SPATIOTEMPORAL SCALING OF VISUALLY EVOKED HUMAN NEUROMAGNETIC SIGNALS

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Annotation

In this work, we carry out a fractal analysis of visually evoked neuromagnetic responses of the human cerebral cortex in response to flickering light stimuli of different color combinations. The modified Higuchi method is used to calculate the fractal dimension *D*. The most significant change in the self-similar properties of the studied signals is observed for the frontal and occipital regions. The results obtained will be of interest to data science, neurophysiology and cognitive psychology.

Introduction

Earlier, within the framework of the Memory Functions Formalism and the Flicker-Noise Spectroscopy, theoretical approaches based on the provisions of nonequilibrium statistical physics, the analysis of magnetoencephalogram (MEG) signals from healthy subjects and a patient with photosensitive epilepsy (PSE) was carried out [1–3]. This paper presents the results of the analysis of spatial-temporal scaling (scale invariance) in the dynamics of magnetoencephalograms of healthy subjects "before" and "after" the exposure to flickering light stimuli of different color combinations. Color combinations: red-blue, red-green, blue-green were generated using two projectors. Comparative analysis of the averaged values of the fractal dimension *D* was carried out both for different areas of the cerebral cortex and for each light stimulus. The higher the index of fractal dimension *D*, the more the scale invariance is manifested.

Quantitative evaluation of the fractal dimension

The determining of dimension *D* of the time series of human MEG was performed on a basis of a modification of the Higuchi algorithm [4]. Consider a partially ordered finite set $X(N)$. Here N is the number of elements in a set x_i , $i=1,\dots,N$. Let's make a sample of the elements of the original time series by imposing on it n modules of equal length $\alpha=(N-k)/n$ to completely cover it. N is number of time series points, $k=1,\dots,n$ is the initial time count.
We define the fractal dimension D_ε of the set $X(N)$ by the property $H_\varepsilon(x)$ by the slope $\log Y_\varepsilon\alpha$ of $\log\alpha$:

$$D_\varepsilon=\sum_\gamma \frac{\log Y_\varepsilon\alpha_\gamma-\log Y_\varepsilon\alpha_{\gamma-1}}{\log\alpha_\gamma-\log\alpha_{\gamma-1}}\left[\frac{n_\gamma-n_{\gamma-1}}{(N-k)(\alpha_\gamma-\alpha_{\gamma-1})}\right].$$

The total contribution of disjoint modules is defined as:

$$Y_\varepsilon=\sum_{i=1}^{n} x(k+i\alpha)-x\left[k+(i-1)\alpha\right].$$

Description of experimental data

The registration of cortex neuromagnetic signals caused by the flickering stimuli was carried out using Neuromag-122 (Neuromag Ltd., Finland) with 61 SQUID (superconducting quantum interference device) sensors with a sampling frequency of 500 Hz.

