Processing the Results of Electroencephalography for Patients Suffering from Depression after Neuro-electrostimulation Course: Case Study

Vladimir Kublanov and Anton Dolganov
Research Medical and Biological Engineering Centre of High Technologies, Ural Federal University,
Mira 19, 620002, Yekaterinburg, Russian Federation

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Abstract: The article presented the results of electroencephalography (EEG) signal processing in a case study of neuro-electrostimulation application for patients suffering from depression. Neuro-electrostimulation was performed by the SYMPATHOCOR-01 device in two modes - multichannel and single-channel stimulation. The analysis of changes in the EEG activity maps during neuro-electrostimulation course was carried out. The common conclusion for all patients is an increase in the homogeneity for the distribution of spectral power density for EEG signals. A quantitative method for estimating the level of the brain zones activation was proposed. For patients from the multichannel stimulation group, an increase in the activation level was observed. It was noted that for patients from the single-channel stimulation group there were zones in which a significant decrease in the level of activation was observed.

1 INTRODUCTION

The depressive disorder is rapidly spreading of among the able-bodied population in the developed countries. This determines the relevance for search of an effective ways of treatment and rehabilitation approaches to mitigate this disease. Unfortunetley the depressive disorder can occur at any age, resulting in sharp limitation of a person’s adaptation to constantly changing environmental conditions (Culpepper et al., 2015).

The problem of depression is primarily determined by the lack of knowledge about the pathophysiological mechanisms of this disease. Recently, in developed countries, number work has emerged on the use of neuroimaging techniques to solve this problem. For example, when analyzing brain activity using fMRI, it was found that, compared with practically healthy patients, patients with depression experience different patterns of impairment of the cerebral cortex during the patient's life (Schmaal et al., 2017).

The most common approach to normalize and strengthen the physiological activity of brain tissue is neuroprotective therapy (Kupfer et al., 2012). This therapy is mainly implies application of drugs. The use of drugs does not always exclude side effects. To a lesser extent, this refers to physiotherapeutic methods, especially methods that use low-intensity electric current for stimulation (Cook et al., 2016).

Promising for solving the problems of neurorehabilitation are technologies in which multi-electrode stimulation systems are used. This direction is actively developed in the works of research teams headed by Y. Danilov and V.S. Kublanov. There, for neurorehabilitation, a spatially distributed field of monopolar low-frequency current pulses is used, the characteristics of which are similar to endogenous processes in neural networks. In the known technical implementations of such devices, either branches of the cranial nerves (PoNS device (Danilov et al., 2015)) or cervical ganglia of the sympathetic nervous system (SYMPATHOCOR-01 device (Kublanov et al., 2017)) are used as targets for stimulation.

The SYMPATHOCOR -01 device implements the technology of multichannel neuro-electrostimulation. This technology allows physician to manage the activities of conductive formations and performs the process of neuromodulation. Medical use of the device SYMPATHOCOR -01 is implemented as a method of DCASNS - a dynamic

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correction of the activity of the sympathetic nervous system. The DCASNS method provides correction of autonomic balance, determined by the ratio between the activity of the parasympathetic and sympathetic divisions of the autonomic nervous system (Petrenko et al., 2015).

The purpose of this work is to process the results of electroencephalography (EEG) in assessing the effectiveness of electrical neurostimulation device SYMPATHOCOR-01 for patients suffering from depression.

2 MATERIALS AND METHODS

2.1 Case Study Group

The case study involved 6 subjects diagnosed with a depression. The study was approved by the ethical committee of the State Scientific-Research Institute of Physiology & Basic Medicine (Protocol No. 13 of November 16, 2017).

The subjects were divided into two groups. In the first group, the neuro-electrostimulation device SYMPATHOCOR -01 was used in the multichannel stimulation mode. The upper and middle ganglia of the sympathetic nervous system were selected as targets.

