Synchronization of EEG activity in patients with bipolar disorder

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Abstract. In paper we apply the method based on the Flicker-Noise Spectroscopy (FNS) to determine the differences in frequency-phase synchronization of the cortical electroencephalographic (EEG) activities in patients with bipolar disorder (BD). We found that for healthy subjects the frequency-phase synchronization of EEGs from long-range electrodes was significantly better for BD patients. In BD patients a high synchronization of EEGs was observed only for short-range electrodes. Thus, the FNS is a simple graphical method for qualitative analysis can be applied to identify the synchronization effects in EEG activity and, probably, may be used for the diagnosis of this syndrome.

1. Introduction

The instrumental methods, such as the electroencephalography for diagnosis of various psychiatric disorders (BD, schizophrenia) are used restrictedly. However, at the present time few studies point out directly to a high diagnostic capability of these methods. For example, Timashev and coauthors on the basis of the FNS have formulated the criteria of degree of the susceptibility to schizophrenia in children/adolescents [1]. Panischev et al. have demonstrated that the method based on the memory function formalism [2] can discover the susceptibility to schizophrenia by analyzing the collective phenomena in the cerebral cortex bioelectric activity [3]. El-Badri and coauthors found alterations in spectral power of electroencephalograms (EEG) from BD patients [4]. Bhattacharya et al. discovered that for EEG of BD patients the long-range alpha coherence between frontal-temporal regions is reduced [5]. Kam and colleagues found the increase of high frequency power and disruptions in neural synchronization at BD
compared with healthy subjects [6]. Kim et al. revealed in EEG of BD patients the decrease of mean synchronization in the alpha band, and the significant decreases of fronto-central and centro-parietal connections [7]. Thus the BD existence is reflected in frequency characteristics and synchronization properties of EEG activity.

Bipolar affective disorder (earlier called manic-depressive illness) is a severe anticipate mental disorder characterized by alternations of episodes of elevated mood, depression and periods of normality. The diagnosis of BD is performed by psychiatrist based on the anamnesis and clinical features of subject according to criteria assumed by World Health Organization (ICD-10) and American Psychiatric Association (DSM-5). The BD occurs as either separate disease or syndrome of other mental diseases (for instance, schizophrenia).

In this paper within the framework of the FNS we study the properties of the frequency-phase synchronization EEG activity at bipolar disorder by using two-point cross-correlator. We will show that the BD existence leads to reducing the level of synchronization of EEG signals from the long-range electrodes (if at least one electrode was situated in between or the two electrodes were from opposite hemispheres see [5], Fig. 2). The FNS-method, based on phenomenological equations for separating the studied signal into components depending of time scale, contains the parameters describing the frequency-phase synchronization [1, 8, 9].

2. Background of the Flicker-Noise Spectroscopy analysis

The FNS-analysis [1, 8, 9] assumes two types of irregularities in responses relative to a time series:

1) spike-like irregularity (i.e. chaotic component) occurs at small or short time scale,
2) jump-like irregularity (i.e. resonant component) occurs at more longer time scale.

To describe these components of irregularity at different frequency ranges of EEG activity the power spectrum $S(f)$ and structure function $\Phi^{(2)}(\tau)$ were calculated:

$$S(f) = 2 \int_0^{\frac{T}{M}} (V(t)V(t + t_1))_{T-\tau} \cos 2\pi ft_1 dt_1, \quad (1)$$

$$\Phi^{(2)}(\tau) = \langle (V(t) - V(t + \tau))^2 \rangle_{T-\tau}, \quad (2)$$

which are derived on the basis of time correlation function

$$\psi(\tau) = \langle V(t)V(t + \tau) \rangle_{T-\tau}, \quad (3)$$

$$\langle (\ldots) \rangle_{T-\tau} = \frac{1}{T-\tau} \int_0^{T-\tau} (\ldots) dt, \quad (4)$$
where $\tau$ is the lag-time ($0 < \tau < \tau_M; \tau_M \leq T/2$). The stochastic component of structure function $\Phi^{(2)}(\tau)$ includes only jump-like irregularities, while the stochastic component of power spectrum $S(f)$ includes spike-like and jump-like irregularities.

