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THE ANALYSIS OF SYNCHRONIZATION EFFECTS OF HUMAN NEUROMAGNETIC RESPONSES IN RESPONSE TO FLICKERING LIGHT STIMULI

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Annotation

In the framework of basic provisions and concepts of memory function formalism (MFF), we study the effects of synchronization between SQUID's, which are located on the head of 9 healthy subjects, when exposed to different color combinations of light. Information about the brain functional activity is presented in the form of a sequence of values of simultaneously recorded MEG signals. It is shown that for each subject, it is possible to establish the nature of the interaction: the synchronization effects between certain areas of the cerebral cortex under different color combinations of light.

Introduction

The properties of complex systems are fully reflected in the processes occurring in the human brain. The respond of different areas of the cerebral cortex in response to external influences is individual for each person and depends on the frequency of exposure. For the study of the synchronization effects of neuromagnetic signals we have used MFF. Previously, researchers found that the most significant reaction in response to light stimulation occurs in the occipital region of the cerebral cortex [1]. In study [2] the authors showed the effect of light flicker with a γ-rhythm frequency on brain function. Significant response was found in different parts of the occipital region. In paper [3], authors showed the increase in α-activity in the occipital region of the brain when exposed to alternating flashes of red and blue colors. MFF allows obtaining a significant array of analytical indicators and characteristics from experimental data. We demonstrate certain parts of MFF analysis possibilities in studying the synchronization effects in the dynamics of MEG signals in healthy subjects in response to flickering light stimuli, as well as during the transition from one stimulus to another.

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Methods

MFF is based on a finite-difference analogue of the Zwanzig-Mori kinetic equations [4]. The normalized cross-correlation function, CCF, is used as the base image:

$$c(t) = \frac{1}{(N-m)\sigma_x\sigma_y} \sum_{j=0}^{N-m-1} \delta x(T + j\tau)\delta y(T + (j+m)\tau),$$

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

It expresses the relationship between two random variables X and Y (sequences of values of simultaneously recorded MEG signals). The CCF is related to the statistical memory functions by a chain of finite difference equations:

$$\frac{\Delta M_{n-1}^{XY}(t)}{\Delta t} = \lambda_n^{XY} M_{n-1}^{XY}(t) - \tau \Lambda_n^{XY} \sum_{j=0}^{m-1} M_n^{XY}(j\tau) M_{n-1}^{XY}(t - j\tau).$$

To analyze frequency-phase synchronization, power spectra of cross-correlation memory functions are used:

$$\mu_0^{XY}(\nu) = \left| \Delta t \sum_{j=0}^{N-1} c(t_j)\cos 2\pi\nu t_j \right|^2, \dots, \mu_i^{XY}(\nu) = \left| \Delta t \sum_{j=0}^{N-1} M_i^{XY}(t_j)\cos 2\pi\nu t_j \right|^2.$$

A statistical memory measure (the non-Markovian parameter) is introduced to separate stochastic processes into Markov and non-Markov ones, as well as to quantify memory effects in the mutual dynamics of simultaneously recorded time signals. Below the frequency-dependent case of the non-Markovian parameter is presented:

$$\varepsilon_i^{XY}(\nu) = \sqrt{\frac{\mu_{i-1}^{XY}(\nu)}{\mu_i^{XY}(\nu)}},$$

Results

Figure 1 shows the power spectra of the first-order memory function calculated for the MEG signals of two subjects before and after the application of a flickering stimulus. The difference in the structure of the spectra is significant. The maximum amplitude of the spectra for the first subject changed 10 times, for the second one — 5 times. These bursts reflect the brain rhythms of healthy subjects, which are formed in response to external light exposure. Turning on the stimulus leads to transition from α-activity to β- or γ-activity. At the same time, if in the case of the first subject, brain rhythms are clearly detected at frequencies that are multiples of 8–10 Hz, then in the case of the second subject, overlapping of resonant frequencies with additional periodic processes is observed. This remark may indicate some asynchrony in the activity of ensembles of neurons in the areas of the scalp of the second subject, where the sensors are localized.

