Toward EEG Spectral Analysis of Tomographic Neurofeedback for Depression

Chamandeep Kaur and Preeti Singh

Abstract Neurofeedback (NF) or electroencephalography (EEG) biofeedback is a capable of expansion of brain–computer interface (BCI). It uses the fact of training subjects to achieve cortical oscillation modulations which has been facilitated using human–machine interface by making use of computer softwares. Up till now, many reports have focused on efficacy of NF in context of clinical and non clinical applications. In that direction, this work is focused to evaluate the spectral analysis of EEG signals for tomographic NF (a solution to EEG inverse problem). Z-score standardized low resolution electromagnetic tomography (sLORETA) NF has been provided to a patient detected with depression. Proposed work observed the increase in alpha, theta/beta ratio and decrease in beta after providing the 16 sessions. It illustrates the fact that tomographic NF could have greater impact on depression.

Keywords EEG · Neurofeedback · Human–machine interface · *z*-Scores · sLORETA

1 Introduction

One of the major challenges in modern society is to boost the cognitive functions, to improve cognitive impairments or psychosomatic ailments, thus, improving the quality of life. The knowledge of immense trouble linked with neurological and cognitive disorders is being considered. The progress of HMIs (Human–Machine Interfaces) has offered various strategies to provide neurorehabilitation. Neurofeedback (NF) based operant conditioning is one of them. Up till now, many reports have focused on efficacy of NF in context of clinical and non clinical

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applications. NF is achieving recognition for improving the signs of depression but more rigorous real-world researches are required to explore information of neural correlates of performance under NFT (Neurofeedback Training) to evaluate its effectivity. So, there is need to design and implement NF system to treat mild to moderate depression. Further, there have recently been developments in traditional NF procedures. The present work presents an advanced tomographic NF system based on electroencephalography (EEG) neuroimaging technique for depression. Here, superseding purpose is to examine rapidly building up evidence base for efficacy of *z*-score standardized low resolution electromagnetic tomography (sLORETA) NF in terms of EEG spectral power analysis.

2 What is Neurofeedback

Human–machine interface interprets various brain processes to derive external computer devices using software applications. NFT is state-of-the-art training that is based on principle of operant learning. NF accounts for permitting the individuals to change their cortical activity based on the biofeedback that is facilitated through HMIs using computer applications. The feedback is defined on the particular features of brain cortical action, so that the behavior should be influenced potentially. Subjects change their electrical activities such as amplitude, frequency, or the coherency. In this training, first of all, individual EEG signal is recorded; required intended frequency part is cut off using filtering, specified information concerned with that component is fed back using video and/or audio signal [1].

2.1 Tomographic Neurofeedback

EEG has the disadvantages of poor spatial resolution due to inverse problem and increased distance between source and the sensors. Such points account for limitations of traditional NF. Spatial nonspecificity of particular electrode site results in little spatial information from single channel EEG. This limitation can be improved by involving information that is more spatially specific and that can be achieved through electromagnetic tomographic method that is, an inverse solution method. So, major limitation of traditional method is spatial nonspecificity. General model of EEG source localization is generated expressing the experiential EEG data $S(t)$ as linear function of BES (Brain Electrical Sources) $J(t)$ according to quasi-static approximation of Maxwell's equation.

$$S(t) = GJ(t) + E \tag{1}$$

This is the branch of EEG inverse problem typical formulation [2]. So, the inverse problem deals with dilemma of estimating the distribution of BES (factors such as orientation, position and the magnitude) from measurements of EEG that is noisy. In Eq. (1), G is gain matrix of lead fields of dipole sources and this transfer matrix is denoted as lead field matrix. E is additive noise. This estimation problem is very exigent because $J(t)$ is dimensionally much bigger than $S(t)$. Nonetheless, fairly accurate guess of $J(t)$ is possible to acquire. The nonparametric inverse solver methods include MNE (Minimum Norm Estimate), LORETA (Low Resolution Electromagnetic Tomography), sLORETA, and Bayesian approach [3], etc. Faster knowledge by low-cost EEG-based NF can be stimulated if a process is generated that provides training in a specific area of brain, which is termed as an inverse solution scheme.

2.2 z-Score sLORETA NFT

Various new methods are rising for enhancing the training designs and also it is possible in present time to identify definite brain procedures which lie beneath behavior and symptomatology so that targeted feedback can be directly provided like live z-scores. The live z-Score training is based on the normal equation given as,

$$z = \frac{x - \bar{x}}{\sigma}, \tag{2}$$

where x is current sample, $\bar{x}$ is the mean reference value and σ is the standard deviation. The amalgamating rationale of z-Score biofeedback is to emphasize extreme scores (outliers) in the direction of $Z = 0$, which is arithmetical center of a group of healthy normals.

The sLORETA is based on least square (min two norms) solution which is discrete, distributed, linear, and instantaneous solution of inverse problem. MNE can be changed to noise-normalized methods like sLORETA by conversion to statistical parametric maps considering the noise. It regiments the source distribution a posteriori by taking variance of each projected source,

$$\hat{J}_{\text{sLORETA}} = \hat{J}^{T}_{\text{MNE},l}\left\{\left|V_{\hat{J}}\right|_{ll}\right\}^{-1} \tag{3}$$

The $\hat{J}_{\text{MNE},l}$ is the density estimate of current density of lth voxel as defined by MNE. $V_{\hat{J}}$ is variance of current density estimate and $\left\{\left|V_{\hat{J}}\right|_{ll}\right\}$ is diagonal block at position l of resolution matrix $V_{\hat{J}}$. SLORETA is not the estimation of intensity of source but its probability to reveal high amplitude compared to others [4]. One study based on sLORETA concluded important aspects of tNF albeit no significant improvement observed in the ROT, which was, ACC (Anterior Cingulate Cortex) [5].

