of the forty (40) minute experiment. The results obtained during this meditation practice indicated that there was a significant increase in alpha brainwave activity in the frontal area of the brain, increase of occipital beta power and an increase in theta power. While the meditators showed changes in alpha, beta and theta brainwaves, the subjects of the controlled group displayed no significant changes which supports the conclusion that "Zen Meditation" generates changes in the electro-cortical activity in the brain.

Kaur and Singh (2015) hypothesized that a positive increase in the neurophysiological state of meditation can be explained by behavioral and psychological changes. With this in mind, their study focused on the examination of EEG brainwave frequencies obtained from recent scientific studies involving the practice of meditation. Recent research has found evidence that meditation relieves anxiety and depression, leading to a state of psychological well-being. More research is required with other designs with consideration on personality characteristics, to avoid negative effects, large sample size and randomized control trials.

Khare and Nigam (2000) performed research on meditators using an EEG machine on thirty (30) subjects who were normal, healthy, and practiced meditation and was compared with ten (10) subjects who were also normal and healthy but did not practice meditation. A significant increase of alpha wave activity was prominent, and voltage was increased in those who were meditating as compared to the controls who did not meditate. Increased alpha waves indicates a relaxed state of mind thereby proving that meditation aids in relaxation. The practice of coherent meditation also benefits the brain by providing it with “homogeneity, uniformity and orderliness” (Khare and Nigam, 2000) thereby reducing the stress levels of modern life. Khare and Nigam (2000) obtained EEG results proving that the increase in alpha brainwave activity was influenced by the meditation practices given because of decreased metabolism in the brain. Their findings involving the increase of alpha brainwave activity during meditation are consistent with previous experiments conducted by those such as Kaur and Singh (2015), and Huang and Lo (2005). Diaphragmatic breathing activates the alpha activity produced in meditators, unlike thoracic breathing. In most meditational methods, the breath becomes the object of awareness. Khare and Nigam (2000) stated that meditation develops the right hemisphere of the brain, which is associated with ten (10) abilities. During deep coherent meditation, it was found that brainwaves have the tendency to synchronize which directly correlated with the synchronization of both hemispheres of the brain allowing for the unification of logic and intuitive brain functions. This harmonization of brainwaves coincides with uniform frequencies and amplitudes of brain electrical activity as detected by EEG. These changes in brainwave activity, specifically alpha waves, were shown to persist even after the meditation practice was concluded. Improved mental health benefits were also observed in terms of self-confidence, a sense of well-being, increased concentration, reduced stress levels and enhanced cognitive functions.

The research done by Rodriguez-Larios, et. al., (2021) focused on determining the difference between the EEG spectral modulation of meditators versus non-meditators in order to quantify the distraction levels of both groups under observation. EEG was used to measure brainwave frequencies during the relaxation segment with a focus on two breaths during meditation practice. Twenty-nine (29) subjects with more than three (3) years’ experience in meditation and twenty-nine (29) subjects without any experience in meditation were observed for moments of distractions driven by task- irrelevant thoughts. It was reported that meditators showed a greater level of focus and reduced mind wandering during meditation while the controlled group did not show a reduction in mind wandering. EEG spectral modulations associated with meditation and mind wandering differed significantly between both control and experimental groups where meditators showed a significant decrease in alpha wave when meditators focusing on the breath was applied during meditation. It showed that meditation and mind wandering differs between meditators and non-meditators.

Deolindo, et. al., (2020) discussed a “critical analysis characterizing meditation through the use of EEG”, stating that “meditation has potential benefits to one’s mental and physical health”.

EEG was used as a tool to observe meditation experiences in healthy persons by implementing EEG signal processing techniques, and translating the measurements obtained in relation to meditation.

SPECTRAL ANALYSIS OF EEG DATA WITH RESPECT TO MEDITATION

(Data obtained during the practice of silence and meditation)

Meditation is comprised of many practices, various styles and forms. Some ancient practices that are carried out in present day are Buddhist meditation, Yoga, Tai Chi and Qigong. Due to the positive effects of meditation observed in research over the past few years, these practices have increased significantly in recent times to promote stress reduction, a state of well-being, regulation of emotions, attention control and cognitive performance, thus prompting the scientific community to take an interest in this area with adequate scientific methodology and instruments. Meditation has many methodological challenges because it encompasses subjective features (personal feelings) therefore until there is a universal definition for meditation, there will be limitations to this type of scientific research. Scientists have, however, developed initiatives to work with this limitation.

According to Deolindo, et. al., (2020), EEG was used as an assessment tool to measure meditation which determined that there was a correlation between the practice of meditation and the central nervous system. EEG is non-invasive, used in clinical practice extensively and it is relatively low-cost. The complexity of the EEG signals emits countless signal processing approaches that can explore the phenomenon of meditation. One of the primary features discovered during their EEG experiments was the emanation of alpha brainwaves from the occipital area, during eyes closed in meditation. EEG detects and measures the electrical signals on the scalp, and it is a direct and robust measurement of the synchronized activity of myriad neurons in the brain.

