Journal of Physics: Conference Series **741** (2016) 012073 doi:10.1088/1742-6596/741/1/012073

Cross MFF–analysis in studying the obsessive-compulsive disorder

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Abstract. There were demonstrated capabilities of the Memory Function Formalism (MFF) in analyzing cross correlations in human brain bioelectric activity at obsessive–compulsive disorder (OCD). To extract the information about collective phenomena in (electroencephalogram) EEG brain activity we use the power spectra of memory functions and the memory quantifiers. We discover the pairs of the electrodes with the greatest differences in dynamic and stochastic parameters for patients with the different condition. The high OCD condition is characterized by the influence of the memory effects. The MFF cross correlation analysis allow to describe the collective phenomena in EEG dynamics at OCD including the dynamic, spectral and stochastic behavior.

1. Introduction

The objective diagnostics of mental disorders at early developmental stages is obstructed due to absence of instrumental method of fixation, though relation of such disease to inevitable changes in the activity of separate areas of the brain cortex of a man seems evident. The most disorders haven't the objective diagnostic criteria. At this rate, schizophrenia, bipolar affective or obsessive-compulsive disorders (BAD and OCD) are diagnosed based on criteria in either the American Psychiatric Association's fifth edition of the Diagnostic and Statistical Manual of Mental Disorders (DSM 5), or the World Health Organization's International Statistical Classification of Diseases and Related Health Problems (ICD-10). One of the limitations of instrumental diagnosis of psychiatric disturbances is a study of the signals of human brain


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activity: electroencephalogram (EEG), magnetoencephalograms (MEG), reflecting functional activity of different brain regions. However in papers [1, 2] it is shown that BAD and epilepsy are manifested in the specific behavior of synchronization effects and in spectral properties of alpha rhythm. In [3] on the basis of the flicker-noise spectroscopy authors have formulated the criteria of degree of the susceptibility to schizophrenia in children/adolescents. In [4] it is demonstrated that the method based on the memory function formalism (MFF) can discover the susceptibility to schizophrenia by analyzing the collective phenomena in the cerebral cortex bioelectric activity. Within the framework of MFF [5, 6, 7] the present work analyzes the spectral properties and effects of statistic memory of bioelectric activity of the cerebral cortex of healthy subjects (with low level of OCD) and patients with high level of OC-symptoms for the purpose of determination of diagnostic criteria. MFF is a method that allows to bring in a complex of information measures for quantitative comparison of correlation fall time and existence of statistic memory in the dynamics under. The method contains equations for describing the frequency-phase synchronization.

2. Theory and method

We consider the stochastic dynamics of the studying signals, registered in two different brain regions as the sequences x_j and y_j of random values X, Y [4]:

$$X = \{x_0, x_1, x_2, \ldots, x_{N-1}\}, \quad Y = \{y_0, y_1, y_2, \ldots, y_{N-1}\}. \tag{1}$$

Mean values and fluctuations are determined as follows:

$$\langle X \rangle = \frac{1}{N}\sum_{j=0}^{N-1} x_j, \quad \delta x_j = x_j - \langle X \rangle; \quad \langle Y \rangle = \frac{1}{N}\sum_{j=0}^{N-1} y_j, \quad \delta y_j = y_j - \langle Y \rangle.$$

Here τ is the time interval of signal discretisation.

To describe the probabilistic relation between the sequences of random variables X and Y we use the normalized time dependent cross-correlation function (CCF):

$$c(t = m\tau) = \frac{1}{(N-m)\sigma_x\sigma_y}\sum_{j=0}^{N-m-1} \delta x_j \delta y_{j+m}, \tag{2}$$

$$t = m\tau, \qquad 1 \le m \le N-1.$$

Parameters σ_x and σ_y – are the mean-square derivations of random variables X and Y:

$$\sigma_x = \sqrt{\frac{1}{N}\sum_{j=0}^{N-1} \delta x_j^2}, \quad \sigma_y = \sqrt{\frac{1}{N}\sum_{j=0}^{N-1} \delta y_j^2}.$$

