FLICKER-NOISE SPECTROSCOPY ANALYSIS OF MAGNETOENCEPHALOGRAM SIGNALS IN DIAGNOSIS AND TREATMENT OF PHOTOSENSITIVE EPILEPSY

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Introduction

Frequency and phase synchronization, manifestation of specific correlations between characteristic frequencies and phases of the excitations in different regions of the brain (specific neural ensembles), and synchronization of the excitation amplitudes are the necessary conditions for the brain to function as an integral system. A normally functioning brain responds to external actions on the human organism by establishing some optimal level of such correlations. A significant deviation from this optimal level, such as an anomalously high level of synchronization or lack of synchronization, may be considered as an indicator of a pathology in brain activity.

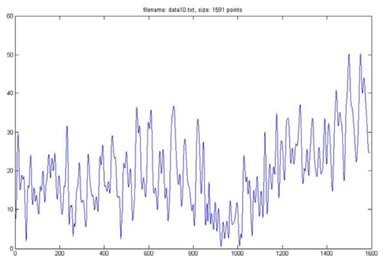
Our previous studies show that the analysis of cross-correlations introduced within the framework of flicker-noise spectroscopy (FNS) [1, 2] for sets of magnetoencephalogram (MEG)/electroencephalogram (EEG) signals can identify and quantify the effects of frequency-phase synchronization in the brain, which may be essential for the diagnosis of psychiatric disorders (schizophrenia) as well as some neurological and neurodegenerative diseases [3-5].

MEG signals in analysis of photosensitive epilepsy (PSE)

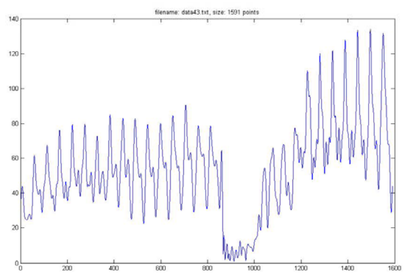
MEG signals were recorded as the neuromagnetic response from a group (9 adolescents) of control subjects and a patient (a 12-year girl) with photosensitive epilepsy while they were viewing equiluminant flickering stimuli during 1.7 s of different color combinations (RB – red-blue and RG – red-green) [6-8]. The interest to such analysis was initiated, in particular, by the perceived potential danger of modern cartoons to provoke PSE in children and adults. The experimental data were generated by 61 SQUID (superconducting quantum interference device) sensors attached to different points around the head, which can record weak magnetic induction gradients of about 10 –11 – 10 –10 Tl/cm. The sampling frequency of MEG signals was 500 *Hz*.

It was reported [3-5] that the power spectrum of the signals in the patient contains a significant high-frequency component at approximately 50 *Hz*, and for sensors 10 (frontal lobe), 59 (central zone), and 46, 51, 53 (forehead) an additional frequency component at approximately 100 *Hz*, both of which are not seen in the data for healthy subjects.

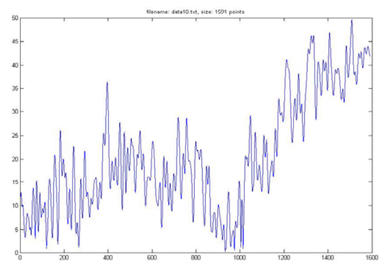
MEG signals (examples)



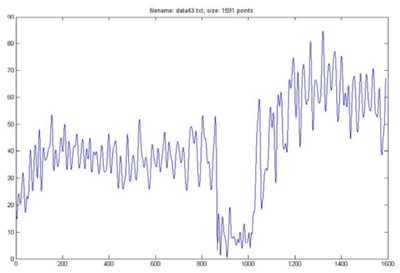
7th control subject 10th sensor (frontal zone), RB-stimulus