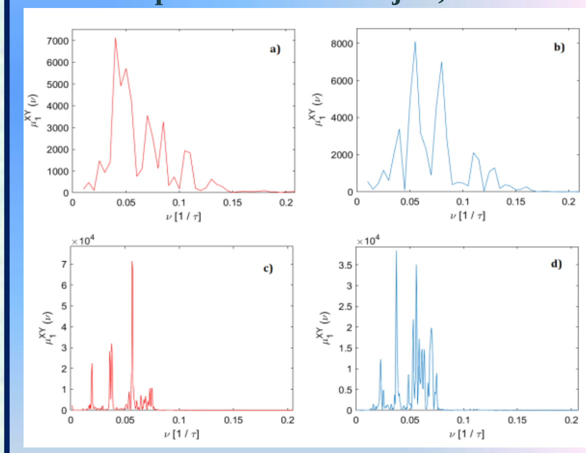

Fig. 1. Power spectra of the first-order memory function for neuromagnetic signals of two healthy subjects' brain (a, c – the first volunteer, b, d – the second volunteer) before (a, b) and after (c, d) turning on a flickering light stimulus. Sensors from the frontal and occipital lobes were used

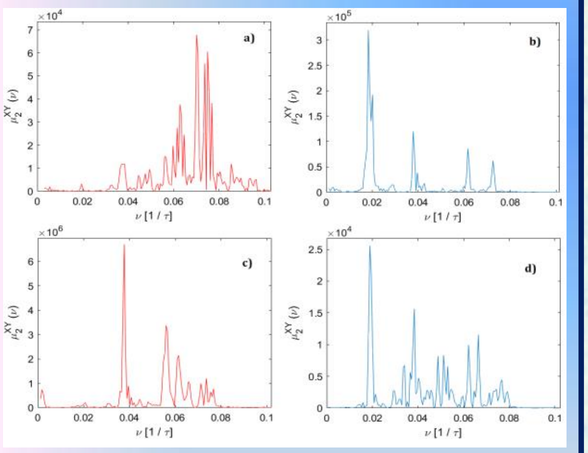

Fig. 2. Power spectra of the second-order memory function for neuromagnetic signals of two healthy subjects' brain (a, c – the first volunteer, b, d – the second volunteer) during the change from the blue-green stimulus (a, b) to the red-green stimulus (c, d). Sensors from the frontal and occipital lobes were used

Results

Figure 2 shows the power spectra of the second-order memory function calculated for the MEG signals of two subjects during the transition from one flickering light stimulus to another. Changes in the dynamics of periodic processes corresponding to brain rhythms in the bioelectrical activity of the cerebral cortex of healthy subjects should be noted. In the case of the first subject, more distinct synchronization effects are revealed for the red-green stimulus, for the second subject, for the blue-green one. The maximum values of the power spectra of the second-order memory function also change significantly. For the first subject, the value for the red-green combination increased 100 times compared to the blue-green. For other subjects, changes were found in the range of 10–500 times.

A comparative analysis of the parameter values at zero frequency reflects mainly the quasi-Markov scenario with the manifestation of moderate statistical memory effects. We have established an increase or decrease in the effects of statistical memory in the mutual dynamics of different certain areas.

Conclusions

In this work, based on the analysis of synchronization effects and statistical memory effects between MEG signals of different cerebral cortex areas of healthy subjects, we established the effect of turning on the stimulus on the neuromagnetic activity of the human brain, which was reflected in power spectra of cross-correlation functions. A multiple change in the maximum values of bursts in the power spectra of statistical memory functions was established when changing color stimuli. A moderate degree of statistical memory effects manifestation was found in the analyzed neuromagnetic responses of healthy subjects.

The results and conclusions of this study will allow further finding statistical patterns: diagnostic criteria for neurological and neurodegenerative diseases, such as photosensitive epilepsy, primarily due to external influences.

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