Further we represent the CCF through the vectors of system state: initial

$$\mathbf{A}_k^0 = \mathbf{A}_k^0(0) = \{\delta x_0, \delta x_1, \ldots, \delta x_{k-1}\}, \quad \mathbf{B}_k^0 = \mathbf{B}_k^0(0) = \{\delta y_0, \delta y_1, \ldots, \delta y_{k-1}\}; \tag{3}$$

and in time moment $t = m\tau$:

$$\mathbf{A}_{m+k}^m(t) = \{\delta x_m, \delta x_{m+1}, \ldots, \delta x_{m+k-1}\}, \quad \mathbf{B}_{m+k}^m(t) = \{\delta y_m, \delta y_{m+1}, \ldots, \delta y_{m+k-1}\}; \tag{4}$$

$$c(t) = \frac{\langle \mathbf{A}_k^0(0)\ \mathbf{B}_{m+k}^m(t)\rangle}{\langle \mathbf{A}_k^0(0)\ \mathbf{B}_k^0(0)\rangle}. \tag{5}$$

Then, using the technique of projector operators we derive the dynamic orthogonal variables:

$$\begin{aligned} \mathbf{W}_0^X = \mathbf{A}_k^0(0),\ \mathbf{W}_1^X = (i\hat{L} - \lambda_1^{XY})\mathbf{W}_0^X,\ \mathbf{W}_2^X = (i\hat{L} - \lambda_2^{XY})\mathbf{W}_1^X - \Lambda_1^{XY}\mathbf{W}_0^X - \ldots\ , \\ \mathbf{W}_0^Y = \mathbf{B}_k^0(0),\ \mathbf{W}_1^Y = (i\hat{L} - \lambda_1^{XY})\mathbf{W}_0^Y,\ \mathbf{W}_2^Y = (i\hat{L} - \lambda_2^{XY})\mathbf{W}_1^Y - \Lambda_1^{XY}\mathbf{W}_0^Y - \ldots\ , \end{aligned} \tag{6}$$

kinetic and relaxation parameters, memory functions (CCFs of the higher order)

$$\lambda_n^{XY} = \frac{\langle \mathbf{W}_{n-1}^X \hat{L} \mathbf{W}_{n-1}^Y\rangle}{\langle \mathbf{W}_{n-1}^X \mathbf{W}_{n-1}^Y\rangle},\ \Lambda_n^{XY} = i\frac{\langle \mathbf{W}_n^X \mathbf{W}_n^Y\rangle}{\langle \mathbf{W}_{n-1}^X \mathbf{W}_{n-1}^Y\rangle}, \tag{7}$$

$$M_{n-1}^{XY}(t) = \frac{\langle \mathbf{W}_{n-1}^X \{1 + i\tau\hat{L}_{22}\}^m \mathbf{W}_{n-1}^Y\rangle}{\langle \mathbf{W}_n^X \mathbf{W}_n^Y\rangle}. \tag{8}$$

To analyze the phase synchronization we use the power spectra of memory functions:

$$\mu_i^{XY}(\nu) = \left| \tau \sum_{j=0}^{N-1} M_i^{XY}(j\tau) \cos 2\pi\nu j\tau \right|^2. \tag{9}$$

To analyze the stochastic and memory effects in the studied collective dynamics we use the frequency-dependent non-Markovian parameter:

$$\varepsilon_i^{XY} = \left\{ \frac{\mu_{i-1}^{XY}(\nu)}{\mu_i^{XY}(\nu)} \right\}^{\frac{1}{2}}. \tag{10}$$

3. Experimental Data

Obsessive-compulsive disorder is a mental disorder where people feel the need to check things repeatedly, perform certain routines repeatedly, or have certain thoughts repeatedly [8]. People are unable to control either the thoughts or the activities. The EEG data obtained from a group of ninety eight subjects including fifty patients with low OCD symptoms and forty eight patients with high OCD symptoms. Sixty-four channel EEG signals were continuously recorded by active scalp electrodes according to the extended 10-20 International system of electrode placement (figure 1). Additional electrodes were placed above and below each eye, and at the

outer can thus of each eye, to record vertical and horizontal eye movements, respectively. The sampling rate was 512 Hz. EEG data during the 2 min eyes closed resting state were re-referenced offline to the average of the earlobe electrodes and data were notch-filtered between 49 and 51 Hz to remove line-noise. The data was then separated into 2 sec epochs, and bad channels were replaced by means of nearest neighbor interpolation [9, 10].