EEG emits an electric field thus producing electrical activity through the biological tissue where the farther away the source of the current, the greater the reduction of the amplitude of a signal (electric current or other oscillations), and the greater the coverage area. This process is called volume conduction, resulting in each EEG electrode measuring the activity from its vicinity, from distant cortical areas, and other electric sources. The source was seen to affect multiple electrodes, hence making the interpretation of EEG oscillatory challenging. It emphasized that EEG patterns that look alike cannot be used to infer that subjects have the same mental state as EEG signals change in real time with millisecond precision. Many neurons have a controlling influence on their activity to be detected by the EEG instrument, these can be observed with a low frequency. The EEG waves are higher power, in which the frequencies range from 1 to 30 Hz, and these frequencies are divided into bands. In the case of certain general boundaries not in consensus, some proposals have been made to establish the boundaries by considering the specificities of every person. The most common ranges are "Delta (0 – 4Hz), Theta (4 -8Hz), Alpha (8-14Hz), Beta (14-35Hz), and Gamma (35-45Hz)" while some research takes into consideration frequencies up to 200Hz as Gamma.

Recent research on meditation has predominantly used spectral analysis of EEG signals instead of simply performing a visual inspection of the scans in order to increase the accuracy of determining the signal characterization in the frequency domain. This allows for the EEG scans to be broken down into specific frequency bands thereby providing a more comprehensive description of the neuronal activity observed. FFT is largely used today as it was in the 1970's with Deolindo, et.al., (2020) reporting variations of spectral characteristics of EEG signals with an increased alpha brainwave activity in amplitude and reduction in frequency.

Dressler, et.al., (2004) stated that "spectral analysis is one of the standard methods used to quantify EEG signals and the power spectrum or spectral density reflects the frequency content of the EEG signals or the distribution of signal power over the frequency". Power spectral analysis calculates the "total power, spectral band power, median and spectral edge frequency" (Dressler et. al., 2004).

SPECTRAL ANALYSIS OF EEG RECORDINGS OBTAINED DURING RELAXATION TECHNIQUES

Jacobs and Friedman (2004) stated that "Relaxation Techniques (RT) have not been studied in detail and systematically and thus conducted on the effects of RT on the central nervous system (CNS) using spectral analysis of EEG data". Their experiment comprised of thirty-six (36) subjects influenced by music and RT for six (6) weeks to compare the effects on the CNS. The subjects listened to the practice through audio tapes and based on the power spectral analysis of the EEG scans, it was determined that all cortical areas of alpha and theta waves were affected. This was determined with the use of EEG as their tool for measuring brainwave frequencies of their subjects. The results showed that RT created a significant change and a greater increase of theta brainwave frequency in multiple cortical areas of the brain when it is compared to music.

Jacobs and Friedman (2004) experiments utilized power spectral analysis of alpha and theta brainwaves throughout all cortical areas of the brain. This method proves to be the most reliable for measuring the effects of RT on the CNS. Other findings were found to be consistent with the reduction of cortical activity and it showed that RT produced a greater reduction in CNS activity. Jacobs and Friedman (2004) concluded that RT created a hypoactive CNS state which corresponds to stage 1 sleep and "RT exerts its therapeutic effects through cerebral energy conservation restoration".

Jacobs and Benson (1996) discussed a "topographic EEG mapping of the relaxation response (RR)" and assessed the CNS effects on twenty (20) subjects listening to an audio tape to induce RR. The brainwaves of the subjects were detected and recorded by placing fourteen (14) EEG electrodes on their scalp. The RR produced an increase "$p<.0164$" reduction in the frontal area of the brain in EEG beta brainwave activity and it was reported that there were no significant differences observed in any other frequencies. The findings revealed that the RR produced a significant decrease in cortical activation in the brain.

In accordance with Sinha, et. Al., (2020), the cardiac center and cortical activity were affected by altered patterns of respiration. Theta brainwaves were associated with learning and a relaxed alert state while an altered state of breathing was effective in restoring cardiac autonomic balance. Thirty-two (32) male subjects participated in this experiment. EEG brainwaves were continuously recorded on "F3, F4, P3, P4, O1 and O2, cortical areas" during the respiratory intervention. Power spectral analysis for EEG was used to measure theta brainwaves and "Heart Rate Variability" (HRV) which resulted in apnea which caused theta power to decrease. It was concluded that altered respiration patterns caused a decrease in parasympathetic and an increase in the sympathetic nervous systems. There was also an increase in theta power in post tachypnea with a "posterior change of correlation between theta power and heart rate variability" (Sinha, et. al., 2020). A link determined between the cortical activity and the autonomic output due to altered respiratory patterns.

Brandani, et. al., (2017), examined "the hypotensive effect of Yoga's breathing exercises: A systematic review". They concluded that complementary therapies in clinical practices revealed a significant reduction of blood pressure and hypertension after the practice of pranayama.