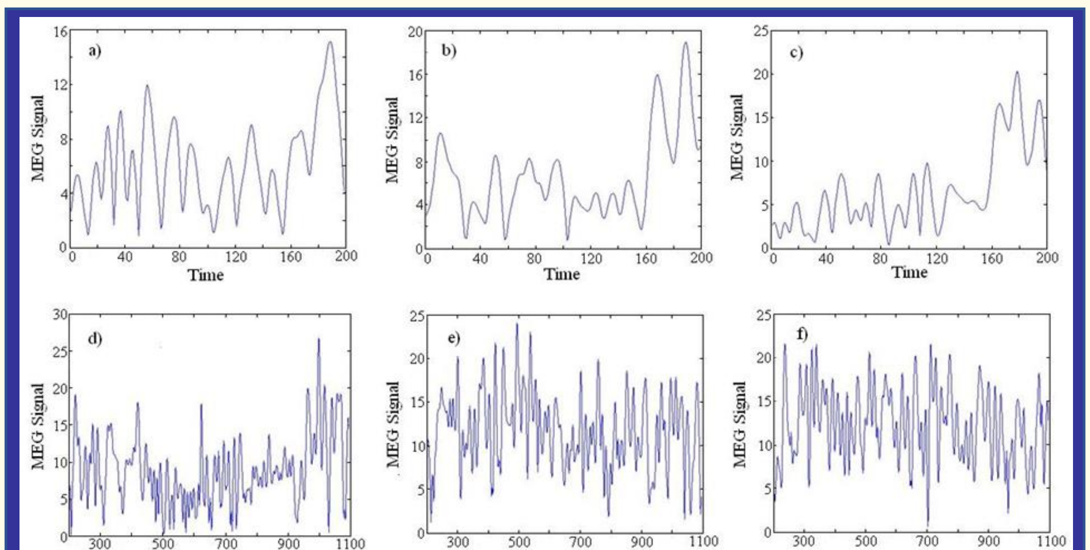

Fig. 1. Representative examples of time series of magnetoencephalograms recorded by SQUID sensor № 21.

Results

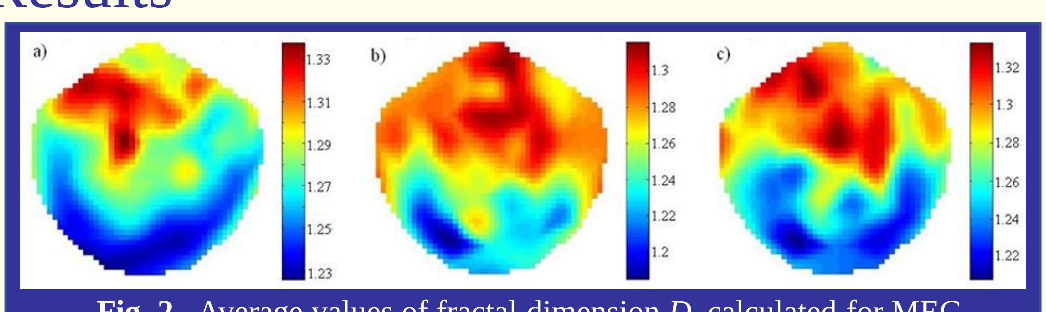

Fig. 2. Average values of fractal dimension *D*, calculated for MEG of nine healthy subjects before switching on of color stimuli: a – red-blue, b – red-green, c – blue-green.

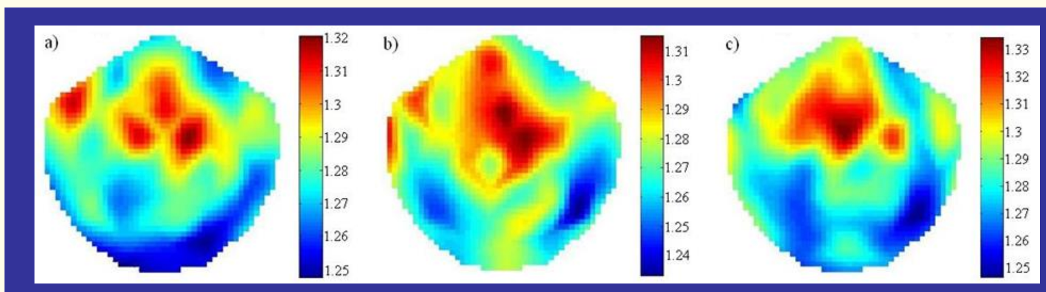

Fig. 3. Average values of fractal dimension *D*, calculated for MEG of nine healthy subjects after switching on of color stimuli: a – red-blue, b – red-green, c – blue-green.

