The analysis of local correlation characteristics of human bioelectric signals while performing cognitive tasks

Valentin Yunusov
Institute of Computational Mathematics and Information Technologies
Institute of Physics
Kazan Federal University
Kazan, Russia
valentin.yunusov@gmail.com

Sergey Demin
Institute of Physics
Kazan Federal University
Kazan, Russia
serge_demin@mail.ru

Kazan Federal UNIVERSITY

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Annotation

In this work, within the Memory Functions Formalism (MFF), we carry out an autocorrelation analysis of local segments of electroencephalogram signals for two groups of people. The first group consisted of 8 musicians professionally engaged in music for at least 5 years, the second group was represented by 11 people without any musical education. The subjects performed the tasks of perceiving a fragment of a musical work and perceiving a text. As a result, areas of the cerebral cortex were identified, in the activity of which the greatest differences are manifested for the two groups of people.

Introduction

The human brain consists of tens of billions of neurons communicating through hundreds of trillions of synapses. This is a complex system in which correlations between individual parts are continuously formed and changed. To solve such problems in modern data sciences, various methods of statistical analysis of brain activity signals are widely used: analysis of correlation and spectral characteristics, machine learning, and neural networks.

The analysis of time signals by numerical methods allows studying with greater accuracy the features of dynamic relationships that are built during the evolution of complex systems.

The main features of the analysis of local correlation characteristics

In this paper, we develop an original method for determining the distinctive parameters of electroencephalogram (EEG) signals of people with different levels of development of cognitive abilities based on the MFF [1] and quantile regression. The temporal dynamics of an experimentally recorded parameter of a complex system can be represented as a discrete time series x_j of a variable X:

$$X = \{x(T), x(T+\tau), x(T+2\tau), \dots, x(T+(N-1)\tau)\},$$

where T is the initial time of start from which recording of experimental parameter started, $(N–1)\tau$ is the signal recording time, $\tau=\Delta t$ is the sampling time step. The average value of the dynamic variable $\langle X \rangle$, fluctuations δx_j, absolute variance σ^2 can be represented as follows:

$$\langle X \rangle = \frac{1}{N}\sum_{j=0}^{N-1} x(T+j\tau), \qquad \delta x_j = x_j - \langle X \rangle, \qquad \sigma^2 = \frac{1}{N}\sum_{j=0}^{N-1} \delta x_j^2 .$$

For a quantitative description of the dynamic properties of the living system under study (correlation dynamics), it is convenient to use the normalized time correlation function:

$$a(t) = \frac{1}{(N-m)\sigma^2}\sum_{j=0}^{N-m-1}\delta x_j \delta x_{j+m} = \frac{1}{(N-m)\sigma^2}\sum_{j=0}^{N-m-1}\delta x(T+j\tau)\delta x(T+(j+m)\tau),$$

$$t = m\tau, \quad 1 \le m \le N-1,$$

where x_j, x_{j+m} are the values of variable X on steps j, $j+m$ correspondingly, δx_j, δx_{j+m} are fluctuations of values x_j, x_{j+m}, σ^2 is the absolute variance of the variable X.

For greater convenience and clarity in terms of the temporal dynamics of the time series, we will consider not the temporal correlation function, but, in addition to it, the autocorrelation coefficient calculated according to the following equation:

$$a(t) = \frac{\overline{x_T x_{T+t}} - \bar{x}_T \bar{x}_{T+t}}{\sigma_T \sigma_{T+t}}.$$

For greater convenience and clarity in terms of the temporal dynamics of the time series, we will consider not the temporal correlation function, but, in addition to it, the autocorrelation coefficient calculated according to the following equation:

$$\min_{\beta\in\Theta} E\{\rho_p(\mathbf{Y}-\mathbf{X}'\beta) \mid \mathbf{X}=x\}, \qquad \rho_p(z) = pzI_{[0,\infty)}(z) - (1-p)I_{(-\infty,0)}(z),$$

which is called check function, where $I_A(z)$ is the usual indicator function of the set A, Θ is a parametric space for β. In our study, dependent variable is the value of local autocorrelation coefficient and independent variable is time stamp on which the localization is performed.

The study of local autocorrelation features of brain activity

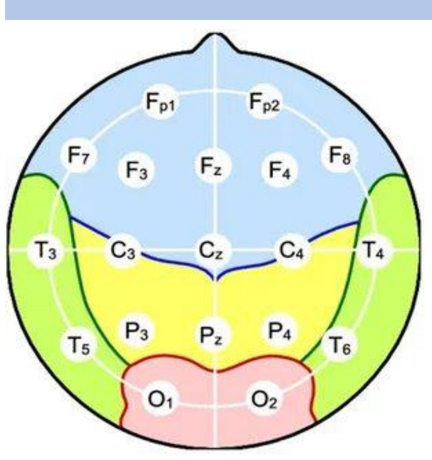

Fig. 1. The location of the electrodes according to the international system "10–20%".