In the second group, a neuro-electrostimulator was used in the single-channel stimulation mode; descending nerve fibers to the stellate ganglion were selected as targets.

Table 1 summarize data on the case study group.

Table 1: Case study group data.

Case history	Mode
794	multichannel
798	single-channel
864	single-channel
862	multichannel
863	single-channel
865	multichannel

2.2 Study Description

The study used a 126-channel EEG recording system. The sampling rate was 1000 Hz. Registration of EEG took place simultaneously with fMRI studies (Sokolov et al., 2017). During the study, the subjects lay at rest (Rest State). In the study the electrode location system 10–5, which is a more dense version of the system 10–20 (Oostenveld and Praamstra, 2001). An example of the location of the electrodes in three-dimensional space is presented in Figure 1.

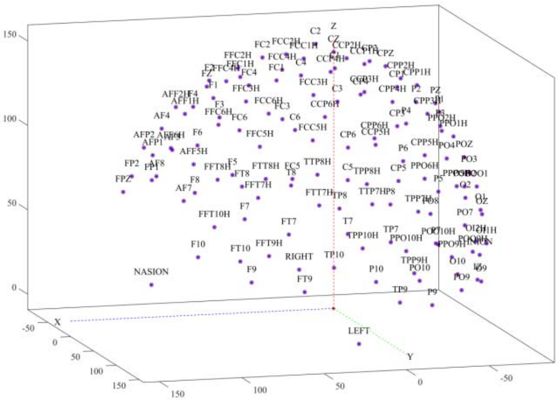

Figure 1: 3-D representation of the electrode location.

In the present work, the features of EEG signals recorded during primary studies (prior to the neuro-electrostimulation course) and after stimulation procedures.

The time of registration of EEG signals was about 10 minutes. The first and last minute of the EEG signals were excluded from the analysis due to the presence of motion artifacts.

2.3 Data Analysis Methods

To process the EEG signals, is an open source software toolkit for MATLAB – EEGLAB – was used. This toolkit is a practical implementation of the functions and graphic interface used in the processing and visualization of electrophysiological signals (Delorme and Makeig, 2004).

After importing the “raw” EEG signals, spectral powers were evaluated. In this wour, we investigated four spectral ranges:

- Delta rhythm - from 3 to 4 Hz;
- Theta rhythm - from 4 to 7 Hz;
- Alpha rhythm - from 8 to 15 Hz;
- Beta rhythm - from 16 to 31 Hz;

It should be noted that in the delta rhythm frequencies below 3 Hz were not analyzed, due to the presence of noise.

Evaluation of the spectral components in the EEGLAB is carried out using the function *pop_spectopo*(*EEG*, *TIME*), where the *EEG* variable is a matrix of EEG signals from time for each of 126 channels. The *TIME* variable contains information about the beginning and end of the time interval, within which the spectral component is assessed. In the present work, the evaluation of the spectral components was carried out in 10-second windows, with an overlap of 5 seconds. In total, spectral indices were obtained for each subject in 80 epochs. The result of using the *pop_spectopo* function is the Spectral Power Density, estimated by the Welch method, for each channel for all frequencies. The spectral power estimates are presented on a logarithmic scale (Welch, 1967).

The power estimation in the studied frequency ranges was carried out by summation over the corresponding frequencies. Thus, for each channel, for each subject, four spectrograms were obtained, describing the change in spectral power densities by epochs.

For evaluation of the localization in different activation zones, it was proposed to group 126 EEG channels into 11 zones - frontal (left and right - F_L, F_R), temporal (left and right - T_L, T_R), central (left and right - C_L, C_R), occipital (left and right - P_L, P_R), parietal (left and right - O_L, O_R). Separately zone Z was considered, which took into account the channels located on the central axis. The division of the EEG channels into zones is presented in Table 2.

Table 2: Distribution of channels by zones.