REFERENCES

[1] Ahani, A., Wahbeh, H., Nezamfar, H., Miller, M., Erdogmus, D., & Oken, B. (2014). Quantitative change of EEG and respiration signals during mindfulness meditation. Journal of Neuroengineering and Rehabilitation, 11(1), 87. https://doi.org/10.1186/1743-0003-11-87

[2] Azar, Y., Fiat, A., Karlin, A., McSherry, F., & Saia, J. (2001). Spectral analysis of data. Proceedings of the Thirty-Third Annual ACM Symposium on Theory of Computing - STOC '01.

[3] Brandani, J. Z., Mizuno, J., Ciolac, E. G., & Monteiro, H. L. (2017). The hypotensive effect of Yoga's breathing exercises: A systematic review. Complementary Therapies in Clinical Practice, 28, 38–46. https://doi.org/10.1016/j.ctcp.2017.05.002

[4] Bose, P. (2019). What is spectral analysis in research methodology?. AZoOptics.com. https://www.azooptics.com/Article.aspx?cv=1&ArticleID=1649

[5] Cygankiewicz, I., & Zareba, W. (2013). Heart rate variability. Handbook of Clinical Neurology, 117, 379–393. https://doi.org/10.1016/B978-0-444-53491-0.00031-6

[6] Deolindo, C. S., Ribeiro, M. W., Aratanha, M. A., Afonso, R. F., Irrmischer, M., & Kozasa, E. H. (2020). A critical analysis on characterizing the meditation experience through the electroencephalogram. Frontiers in Systems Neuroscience, 14, 53. https://doi.org/10.3389/fnsys.2020.00053

[7] Dressler, O., Schneider, G., Stockmanns, G., & Kochs, E. F. (2004). Awareness and the EEG power spectrum: analysis of frequencies. British Journal of Anaesthesia, 93(6), 806–809. https://doi.org/10.1093/bja/aeh270

[8] Huang, H.-Y., & Lo, P.-C. (2009). EEG dynamics of experienced Zen meditation practitioners probed by complexity index and spectral measure. Journal of Medical Engineering & Technology, 33(4), 314–321. https://doi.org/10.1080/03091900802602677

[9] Jacobs, G. D., Benson, H., & Friedman, R. (1996). Topographic EEG mapping of the relaxation response. Biofeedback and Self-Regulation, 21(2), 121–129. https://doi.org/10.1007/bf02284691

[10] Jacobs, Gregg D., & Friedman, R. (2004). EEG spectral analysis of relaxation techniques. Applied Psychophysiology and Biofeedback, 29(4), 245–254. https://doi.org/10.1007/s10484-004-0385-2

[11] Kaur, C., & Singh, P. (2015). EEG derived neuronal dynamics during meditation: Progress and challenges. Advances in Preventive Medicine, 2015, 614723. https://doi.org/10.1155/2015/614723

[12] Khare, K. C., & Nigam, S. K. (2000). A study of electroencephalogram in meditators. Indian Journal of Physiology and Pharmacology, 44(2), 173–178.

[13] Kora, P., Meenakshi, K., Swaraja, K., Rajani, A., & Raju, M. S. (2021). EEG based interpretation of human brain activity during yoga and meditation using machine learning: A systematic review. Complementary Therapies in Clinical Practice, 43(101329), 101329. https://doi.org/10.1016/j.ctcp.2021.101329

[14] Mariappan, R., & Subramanian, M. R. (2019). Experimental investigation of cognitive impact of yoga meditation on physical and mental health parameters using electro encephalogram. In Soft Computing and Medical Bioinformatics (pp. 129–139). Springer Singapore.

[15] Rodriguez-Larios, J., Bracho Montes de Oca, E. A., & Alaerts, K. (2021). The EEG spectral properties of meditation and mind wandering differ between experienced meditators and novices. NeuroImage, 245(118669), 118669. https://doi.org/10.1016/j.neuroimage.2021.118669

[16] Saidatul, A., Paulraj, M. P., Yaacob, S., & Yusnita, M. A. (2011). Analysis of EEG signals during relaxation and mental stress condition using AR modeling techniques. 2011 IEEE International Conference on Control System, Computing and Engineering.

[17] SCCN. (2023). "What Is EEGLAB?". Swartz Center for Computational Neuroscience. sccn.ucsd.edu/eeglab/index.php#:~:text=EEGLAB%20is%20an%20interactive%20Matlab,of%20the%20averaged%20and%20single. Accessed 17 Mar. 2023.

[18] Sinha, M., Sinha, R., Ghate, J., & Sarnik, G. (2020). Impact of altered breathing patterns on interaction of EEG and heart rate variability. Annals of Neurosciences, 27(2), 67–74. https://doi.org/10.1177/0972753120950075

[19] Zhuang, T., Zhao, H., & Tang, Z. (2009). A study of brainwave entrainment based on EEG brain dynamics. Computer and Information Science, 2(2). https://doi.org/10.5539/cis.v2n2p80