Another new domain of NF has been shown relevant to z-scores. LORETA and sLORETA can be shared with z-scores, so that each of the brain region is estimated in comparison with a database of brain action.

3 Literature Review

NF field was started in 1960s with experiment conducted by Kamiya et al. who proposed the possibility of learning brain activity controls with the help of feedback in the form of EEG-based frequency power, ERP (Event Related Potential), and SCP (Slow Cortical Potential) protocols [6]. Later on, various successive studies showed successful efficacy of NF for ADHD (Attention deficit hyperactivity disorder), epilepsy, schizophrenia, and many more applications [7–9]. It has been theorized that NF can be used as an alternate to antidepressants [10]. Baehr et al. theorized NF to be effective than psychotherapy for improving symptoms of depression disorders [11]. Hammond acknowledged intense declines in depression symptoms after providing NF and photic stimuli [12]. Another research concluded the alpha–theta NFT for alchoholics with symptoms of depression to be effective [13]. Also reducing the beta3 frequencies could have more impact on the analysis [14]. There are limited studies taking tomographical specificity into consideration. In that direction, an individualized protocol has been designed for depression in this paper by using new design measure like z-Score sLORETA-based NF training.

4 Methodology

4.1 Neurofeedback Protocol and Data Collection

EEG biofeedback has been provided using the BrainMaster Atlantis hardware to a single patient detected for depression on the basis of the (i) rating scale scores (ii) after comparing the deviances in standard deviations from normative database stored in Neuroguide software. Total 16 sessions, each of 20 min has been provided by using 19 electrode z-scores based PZOKUL sLORETA training. Individualized qEEG (quantitative EEG) protocol was provided for each session. Sampling rate of the data is 256 Hz.

4.2 EEG Signal Processing

First of all, EEG signals in edf (European data format) were preprocessed using EEGLAB toolbox. For analyzing the NF system, relative powers of EEG were analyzed. The discrete wavelet transform with db5 wavelet function was used for calculating the relative powers. Also, for some of the bands, ratios of corresponding powers were evaluated for all the sessions.

5 Results and Discussion

Main aim of the present paper was to find out the relative power changes in EEG bands. Along with it, power ratio of theta/beta has been identified within each session and from session 1 to 16. For evaluating the importance of EEG changes within each session and with the number of sessions, statistical analysis using one-way ANOVA has been performed with $\alpha = 0.05$.

EEG spectral changes within each session: Results show that within a session, changes were significant for relative powers of theta, alpha, and beta. Within the session theta and alpha were increasing with more significant change for alpha with $F(1, 7)$ 11.8 with $p = 0.01$. The value of beta was decreasing with $p < 0.01$ as shown in Table 1. Figure 1a shows the average theta/beta ratio change within 20 min of a session.

EEG spectral changes across the sessions: ANOVA supports the changes in EEG powers with significant change in alpha with $F(1, 31) = 35.4$ and for theta/beta ratio as $F(1, 31) = 36.7$ with $p < 0.001$ as shown in Table 2. Increased alpha activity and decreased beta accounts for relaxation. Figure 1b shows the average change in theta/beta ratio from session 1–16. As overall alpha is increasing, it may represent alleviating the symptoms of depression after the training.

Table 1 ANOVA results for EEG changes within a session

EEG spectral measure	Degree of freedom	F statistic	P	Direction
Relative_Theta_Power	7	6.97	0.03	Increase
Relative_Alpha_Power	7	11.8	0.01	Increase
Relative_Beta_Power	7	14.7	0.008	Decrease
Theta/Beta ratio	7	12.07	0.01	Increase

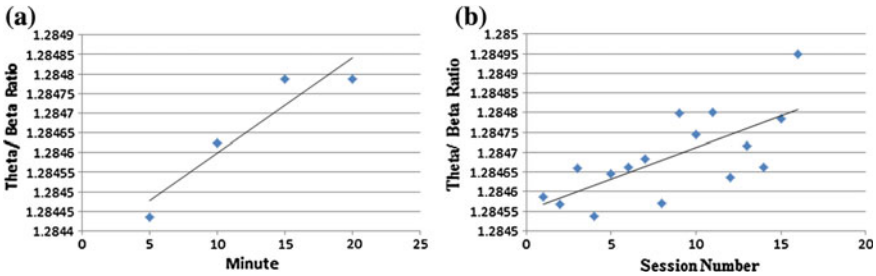

Fig. 1 Average variations in Theta/Beta ratio for **a** within a session for 1–20 min and **b** across 1–16 sessions

Table 2 ANOVA results for EEG band changes across 1–16 sessions

EEG spectral measure	Degree of freedom	F statistic	P	Direction
Relative_Theta_Power	31	14.4	0.006	Increase
Relative_Alpha_Power	31	35.4	<0.001	Increase
Relative_Beta_Power	31	20.6	<0.001	Decrease
Theta/Beta ratio	31	36.7	<0.001	Increase

6 Conclusion

In recent years, there has been a great deal on the progress of HMIs that have offered various strategies to provide neurorehabilitation. NF uses the fact of training subjects to achieve cortical oscillation modulations, which in the past has been extensively explored for treatment of conditions correlated with altered cortical oscillations. In this paper, it has been examined whether NF training can alter cognitive functions in depression disorder. To achieve this, pre and post qEEG analysis has been done after providing z-Score sLORETA NFT to a single subject. The power analysis has shown that there is an improvement in EEG measures. More alpha and theta activity with reduced beta activity accounts for reduction of symptoms of depression. Further, a larger effect size- based analysis with inclusion of control group is being planned. Also, more EEG measures can add up to the efficacy of the modality.

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