# Multiparameter analysis of statistical memory effects and spectral characteristics in bioelectric signals while performing cognitive tasks

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***Abstract*—In this research, in the framework of Memory Functions Formalism, we study statistical memory effects of electroencephalogram data for two groups of people by performing auto- and cross-correlation analysis. The first one consists of 8 professional musicians; the second group was represented by 11 people without any musical education. Bioelectrical activity signals were recorded during rest state and 2 cognitive tasks: perceiving a fragment of musical piece, and perceiving a text read aloud. During autocorrelation analysis, we identify regions of brain cortex, statistical memory effects of signals from which differ the most and use them for the following analysis. During the second stage of work, we identify differences in spectral behavior for both groups and analyze the effects of frequency-phase synchronization. Finally, it is demonstrated that our approach allows detecting differences in the cognitive abilities of people when performing various cognitive tasks.**

***Keywords—data science, living systems, biomedical data, time series analysis, mathematical methods of data analysis, autocorrelations, cross-correlations, frequency-phase synchronization, electroencephalograms, perception, cognitive tasks***

## I. INTRODUCTION

A complex system is a composite object, the parts of which are combined into a single whole according to certain laws or connected with each other by given relationships, because of which such a system acquires new properties that cannot be reduced to the properties of its parts. One of the examples of the most complex system is a human brain. In this work, we analyzed electroencephalogram (EEG) data – one of the methods to record bioelectric human brain activity.

Professional experience and long-term training may lead to a certain change in the activity of human brain cortex, that can be detected by analysis of bioelectric data records [1]. As a result, patterns of brain activity differ between experts and non-experts in different fields. Discrepancies between the biomedical data of professionals and non-professionals can be especially significant during the performance of expert tasks [2, 3].

Modern methods of quantitative and qualitative impact of these changes are actively developing and include different statistical analysis approaches, including machine learning implementation [4].

The work is aimed at developing an original method for analyzing the autocorrelations and cross-correlations of the recording of the bioelectrical brain activity of professional musicians and people without musical education. The presented approach is based on one of the modern biomedical methods investigating the dynamics of discrete non-Markovian random processes in complex systems: Memory Functions Formalism (MFF).

## II. THE STUDY OF AUTO- AND CROSS-CORRELATIONS FEATURES OF BRAIN ACTIVITY

In this work we develop an original method for determining the distinctive parameters of the classification of EEG signals recordings of people with different levels of cognitive abilities development. This method is based on the autocorrelation and cross-correlation analysis in the framework of Memory Functions Formalism and the study of cross-correlation coefficients.

MFF is a theoretical methodology developed by the Kazan school of statistical and computational physics as applied to the discrete dynamics of complex non-Hamiltonian systems of various nature [5, 6]. Here we will not dwell on the basic mathematical relations introduced in the framework of the MFF. Memory Functions Formalism is remarkable in that it allows extracting a large amount of significant features of the studied time series by performing auto- and cross-correlation analysis and the analysis of statistical memory effects.

In this study we consider the correlation characteristics of EEG recordings of signals from two groups of people: 8 musicians who have been professionally involved in music for at least 5 years, and 11 people without any musical education (non-musicians). Recording was performed for 90 seconds at rest with eyes closed. During the recording, the subjects performed cognitive tasks of perceiving 3 fragments of a musical work and listening to a text of neutral content, read aloud [7]. Recordings were made according to the International scheme of layout of electrodes «10-20%» (Fig. 1).

In the first part of this work, for each subject «meaningful» electrodes were identified by performing autocorrelation analysis. These electrodes correspond to the certain areas of brain, in which the statistical memory effects of bioelectric activity differs mostly for the participants in both groups.

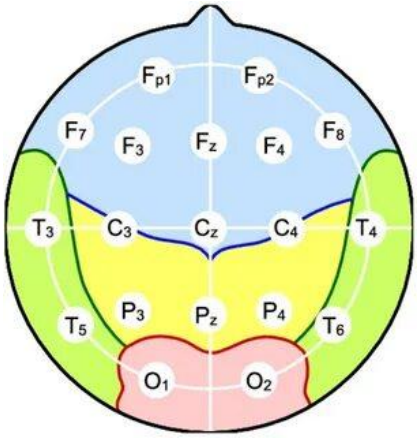


Fig. 1. International scheme of layout of electrodes «10-20%»

Then, for the identified electrodes, cross-correlation analysis was performed, in which the spectral parameters and the value of cross-correlation coefficient were considered. We discovered different a different nature of the spectral behavior of EEG signals for experts and non-experts: the predominance of low-frequency periodic processes in the brain activity of experts, high-frequency processes – for non-experts.

As a result, it was found that, in average, for a representative of the control group, the intensity of the power spectrum peaks is significantly higher (Fig. 2). It can be seen that both groups are characterized by the presence of low-frequency periodic processes (~1–1.5 *Hz* for the representative of the control group and ~0.5 *Hz* for the expert). In addition, for the representatives of the control group, more high-frequency periodic activity (~10 *Hz*) was also significantly manifested.

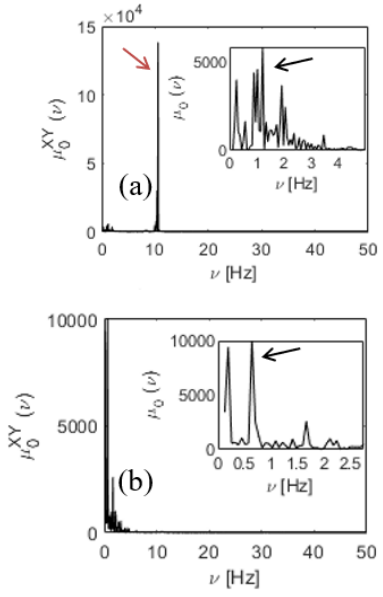


Fig. 2. Power spectra of the cross-correlation statistical memory function of the signal from the $Fp_1$–$T_6$ electrodes for the task of the perception of music for a person from the control group (a) and an expert (b). The arrows mark the peaks with the highest intensity

A certain level of manifestation of the effects of frequency-phase synchronization in the dynamics of EEG signals in various cognitive and sensory processes has been established. In the task of listening to music, a higher level of synchronization is typical for experts (electrodes $T_5$–$Fp_1$); in the task of text perception – for non-experts (combination of $T_3$–$Fp_1$ electrodes).

## III. Conclusions

In this work, an original method for analyzing auto- and cross-correlations of human biomedical data is being developed. The approach is based on the finite-difference analogue of the Zwanzig-Mori equations [8, 9] intended for studying the discrete stochastic dynamics of complex systems.

In the framework of Memory Functions Formalism we discovered that the dynamics of biomedical parameters is characterized by more random nature for non-experts when listening to a fragment of a musical work; for experts – while listening to the text. Also, while performing all tasks in the biomedical data of the representatives of the control group, in contrast to the representatives of the expert group, high-frequency periodic activity was manifested to a much greater extent. Moreover, when analyzing the effects of frequency-phase synchronization, significant differences were found in the degree of correlation of biomedical signals recorded in remote areas of the cerebral cortex for two groups of subjects.

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