In general, a narrow interval of values of the fractality index can be noted. The highest *D* values correspond to the frontal and parietal lobes. The lowest *D* values were noted for the left temporal, left parietal, right temporal, right parietal, and occipital regions.
The spatial-temporal invariance effects are essentially manifested in the generalized area, consisting of the parietal, left parietal, and right parietal lobes. The smallest *D* values are in the frontal, left temporal, right temporal, and occipital regions. In general, when a stimulus of a certain color combination is applied, the degree of manifestation of self-similarity effects for different areas of the human cerebral cortex both increases and decreases.

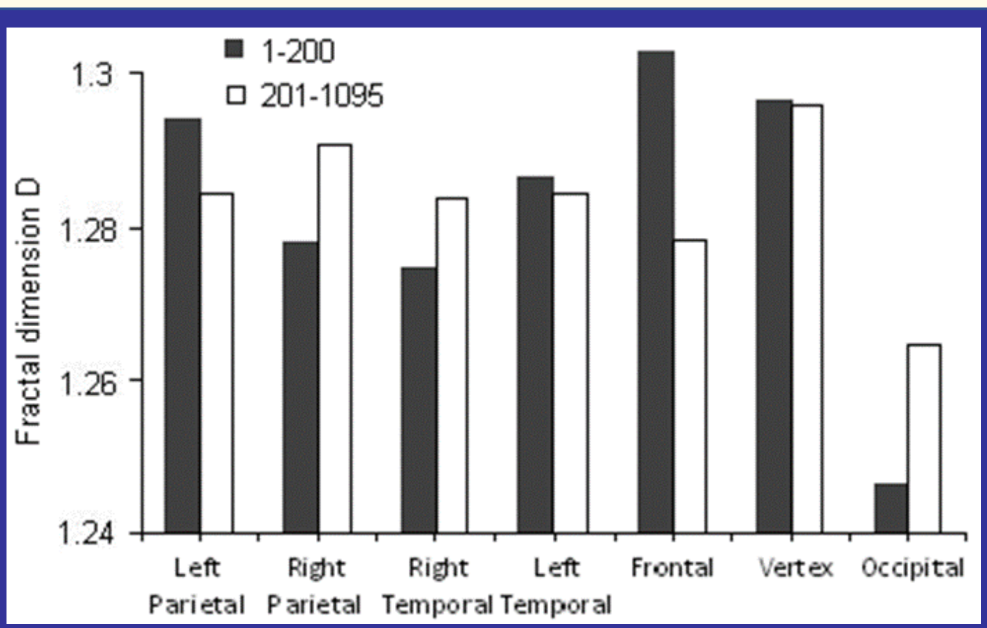

Fig. 4. Histogram of mean values of fractal dimension *D* for different areas of the cerebral cortex of healthy subjects "before" and "after" the application of the red-blue blinking stimulus.

For the comparison of the spread of the recorded parameter before and after the application of the red-blue blinking stimulus, the RMS amplitude values were calculated.

Region of the cerebral cortex	$\overline{A^2_{RB}}/\overline{A^2_C}$
Left Pariental	3.24
Right Pariental	3.19
Temporal	3.26
Right Pariental	2.95
Temporal	3.48
Right Pariental	3.28
Temporal	2.7

Table 1. The ratio of the RMS amplitude values averaged over the areas of the cerebral cortex for the group of subjects. The values used are after the red-blue blinking stimulus (RB) and before it (C).

For the comparison of the spread of the recorded parameter before and after the application of the red-blue blinking stimulus, the RMS amplitude values were calculated. Table I shows the ratios of the RMS amplitude values averaged over the regions of the cerebral cortex for the group of subjects. The most significant scatter is observed for the frontal region, the smallest for the occipital region.

Conclusions

The results of this study allow establishing how the fractal structure of MEG signals changes in response to different light stimuli, as well as in the collective dynamics of neuron ensembles, which determines the random distribution of phases and clustering of bioelectric activity. In particular, the projection of a blinking stimulus, i.e. the transition from spontaneous to induced or evoked neuromagnetic responses leads to a change in the space-time scaling of signals in most areas of the cerebral cortex of healthy subjects.

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