

EEG signal analysis and neural correlates underlying brain stimulation therapies: A Review

Chamandeep Kaur*

Department of Electronics and Communication Engineering, Panjab University Chandigarh.

Preeti Singh,

Ph.D, Assisstant Professor, Department of Electronics and Communication Engineering, Panjab University Chandigarh, India.

Sukhtej sahni

MD Psychiatry, Department of Psychiatry, Cheema Medical Complex, Mohali, India

Abstract— With recent rise in computer and information technology, the area of medicine and rehabilitation has changed the way to provide health care. The overall aim of this study is to review therapeutic effects of brain stimulation therapies and the underlying EEG neural correlates. Signal processing procedures are in growing demand for better understanding of complex non- linear and dynamic behavior of mind. For that, a wide range of feature extraction algorithms extract non linear information in EEG signals. So, a wide research on EEG feature extraction algorithms has also been reviewed as signal processing can contribute to advance this field of neuroplasticity.

Keywords—Brainwave entrainment, binaural beats, EEG signal processing, virtual reality therapy, EEG biofeedback.

I. INTRODUCTION

Cognitive control is essential aspect of intellectual behavior by which cognitive system can manage processes to regulate one's own life [1, 2]. A better functioning brain can well manage depression, sleep disorders and anxiety. So, in recent years, research evidences have suggested that various brain stimulation therapies can have beneficial effects for a healthy brain. Also, neural related changes due to mental trainings are effective for a longer period of time than antidepressants which become inactive after a period of time [3].

The EEG neural correlates of such therapies are being studied in variety of domains. The overall aim of this study is to review therapeutic effects of brain training and the underlying EEG neural correlates. Along with, signal processing challenges for representing and analyzing EEG signals will be explored in detail to scientifically study the neuro-electrophysiology.

II. EEG BRAINWAVE PATTERNS

Neuroplasticity refers to the changing and adapting ability of brain as a result of experience. Numerous researches have been carried out to scientifically of training based neural changes is an open question. Medical imaging applications such as MRI (Magnetic Resonance Imaging), MEG (Magnetoencephalography), rCBF(regional Cerebral Blood Flow) and EEG (Electroencephalography) have allowed to explore neural behavior. An EEG recording has been a very important tool for diagnosing various neurological disorders. The scalp

electrodes, that contain the brain activity in terms of electric potentials, give signals which can be processed using signal processing algorithms to measure different mental activities and to reveal cognitive tasks. The internal language of mind can be understood using different EEG patterns from mind's EM field activity. EEG is a clinically proven analytical tool and analyzing it visually is a brief and complex task. Brain activities are characterized by different frequency bands. Raw EEG data is characterized by delta ($\delta < 4$ Hz), theta (θ , 4-7 Hz), alpha (α , 8-12 Hz), beta (β , 13-30 Hz) and gamma ($\gamma > 30$ Hz) bands [7]. Figure 1 gives a description of these frequency rhythms without including the gamma waves. Gamma waves are higher while maintaining abstract visual profiles in short term memory and higher in focused stimuli. Sometimes gamma waves are of no clinical interest and are filtered out in EEG recordings as muscle artifacts.

III. BRAINWAVE STIMULATION

Brainwave Entrainment: It is also called Audio- Visual Stimuli (AVS) where light or sound stimuli are used to train the brain waves. A study on the regulatory mechanisms of sensory stimulation based central nervous system (CNS) has revealed entrainment to be one of the well known methods for patients suffering from migraine, depression, sleep disorders and endodontic anxiety. The therapeutic effect of audio-visual program has been explored. Recent evidences showed that 3 Hz sound stimuli makes subject to reach theta stage and approximately 10 Hz stimulation takes subject to alpha state i.e. relaxed state. This method has been used for stress related to sports, public interaction, writing tests and phobias [4].

Repetitive AVS showed increase in theta- 1, theta- 2, and alpha-1 in frontal and central cortex. Also, an increase in delta- 1 coherence, gamma coherence and decrease in alpha- 2 coherence in parieto- occipital area was observed. It accounts for increased relaxed period. Alpha and theta power increase reflect sensorimotor and mental rest state. But, a number of findings have been reviewed that showed inconsistent results of changes in alpha band during AVS. Some of the studies showed no significant relaxation but a change in altered state of consciousness [5]. Strong cortical EEG activity has been theorized in response to flash light stimuli than auditory stimuli. Power increases are observed if stimulation frequency overlaps with subject's internal alpha frequency. Response was strongest for resting EEG's peak alpha. Most of the earlier researchers analyzed alpha activity in occipital area but recent studies showed activities of mixed frequencies. Still, extra research is required to analyze EEG changes during photic stimulation [6].