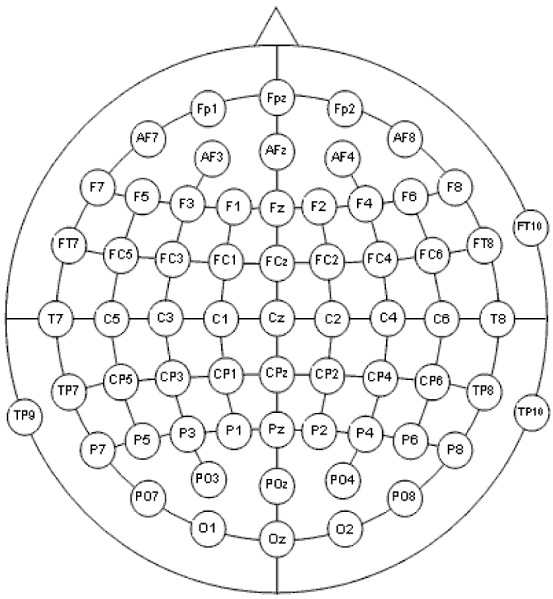


Figure 1. Positions of the 64 electrodes including their number and their designations. The schemata are based on the internationally established 10-20 system.

4. Discussion

Studying the frequency-phase synchronization using the power spectra of memory functions allows to determine the spatial connection distribution of cerebral cortex areas. It is found that the low OCD condition is characterized by long range phase synchronization in comparing with high OCD where the strong synchronization is observed in closely adjacent cortex areas (figure 2). To study the different type of synchronization we use the cross non-Markovian parameter (10) which can describes the synchronization of memory effects. Figure 3 demonstrates the areas with high level of the memory effect synchronization in patients with different OCD conditions. The finding are derived for all subjects. Using the window-time representation [11] we can study the local properties of phase synchronization. Figure 4 demonstrates the local deviations of main frequency peak at high OCD symptoms and it stability at the low OCD condition.

5. Conclusions

It is shown that the cerebral cortex signals from healthy people are characterized by high degree of long-range synchronization, whereas EEG of OCD patients has a strongly pronounced

