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The FNS-based analysis of precursors and cross-correlations in EEG signal related to an imaginary motor task

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ABSTRACT

Flicker noise spectroscopy (FNS) is a time series analysis method to extract information contained in complex nonlinear systems using parameters characterizing the chaotic component of signal in different frequency ranges. In the paper, FNS (precursor function and cross-correlations) is used to study electroencephalography (EEG) signal related to the hand movement imagination. Our analysis of the precursor function calculated for different electrodes reveals a distinct peak just before the imagination which allows for detection of the motor task and distinction of the hand being a subject of the imagination. The EEG rhythms in subsequent stages of the task are determined based on cross-correlation maps which are furthermore used to describe directions of flows between different parts of the sensorimotor cortex.

1. Introduction

Flicker-noise spectroscopy (FNS) is a phenomenological method for time and spatial series analysis, which assumes that all information about the system is contained in its chaotic component and can be extracted from the power spectra and difference moments of various orders [1]. FNS is applied to three types of problems: *(i)* determination of parameters or patterns characterizing the system, *(ii)* identification of precursors of abrupt changes in the state of system, *(iii)* determination of information flows by means of the analysis of dynamic correlations in chaotic signals that are simultaneously measured at different points in space.

Among different applications of the FNS method, which covered a wide range of scientific disciplines from the solid state physics [2], via geology [3,4], to material engineering [5], the most interesting are those related to biomedical signal analysis and medical diagnosis [6]. In this context, the FNS method was successfully used for identification of the photosensitive epilepsy [7]. In Ref. [7], the authors suggested FNS as an invaluable method for diagnosis of numerous neurodegenerative diseases. Their assumptions were confirmed in further studies [8], where the clinical electroencephalogram recorded in children/adolescents with diagnosed schizophrenia symptoms were analyzed. The extracted FNS parameters and cross-correlations between signals measured simultaneously at different points on the scalp allowed to find diagnostic signs of the subject's susceptibility to schizophrenia. In Ref. [8], the cross-correlation analysis was suggested as a useful method to assess the effectiveness of therapy by comparing the value of the frequency–phase synchronization before and after the treatment. Recently, a specific behavior of the FNS-parameters and the cross-correlators calculated for the EEG signal (in comparison with healthy subjects) has been also reported for bipolar affective disorder (BAD) patients [9].

In this paper we use FNS for the analysis of EEG signal related to the hand movement imagination. This work is a continuation of our previous study [10] in which we reported a significant increase in the FNS parameters (visible as peaks) related to the task execution.

The purpose of the present paper is to show that information about the movement imagination can be extracted from the EEG signal by the use of two other quantities of the FNS method, i.e. precursors of abrupt changes and cross-correlation functions. We find that the precursor function faultlessly indicates the moment of the imagination task and the hemisphere which is activated during the imagination of movement. Our analysis of the cross-correlation functions for electrodes located directly above the motor cortex reveals changes in synchronization of neurons in accordance with those usually described in the ERD/ERS maps [11–14]. Finally, the analysis of the signal flow is performed separately for the mu (8 – 13 Hz) and beta (13 – 30 Hz) frequency range, for electrodes located on the right and left hemispheres. EEG channels represent a weighted superposition of the electric potentials driven by active brain sources and artifacts. An ideal, single source always drives a number of electrodes. The calculation of cross-correlations makes it possible to determine the direction of the signal flow between electrodes, as it allows to observe oscillations of small amplitude, arising in specific phase relationships.

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