Zone	EEG channel
Z	'FPZ' 'FZ' 'CPZ' 'CZ' 'IZ' 'PZ' 'OZ' 'POZ'
F_R	'AF3' 'AF7' 'AFF1H' 'AFF5H' 'AFP1' 'F1' 'F3' 'F5' 'F7' 'F9' 'FFC1H' 'FFC3H' 'FFC5H' 'FP1'
F_L	'AF4' 'AF8' 'AFF2H' 'AFF6H' 'AFP2' 'F10' 'F2' 'F4' 'F6' 'F8' 'FFC2H' 'FFC4H' 'FFC6H' 'FP2'
T_R	'FFT7H' 'FFT9H' 'FT7' 'FT9' 'FTT7H' 'T7' 'TP7' 'TP9' 'TPP7H' 'TPP9H' 'TTP7H'
T_L	'FFT10H' 'FFT8H' 'FT10' 'FT8' 'FTT8H' 'T8' 'TP10' 'TP8' 'TPP10H' 'TPP8H' 'TTP8H'
C_R	'FC1' 'FC3' 'FC5' 'FCC1H' 'FCC3H' 'FCC5H' 'C1' 'C3' 'C5' 'CCP1H' 'CCP3H' 'CCP5H' 'CP1' 'CP3' 'CP5'
C_L	'FC2' 'FC4' 'FC6' 'FCC2H' 'FCC4H' 'FCC6H' 'C2' 'C4' 'C6' 'CCP2H' 'CCP4H' 'CCP6H' 'CP2' 'CP4' 'CP6'
P_R	'CPP1H' 'CPP3H' 'CPP5H' 'P1' 'P3' 'P5' 'P7' 'P9' 'PPO1H' 'PPO5H' 'PPO9H'
P_L	'CPP2H' 'CPP4H' 'CPP6H' 'P10' 'P2' 'P4' 'P6' 'P8' 'PPO10H' 'PPO2H' 'PPO6H'
O_R	'O1' 'O9' 'OI1H' 'PO3' 'PO7' 'PO9' 'POO1' 'POO9H'
O_L	'O10' 'O2' 'OI2H' 'PO10' 'PO4' 'PO8' 'POO10H' 'POO2'

The estimation of changes in the level of activation in the zone is proposed. Initial data were used to estimate the average level of the spectrogram value in the zone over the entire time interval for all channels (activation threshold). Then, for each time epoch, the proportion of channels that exceed the activation threshold was estimated. The same activation threshold was used in the analysis of signals recorded after neuroelectrostimulation procedures.

3 RESULTS

3.1 Power Spectral Density Visualization

Figures 2-3 show the visualization of the spectral power density of EEG signals before and after neuro-electrostimulation for a patient CH794.After the procedures of neuro-electrostimulation for patient CH794, normalization of activity is observed — after the stimulation procedures, the distribution of spectral power is more uniform. At the same time, it is worth noting a statistically significant increase in the power level in the frontal and occipital zones by more than 10 dB, for delta and beta rhythms, and by 7 dB for theta and alpha rhythms.

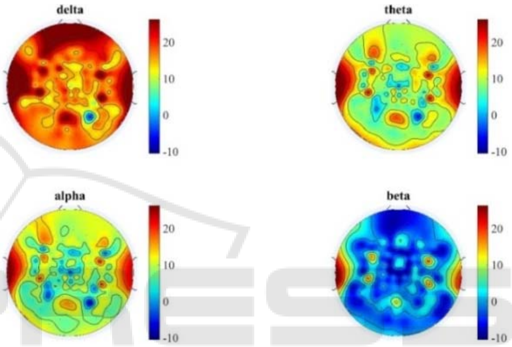

Figure 2: Visualization of power density for patient CH794 before stimulation.