Binaural beat brainwave entrainment is adopted by those who want simple method to relieve anxiety and who find meditation to be hard task to perform. It can be taken to be an alternate for meditation. There is scientific evidence supporting the binaural beats as affecting states of consciousness. More enhanced positive mood and alertness effects are reflected during beta frequency beats as compared to theta/ delta frequency beats [7]. Evidences also support brainwave entrainment in the form of improving moods, deep sleep patterns and increased immune system that is shown by increased delta frequency, 1-4 Hz. It helps in supporting sharpen memory, deep relaxation as evident from theta frequency, 4-8 Hz. Also supports positive thinking and improved learning process, increased alpha frequency (8-13 Hz), and improves alertness as evident from decreased beta frequency (14-24Hz) [8].

It is the process of exciting desired frequency of brain wave using light stimuli, sound stimuli or both. It is also known as Frequency Following Response (FFR) that works by giving some external rhythmic stimuli. The brain responds back to coordinate with that rhythm by coordinating its own electrical cycles. So, the results have proved that binaural beats can enhance mind controllability. But still more reliable and stable results are required to efficiently present this method. Further area of research has been proposed to compare alpha and gamma waves in response to binaural beats. Binaural beat stimulation has beneficial though not significant effects for children with attention deficit hyperactive disorder (ADHD). It has been proved that binaural beats at different sound frequencies resulted in sharpen memory and vigilance. The frequency ranges of binaural beats are

described in table 1. Listening to binaural beat in beta range resulted in increase in theta and decrease in beta compared to children without ADHD. This accounts for improved concentration power [9]. Also, the auditory steady state evoked potential response to other beats e.g. acoustic and monaural beats has been tested in [10, 11].

Virtual Reality Therapy (VRT) and EEG biofeedback: Therapies based on virtual environments are gaining interest in the field of neuroplasticity. Cognitive behavioral therapy aggravates patients with fear and anxiety to generate the required stimuli. VRT provides solution from placing subjects into unsafe situations. Gesture therapy based on virtual environment has been presented to improve cognitive disability in patients suffering from stroke. It is an integrated virtual environment that provided rehabilitation with repetitive movement skills. Such home rehabilitation on the basis of a vision system is called Gesture Therapy (GT). But its advantages over conventional therapies need to be explored in detail though its use has been supported and motivated by those who used this therapy [12- 13].

Biofeedback is a type of neurofeedback that measures brain waves and produces a feedback signal on brain activity and thus teaches self regulation. The brain responds to the feedback given by video display and the desired normal (without disability) EEG pattern is obtained. Gamma based activity (GBA) and beta based activity (BBA) based on neurofeedback showed that improving gamma and beta activity using feedback in the occipital and frontal areas alters the behavior, whereas GBA controls and manages short term and long term memory fastening mappings, BBA improves memory familiarity processes [14]. Another gamma based, increased Sensory Motor Rhythm (SMR) and better controlled theta activity based neurofeedback has been tested on the cocaine addicted subjects. Further research is required to remove the presented limitations in this study [15]. Upper alpha frequency based neurofeedback training improves cognitive stability [16, 17]. The effectiveness of alpha- EEG biofeedback training for stress suppression and for anxiety disorders has also been reviewed. The problem of frequency resolution needs to be minimized for better outcomes. Combination of virtual reality and EEG biofeedback has been beneficial for ADHD (Attention Deficit Hyperactivity Disorder) [18].

Shirodhara Therapy: The therapeutic effectiveness of Shirodhara (Indian oil treatment) has been studied in detail. In this practice, some oil is dropped on the forehead of the subject for 10 minutes. Shirodhara has been one of the curative technique for fighting insomnia, headache, anxiety neurosis, depression, motor neuron diseases. Kazuo et al have presented the physio-psychological changes during shirodhara by using a healing robot as a computerized operator. The state of restfulness with less anxiety is achieved in one month. The LF/HF ratio (cardiac sympathetic index) of R-R variable of ECG showed reduction (due to reduced anxiety levels) while parasympathetic index i.e. HF power showed no significant changes. EEG reflected increased alpha coherence, shift of high alpha power from occipital to frontal region. This alpha power shifted back to occipital region after shirodhara. These changes account for restful alertness. Further exploring, the study showed improved loss-of time perception during routine hours. Altered states of consciousness (ASC) scores were high in area of abstraction, passiveness, timeless sensation, wordless sensation and concentration. Continuous shirodhara helped to improve life styles of smokers, patients with arrhythmias and obesity. So this method theorized that results obtained by ECG and EEG correlate with the relaxed state experience of shirodhara. While increased stress level of technicians supported the use of healing robot. Further research will provide wide knowledge and a new tool for exploring states of consciousness in the field of spiritual biotechnology [19].