We analyzed the correlation characteristics of EEG recordings for two groups of people: 8 musicians, each with at least 5 years of professional training in music, and non-musicians, each without any professional training in music. EEG signals were recorded by electrodes placed according to the international system "10–20%" (Fig. 1), for 90 *s*, in a state of rest of a person with closed eyes. During the recording, the subjects performed cognitive tasks of perceiving a fragment of a musical work and listening to a text of neutral content, read aloud [2].

At the preparatory stage, a localization procedure was carried out: EEG signal recordings were divided into equal time "windows", each with duration of 64 measurement records. The duration was set to half the sampling frequency of the signal recording. Then, for each time window, the autocorrelation coefficient was calculated. The resulting dependences of the autocorrelation coefficient are shown in Fig. 2. The final step was to quantify the dependence of the obtained values on time stamps using the quantile regression method. For our analysis we used Python language and package statsmodel.api in which quantile regression method is realized. Quantile regression allows approximating different quantiles with a linear relationship and forecast the values of the dependent variable for each quantile.

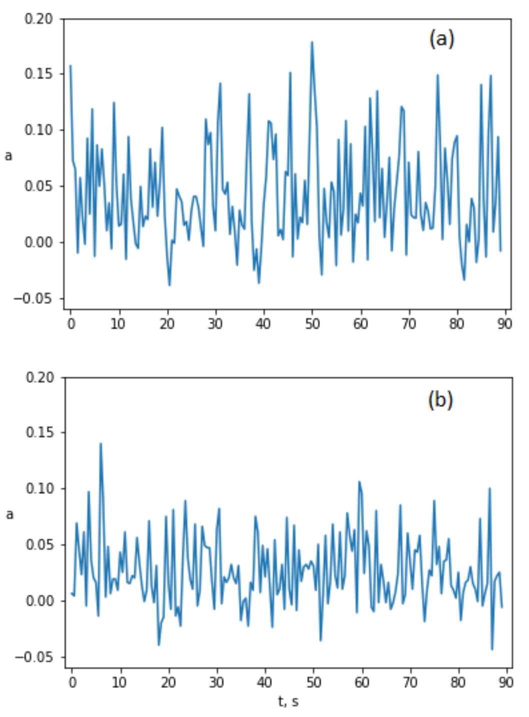

Fig. 2. The values of local autocorrelation coefficient calculated for musician (a) and non-musician (b) during the task of perceiving a fragment of musical work, recorded with electrode Fp_1.

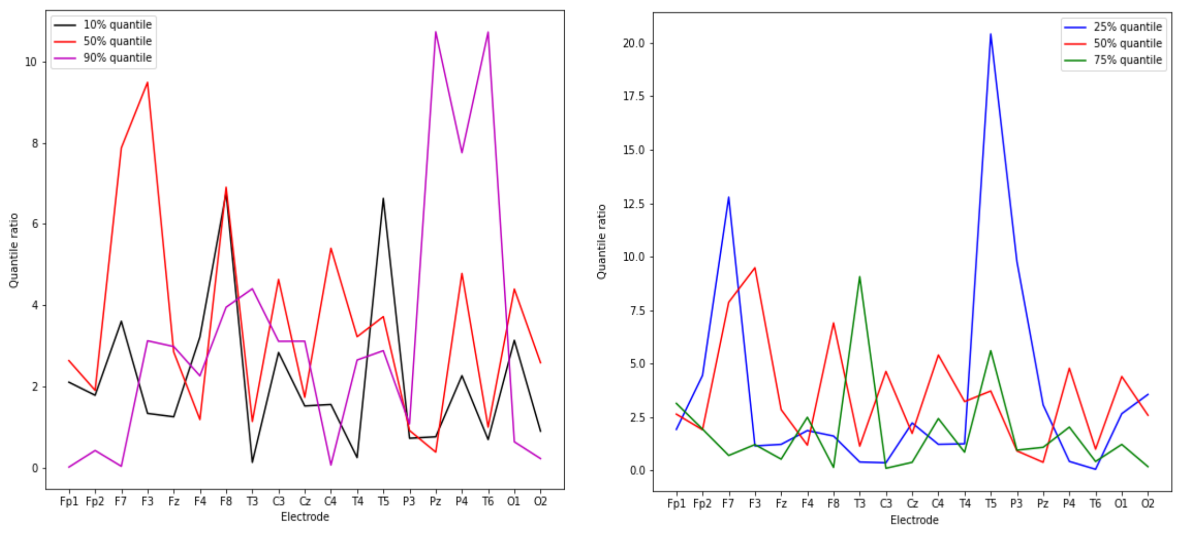

Fig. 3. The ratios of local autocorrelation coefficients for each 10%, 25%, 50%, 75% and 90% quantiles compared with corresponding electrodes for the task of perceveing a fragment of musical work.