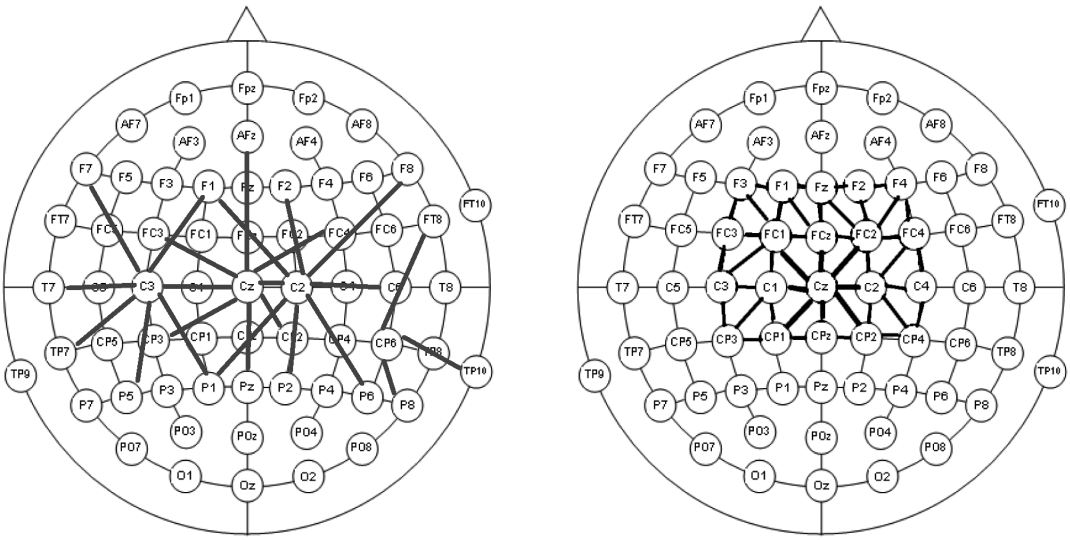


Figure 2. Schematic representation of the ranges of strong phase synchronization at low OCD and high OCD symptoms.

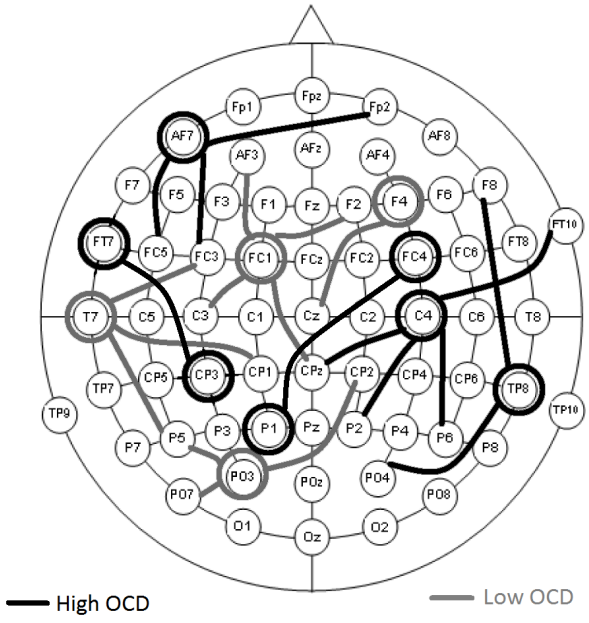


Figure 3. Synchronization of memory effects at low OCD and high OCD symptoms.

short-range synchronization. The obtained results allow to make progress in understanding the physical mechanisms of pathological changes in functioning of the brain cortex of a man, occurring as a result of OCD, and also to control the effectiveness of therapy in prospect. The work observes the possibilities of using EEG records in the development of objective methods of detection and identification of neuropsychopathy.

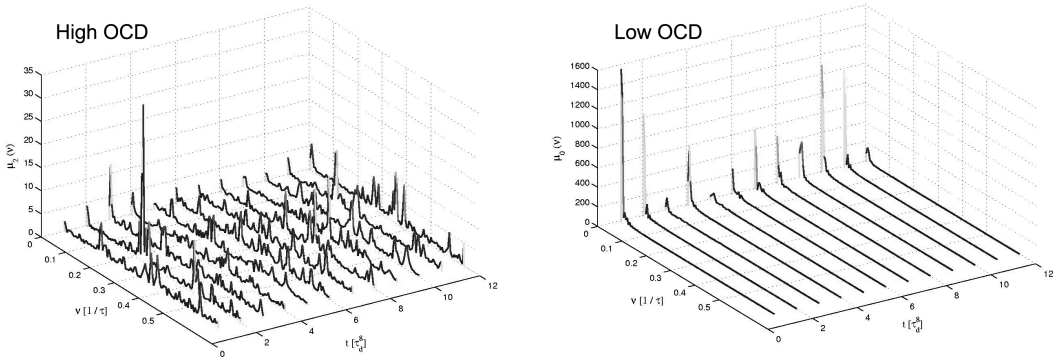


Figure 4. Intermittency in phase synchronization at low and high OCD symptoms.

Acknowledgments

The work is performed according to the Russian Government Program of Competitive Growth of Kazan Federal University. This work was supported by the Russian Foundation for Basic Research, grant No 14-02-31385_mol_a.

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