IV. SIGNAL PROCESSING CHALLENGES

Signal Processing (SP) can contribute to advance the field of neuroplasticity. Extracting the EEG features that are influenced by mental practice defined various dynamics that explained large scale neuronal behavior of mind.

A superior research is still required to categorize the EEG signatures corresponding to training practices. A wide range of algorithms extract the non linear information in EEG signals like algorithms based on Fast Fourier Transform (FFT), Hilbert- Huang Transform, Wavelet Transform, rule based expert systems, time- frequency analysis and numerous other algorithms to define the temporal extents. A method based on PBFT (Period based Frequency Tracker) has been proposed to keep track of rhythmic variations of alpha frequencies. These instantaneous variations are important for studying various modes of meditations. Though STFT (Short Time Fourier Transform) can analyze such spectral variations but this method proved better in terms of fairer frequency resolution. Also, problem of asymmetrical periodicity of EEG has been solved reliably and efficiently [20-21]. Also, Adaptive Auto Regressive parameters (AAR), multivariate and bilinear AAR, Genetic Algorithms (GA), PCA (Principal Component Analysis), ICA (Independent Component Analysis) and Wavelet Packet Decomposition (WPD) have also been used. Out of these most widely used are ICA, PCA, WT, AR, WPD and FFT [22]. The inherent inhomogeneous characteristics and multi nature of EEG signals are dealt with non linear signal processing techniques like biological time series analysis on the basis of various parameters for example- CD (Correlation Dimension), LLE (Largest Lyapunov exponent) and H (Hurst exponent). Another area of research is Multiscale Fractal Dimension (MSFD) method that explains the temporal patterns of EEG [23- 26].

A review of various algorithms proved that one of the superior power extraction algorithms for motor imagery tasks can be the Morlet wavelet in EEG based BCI's (Brain Computer Interfaces) [27]. A crisp and consistent observation of a particular EEG component and its changing direction as either increasing or decreasing are still required. Also, more processing tools and engineering approaches are required to be investigated for exploring EEG information.

V. CONCLUSION

In recent years, cognitive regulation and enhancement is the growing area of research. Nowadays, complementary therapies are being used in clinical practices. In this paper, brainwave entrainment, virtual environment based therapeutic effects and EEG biofeedback has been reviewed as tabulated in table 2. It is required to consider larger samples to properly establish the training effects.

Binaural beat is rhythmic stimuli that makes brainwave to follow a desired audio frequency. Evidences support brainwave entrainment in the form of improving moods, deep sleep patterns and increased immune system that is shown by increased delta frequency, 1-4 Hz. But still more reliable and stable results are required to efficiently present this method. Therapies based on virtual environments like Gesture Therapy and based on EEG biofeedback, are gaining interest in the field of neuroplasticity. Studies have shown the evidences that neuroplasticity changes occur after therapeutic effects of neurofeedback in patients with disorders such as ADHD, dementia and stroke and it improves concentration and working memory performance. But its advantages over conventional therapies need to be explored in detail though its use has been supported and motivated. Shirodhara Therapy reflected the state of restfulness with less anxiety in one month. Further research will provide wide knowledge and a new tool for exploring states of consciousness in the field of spiritual biotechnology.

Signal Processing aspects in the field of cognitive neuroplasticity have also been discussed. Similarly, a brief research on EEG feature extraction algorithms has been done. A superior research is still required to categorize the EEG signatures corresponding to different practices. Still a large area of research for the neural changes underlying brain training is required.