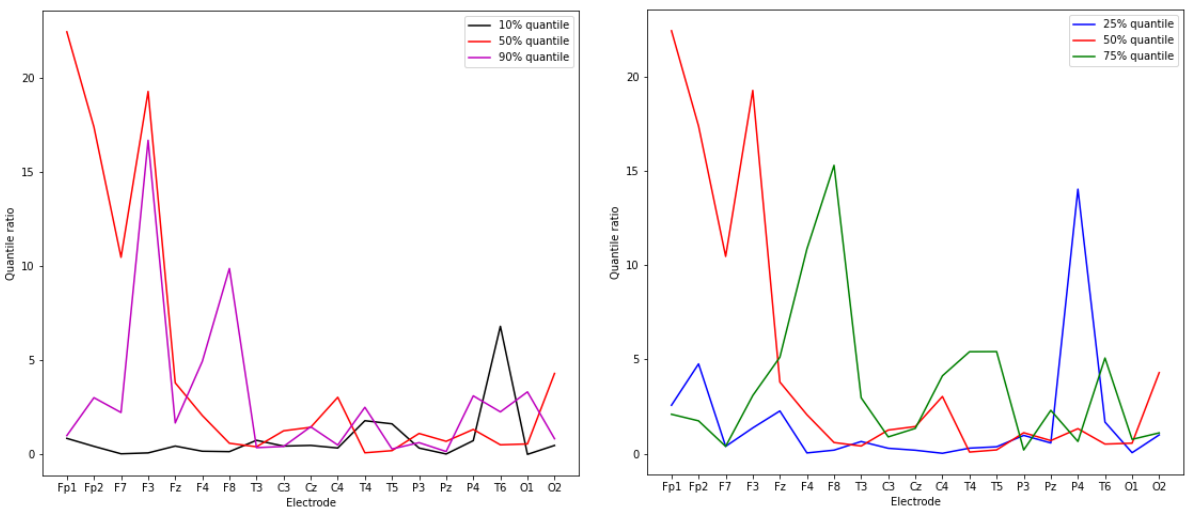

Fig. 4. The ratios of local autocorrelation coefficients for each 10%, 25%, 50%, 75% and 90% quantiles compared with corresponding electrodes for the task of listening to a text read aloud.

In case of task of the perception of piece of music, the greatest differences were manifested in the signals recorded by electrodes F_3, F_7, F_8, T_5 and P_4. In this case, we observe significant differences in different parts of cerebral cortex, including areas of T_5 and P_4 electrodes which correspond to the areas of the auditory cortex.

In the task of perceiving a text of neutral content, the greatest differences were found in the areas of the cerebral cortex, the signals of which were recorded by electrodes Fp_1, F_3, F_8, P_4 and T_6, i.e., the temporal and frontal regions were most significantly involved. Moreover, areas of electrodes P_4 and T_6 are responsible for auditory perception.

Thus, it can be concluded that the temporal dynamics of recorded EEG signals, which is analyzed by autocorrelation method can be used to distinguish bioelectrical activity of people with professional training in creative arts and people without it. During the study, we determined quantitative distinguishing criteria of the brain activity of two groups of subjects under study. It should be noted that the presented results represent only the first step in assessing the correlation relationships that are built in certain areas of the human cerebral cortex in the process of creative activity.

Conclusions

In this work, within the MFF and quantile regression analysis, we determined the distinctive criteria for EEG recordings for subjects with professional training in the field of musical art and without musical education. For the records of the signals of two groups of subjects, divided into local "windows", the autocorrelation coefficient was calculated, after which quantile regression was applied. During the analysis, the areas of the cerebral cortex were identified, for which the difference in the dynamics of bioelectrical activity was manifested to the greatest extent.

[1] S.A. Demin, R.M. Yulmetyev, O.Yu. Panischev and P. Hänggi, "Statistical quantifiers of memory for an analysis of human brain and neuro-system diseases", Physica A, vol. 387, pp. 2100–2110, 2008.

[2] J. Bhattacharya and H. Petsche, "Phase synchrony analysis of EEG during music perception reveals changes in functional connectivity due to musical expertise", Signal Process., vol. 85, № 11, pp. 2161–2177, 2005.

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