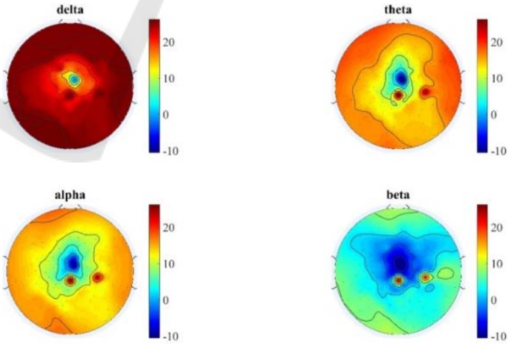

Figure 3: Visualization of power density for patient CH794 after stimulation.

Data for patient CH862 indicate a slight change in the activity of spectral powers. It is worth noting the decrease in power of EEG signals for all four rhythms by 10 dB in the central zone of the brain (electrodes Cz, C1, C2, FCZ, CPZ).

The most significant changes for patient CH865 are observed for the beta rhythm in the right occipital region (about 7 dB). It is worth noting the decrease in EEG activity in the central zone for the delta, theta and alpha rhythms (8 dB), the increase in the activity of the theta rhythm in the frontal zone (4 dB), as well as the increase in the activity of the delta rhythm in the right temporal zone (6 dB).

Figures 4-5 show the visualization of the power spectral density of EEG signals before and after neuro-electrostimulation for patient CH798.Data for patient CH798 indicates that the changes are asymmetrical: for the left side (electrodes F5, F3, FC5, FC3, C5, C3, CP5, Cp3, P5, P3), an increase in the EEG power for theta and alpha rhythms by 8 dB is observed, for delta and beta, the spectral power increase by 4 dB. At the same time, for the right side (electrodes F4, F2, FC4, FC2, C4, C2, CP4, CP2, P4, P2), in delta, theta and alpha rhythms, a decrease in EEG power is observed by 8 dB and by 6 dB in the beta rhythm.

Analysis of the results for patient CH863, indicates a local change in the power of the EEG. For the delta, theta, and alpha rhythms, an increase in the spectral power is observed by 7 dB in the region of the T8, FC6, FC4, FC2, and FC1 electrodes. For the beta rhythm, there is a decrease in EEG power by 8 dB in the area of the electrodes FCZ, Cz and CPZ. It should be noted that after the neuro-electrostimulation procedures, the activity of the EEG rhythms became more homogeneous - local heterogeneities in the center disappeared.

For patient CH864, it is worth noting the decrease in EEG activity for all rhythms in the area of the Cz electrode. At the same time, there is a slight increase in the power of the left half of the brain for the delta and theta rhythms by 4 dB.

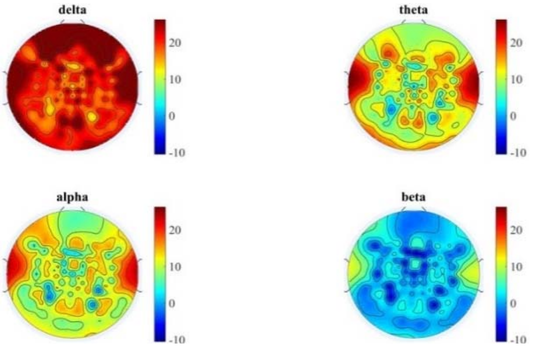

Figure 4: Visualization of power density for patient CH798 before stimulation.

Summarizing the analysis of visualization of the spectral power density of EEG signals, it can be concluded that the most significant changes are observed for patients CH794 and CH798. At the same time, changes for patient CH794 (from the group of multichannel stimulation) were more pronounced, while for patient CH798 (from the group of single-channel stimulation) the changes were asymmetric. In general, for all patients, an increase in spectral power uniformity is observed.