FNS-method describes the dynamic changes of correlation of $V_i(t)$ and $V_j(t)$ variables for points $i$ and $j$ by means of the “two-point” correlation expression (cross-correlator, CCF):

$$q_{ij}(\tau; \theta_{ij}) = \left( \frac{V_i(t) - V_i(t + \tau)}{\sqrt{\Phi_i^{(2)}(\tau)}} \right) \left( \frac{V_j(t + \theta_{ij}) - V_j(t + \theta_{ij} + \tau)}{\sqrt{\Phi_j^{(2)}(\tau)}} \right)_{\tau = |\theta_{ij}|},$$  \hspace{1cm} (5)

where $\theta_{ij}$ is the “time shift” parameter. The value of $\theta_{ij}$ corresponding to maximum values of cross-correlation $q_{ij}(\tau; \theta_{ij})$ characterizes the cause-and-effect relation (“flow direction”) between signals $V_i(t)$ and $V_j(t)$. When $\theta_{ij} > 0$, the flow moves from point $i$ to point $j$, when $\theta_{ij} < 0$, from $j$ to $i$. When the distance between points $i$ and $j$ is fixed, the value of $\theta_{ij}$ can be used to estimate the rate of information transfer between these two points. Analysis of cross-correlators allow to study the collective phenomena in distributed system.

**Figure 1.** Positions of the 16 electrodes including their number and their designations.

### 3. Experimental Data

Data of EEG activity were analyzed in 8 healthy people (with no reported psychiatric or neurological disorders) and 8 patients with BD. Mean age was 32.5 in control group and 30.4 in group of BD patients. Multichannel EEG activity was recorded using 16 electrodes placed at standard positions (see Fig. 1). An average reference was used. The subjects were placed in a sound proof, light attenuated air-conditioned (20°C) room and instructed to relax and close their eyes for some time during the data acquisition period. The sampling rate was 200 Hz.
and the signal was filtered between 0.1-70 Hz. A notch filter of 50 Hz was also used. Baseline drift was subtracted by a polynomial of 2nd order [5, 10]. All experimental procedures were performed with the consent of the subjects.

4. Reducing the level of the EEG long-range synchronization at bipolar disorder

The three-dimensional plots of cross-correlation function $q_{ij}(\tau, \theta_{ij})$ allows to differentiate the degree of synchronization effects in EEG signals from the long-range and short-range electrodes of healthy subjects and BD patients. Fig. 2 demonstrates the combinations of electrodes with high level of the signal synchronization with a strongly marked oscillating CCFs structure. The EEGs of healthy subjects are characterized by higher synchronization for long-range and short-range electrodes. For BD patients this synchronization level is observed only for short-range electrodes.

![Figure 2. EEG signals with high synchronization in healthy subjects and BD patients (group average).](image)

The another picture is observed in EEGs of BD patients for long-range electrodes (Fig. 3): the synchronization degree is lower than for the short-range electrodes. It is reflected in diffuse CCFs structure with a feeble oscillations.
5. Conclusions

Developing the instrumental methods is the important problem for diagnosing the psychiatric disorders. EEG analyzing is one of the perspective approaches to solve ones. In this paper we study the synchronization effects in EEG of healthy subjects and BD patients by means of FNS cross-correlation analysis. Using the three-dimensional two-point cross-correlator is a simple graphical method for qualitative analysis of level of the frequency-phase synchronization. We reveal that the EEGs from healthy subjects demonstrate the high synchrony in short-range and long-range electrodes whilst the EEG signals of BD patients this synchronization level only for short-range electrodes. The signals from long-range electrodes for BD patients are characterized by lower synchrony. Thus the presented method is perspective for developing the new approaches for revealing the psychiatric disorders.

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