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VI. REFERENCES

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Fig. 1: EEG brainwave patterns

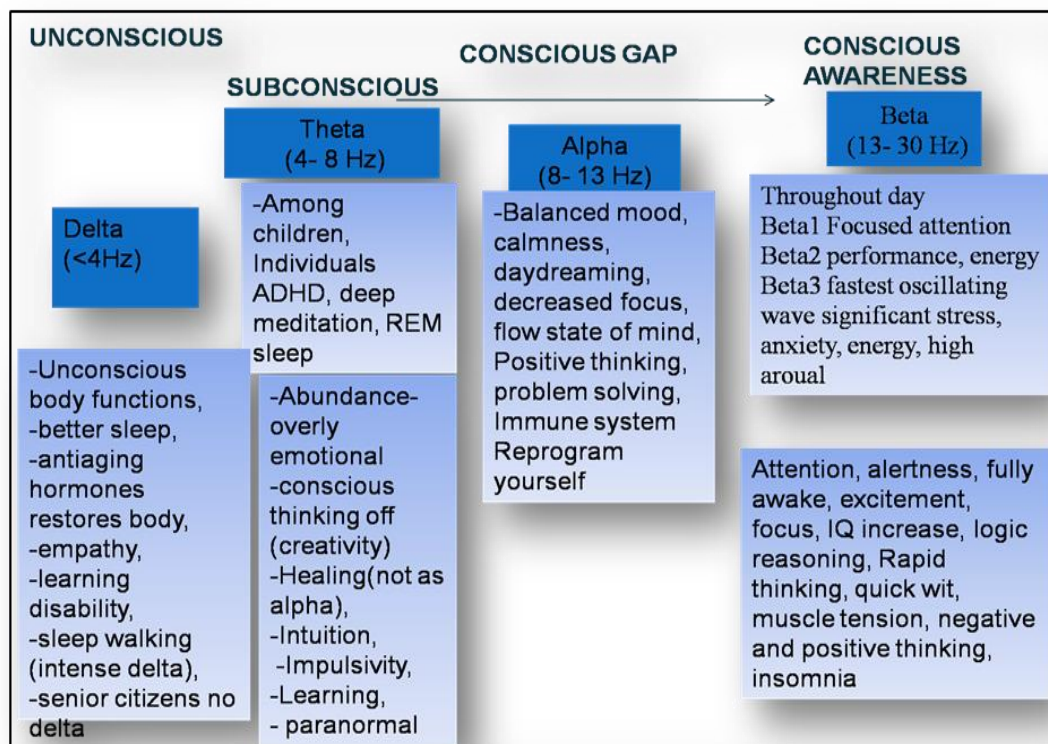


Table 1: Frequency ranges of binaural beats

Frequency Ranges of Binaural Beats	Description
Delta (1-4 Hz)	Associated with sleep
Theta (4- 8 Hz)	Reflects slow brain activity
Alpha (8- 13 Hz)	States of awakesness and relaxation
Beta (16- 24 Hz)	States of alertness and concentration

Table 2: Training induced scientific mechanisms of brain waves by means of EEG bands and coherence

Brain Training	Brain mechanisms	Significance	Challenges
<u>Brainwave Entrainment</u>	<ul style="list-style-type: none"> Increased theta- 1, theta- 2, alpha-1 in frontal and central cortex Increased delta- 1 coherence, gamma coherence and decrease in alpha- 2 coherence in parieto- occipital area Strong cortical EEG activity than for auditory stimuli 	<ul style="list-style-type: none"> Increased relaxed period and mental rest state Improved concentration Enhanced positive mood and alertness, sharpen memory, deep relaxation Positive thinking and improved learning process Improved moods, deep sleep patterns and increased immune system Sharpen memory, deep relaxation 	<ul style="list-style-type: none"> No significant relaxation Inconsistent results More reliable and stable results required
Long term AVS			
Flash light stimuli	<ul style="list-style-type: none"> Beta range beats Alpha range beats 		
Binaural beats	<ul style="list-style-type: none"> Delta range beats Theta range beats 		
<u>Virtual Reality Therapy and Biofeedback</u>	<ul style="list-style-type: none"> Alpha based neurofeedback Gamma based neurofeedback Beta based neurofeedback 	<ul style="list-style-type: none"> Stress suppression, Improved cognitive stability Enhanced Memory Controlled theta activity 	<ul style="list-style-type: none"> Problem of frequency resolution, Advantages over conventional therapies
<u>Shirodhara</u>	<ul style="list-style-type: none"> Decreased nuLF/HF No change in nuHF Increased alpha coherence More frontal alpha than occipital* 	<ul style="list-style-type: none"> Reduced anxiety level Restful alertness 	Needs vast exploration