In this study we investigate the possible applications of cross-correlation analysis in the framework of Memory Functions Formalism for the diagnosis of nocturnal frontal lobe epilepsy (NFLE). During the analysis we study statistical memory effects in brain activity of 8 healthy subjects and 19 patients with NFLE. We discover different nature of the spectral behavior of electroencephalograms (EEG) as well as the difference in the level of manifestation of the frequency-phase synchronization effects for the control group and the patients.

Modern data science faces a lot of challenges, one of which is the search for diagnostic criteria for neurological diseases. With the development of recording equipment and the accumulation of significant arrays of experimental data, methods of statistical analysis are widely used in diagnostics [1].

Nowadays, various methods are used for this purpose: frequency-phase synchronization analysis [2], fractal analysis methods [3], combination of statistical analysis with machine learning methods [4]. In this work, within the framework of Memory Functions Formalism, we search for statistical patterns of pathological brain activity of humans with nocturnal frontal lobe epilepsy. The aim of this study is to search for new diagnostic criteria for NFLE based on statistical analysis of interictal EEG signals.

Using the technique of the Zwanzig-Mori projection operators introduced in nonequilibrium statistical physics allows to obtain a chain of finite difference equations of non-Markov type [5–6] for the initial and higher-order memory functions $M_i(t) (i=1,\ldots,n)$:

$$\Delta \xi_{ij}(t) = \lambda^X_{ii} c(t) - \tau \lambda^X_{ii} \sum_{j=0}^{m-1} M^X_{ij}(t) c(t - j\tau) ;$$

$$\Delta M^X_{ij}(t) = \lambda^X_{ii} M^X_{ij}(t) - \tau \lambda^X_{ii} \sum_{j=0}^{m-1} M^X_{ij}(t) M^X_{ij}(t - j\tau).$$

Then the frequency characteristics of the studied system are presented as $\mu(\nu)$ power spectra, that are determined through the Fourier images of the memory functions $M_i(t)$:

$$\mu^X_{ij}(\nu) = \Delta \sum_{j=0}^{m-1} c(t_j) \cos(2\pi\nu t_j)^2, \quad \mu^X(\nu) = \Delta \sum_{j=0}^{m-1} M^X_{ij}(t_j) \cos(2\pi\nu t_j)^2.$$

Polysomnographic (recorded during sleep) multichannel EEG signals included recordings of 8 healthy subjects and 19 subjects with NFLE. The bioelectrical activity signals from the outer ear zone, parietal and frontal lobe (electrodes A1, P4 and F4 respectively) were recorded, using central electrode C4 as a reference electrode (Fig. 1). Earlier, the authors performed the autocorrelation analysis on the dataset under study [7] and as a result obtained statistical memory parameters that helped to identify electrodes recording pathologic brain activity (denoted on the Fig. 1). In the presented work the combination of these electrodes is considered to study the frequency-phase synchronization effects at the areas of the brain where pathology manifests the most.

In this work crosscorrelation analysis in the framework of the Memory Functions Formalism was performed. The obtained results allow determining the manifestations of pathological activity in neurological disease — NFLE, using the methods of statistical analysis. After additional verification, the proposed methodology will allow diagnosing NFLE with greater accuracy.

**Results**

Fig. 2 shows the spectral features of EEG signals for two groups of subjects. The combination of the $A_1$ and $F_1$ electrodes was chosen due to the proximity to the frontal lobe and occipital lobe. On the graphs of the power spectra of statistical memory functions a manifestation of different types of brain rhythms is shown for the control group subjects (a, b) and patient with nocturnal frontal lobe epilepsy (c, d).

For the healthy subject $δ$-activity is manifested the most (0.25 Hz). This brain rhythm correspond to the natural restful sleep or resting state. On the contrary, for the patient with NFLE, in addition to the $δ$-activity (1.5 Hz), which is natural for the sleeping state, the $α$-activity (12 Hz) is also manifested. The corresponds to wakefulness and resting state with closed eyes.

Besides that, at the pathology the appearance of overlapping periodic processes in the form of bursts of brain activity were established. The manifestation of such bursts may indicate the presence of disease and serve as a criteria for the diagnosis of NFLE.

**Conclusions**

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