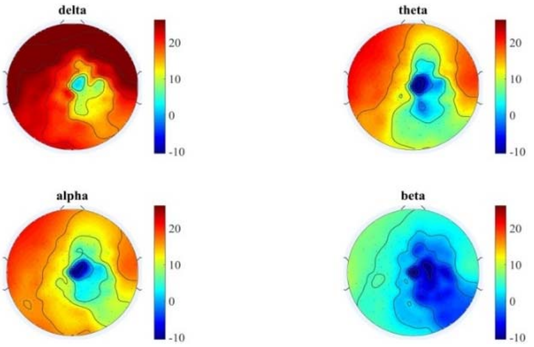

Figure 5: Visualization of power density for patient CH798 after stimulation.

3.2 Evaluation of the Activation Level

Figures 6-8 show the bar graphs of the level of activation of the EEG channels for 11 zones, before (blue) and after stimulation (yellow) for the multichannel stimulation group. Activation of 100% is obtained when spectral power of all channels in zone is higher than threshold.

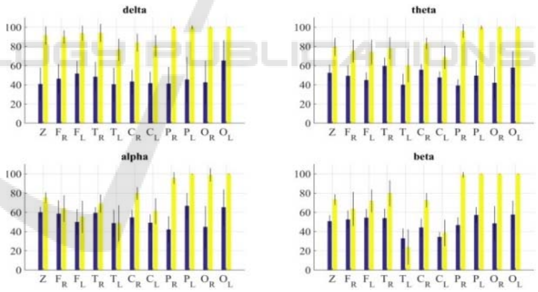

Figure 6: CH794; estimation of activation level, %.

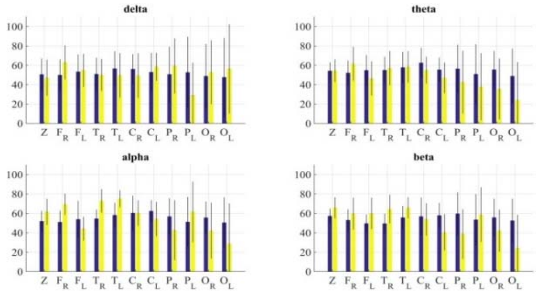

Figure 7: CH862; estimation of activation level, %.

According to Figure 6, it can be concluded that the activation level increases for all EEG rhythms for patient CH794. The most significant changes are in all zones for the delta rhythm, as well as the occipital zones (P and O) for theta, alpha and beta rhythms. It should be noted that the level of activation varies slightly during the study.

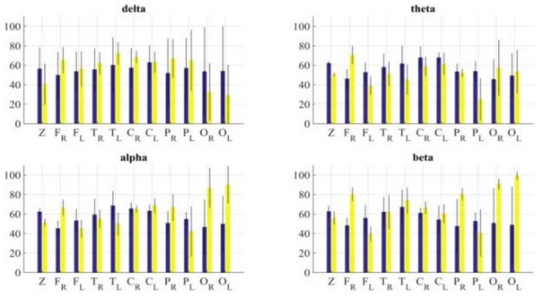

Figure 8: CH865; estimation of activation level, %.

According to Figure 7 for the patient CH862, the level of activation basically remained the same. The increase in activation in the temporal zones (T_R and T_L) for the alpha rhythm is statistically significant. At the same time, it is worth noting the increase in the degree of scatter of the level of activation during the study after the neuro-electrostimulation procedures.

Based on the data of Figure 8, it can be concluded that for patient CH865 is the most significant increase in the level of activation in the occipital zones (O_R and O_L) for alpha and beta rhythms. At the same time, it is worth noting the increase in the activation level for theta, alpha and beta rhythms for the right frontal zone (F_R).

Figures 9-11 show the bar graphs of the level of activation of the EEG channels for 11 zones, before (blue) and after stimulation (yellow) for a single-channel stimulation group.

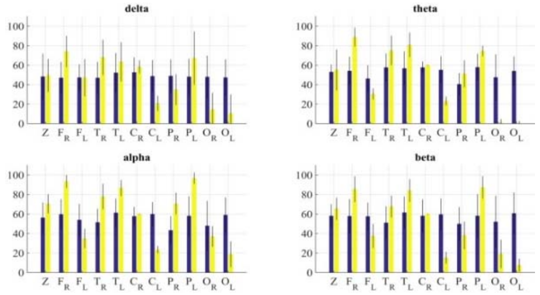

Figure 9: CH798; estimation of activation level, %.

The data on Figure 9 indicate the diversified nature of changes in the level of activation in patient CH798. For all rhythms, an increase in the level of activation is observed for the right frontal zone, as well as a decrease in the level of activation for the occipital zone and the left central zone. For theta, alpha and beta rhythms it is worth noting a significant increase in the level of activation in the temporal zones, as well as in the left parietal zone.

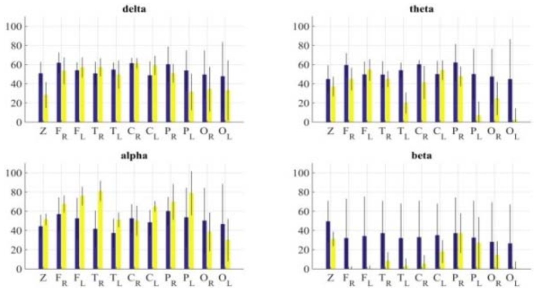

Figure 10: CH863; estimation of activation level, %.

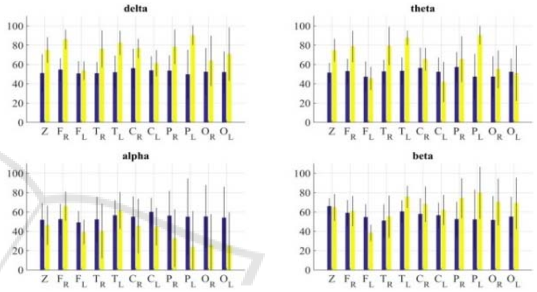

Figure 11: CH864; estimation of activation level, %.

Based on the graphs shown in Figure 10, it can be concluded that for patient CH863, there is a decrease in the level of activation for theta and beta rhythms. For the alpha rhythm, an increase in the activation level is observed for the left frontal, right temporal and left parietal.

The bar graphs shown in Figure 11 indicate that patient CH864 experienced an increase in the activation level for most zones in the delta and theta rhythm. For the alpha rhythm, a decrease in the level of activation in the parietal and occipital zones is observed.

Summing up the evaluation of the brain areas activation level, it can be concluded that an increase in the level of activation is observed for patients from the group of multichannel stimulation, this is especially pronounced for patient CH794. It is noted that for patients from the single-channel stimulation group there were zones in which a significant decrease in the level of activation is observed.

4 CONCLUSIONS

The article has presented the results of EEG signal processing in a case study of neuro-electrostimulation therapy application for patients suffering from depression. The neuro-electrostimulation procedures were tested in two modes – multichannel and single-channel stimulation.

Summarizing the analysis of visualization of the spectral power density of EEG, it can be concluded that the most significant changes have been observed for patients CH794 and CH798. At the same time, changes for patient CH794 (from the group of multichannel stimulation) had been more pronounced, while for patient CH798 (from the group of single-channel stimulation), the changes had been asymmetric. In general, for all patients, an increase in EEG power uniformity has been observed.

A quantitative method for estimating the level of activation of brain zones has been proposed. Initial data (prior to the neuro-electrostimulation procedures application) were used to estimate the average level of the EEG spectrogram value in the zone over the entire time interval for all channels (activation threshold). Then, for each time epoch, the proportion of channels that exceed the activation threshold was estimated. The same activation threshold was used in the analysis of signals recorded after neuro-electrostimulation procedures.

Considering the evaluation of the brain areas activation level, it could be concluded that an increase in the level of activation was observed for patients from the group of multichannel stimulation, this is especially pronounced for patient CH794. It was noted that for patients from the single-channel stimulation group there were zones in which a significant decrease in the level of activation was observed.

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