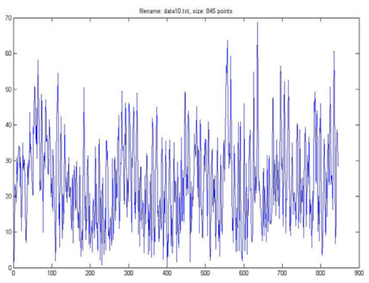
7th control subject 43rd sensor (occipital zone), RB-stimulus



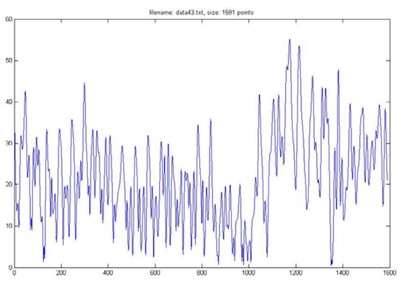
7th subject 10th sensor, RG-stimulus



7th subject 43rd sensor, RG-stimulus



Patient, 10th sensor, RB-stimulus



Patient, 43rd sensor, RB-stimulus

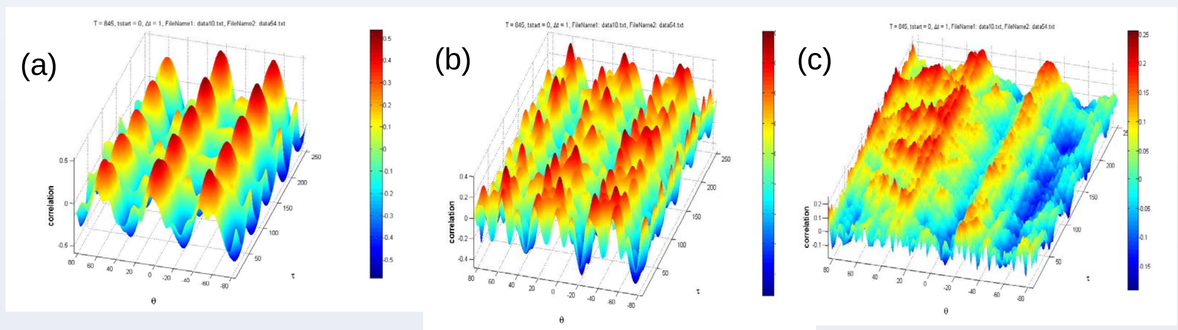
FNS two-point cross-correlation function

A new type of multi-point correlation functions is introduced to obtain spatial-temporal maps of flows in a complex dynamical system. The cross-correlation function $q_{ij}(\tau; \theta_{ij})$, which is formed exclusively by jumps of the dynamic variables $V_i(t)$ and $V_j(t)$ measured in the i-th and j-th points, has a form:

$$q_{ij}(\tau,\theta_{ij}) = \left\langle \left[\frac{V_i(t) - V_i(t+\tau)}{\sqrt{\Phi_i^{(2)}(\tau)}} \right] \left[\frac{V_j(t+\theta_{ij}) - V_j(t+\theta_{ij}+\tau)}{\sqrt{\Phi_j^{(2)}(\tau)}} \right] \right\rangle_{T-\tau-|\theta_{ij}|}$$

$$\Phi_i^{(2)}(\tau) = \left\langle \left[V_i(t) - V_i(t+\tau) \right]^2 \right\rangle_{T-\tau-|\theta_{ij}|}$$

Here, T is the averaging interval, τ is the "lag time"; θ_{ij} is the "time shift" parameter. The cross-correlator is a function of temporal parameters τ and θ_{ij} and can be represented as a three-dimensional plot. Of most interest for the analysis are the intervals where the cross-correlation function approaches positive unity (maximum level of positive correlations) or negative unity (maximum level of negative correlations). The value of corresponding to maximum values of cross-correlation characterizes the cause-and-effect relation ("flow direction") between signals $V_i(t)$ and $V_j(t)$. When $\theta_{ij} > 0$, the flow moves from point *i* to point *j*, when $\theta_{ij} > 0$, from *j* to *i*. When the distance between points *i* and *j* is fixed, the value of θ_{ij} can be used to estimate the rate of information transfer between these points.

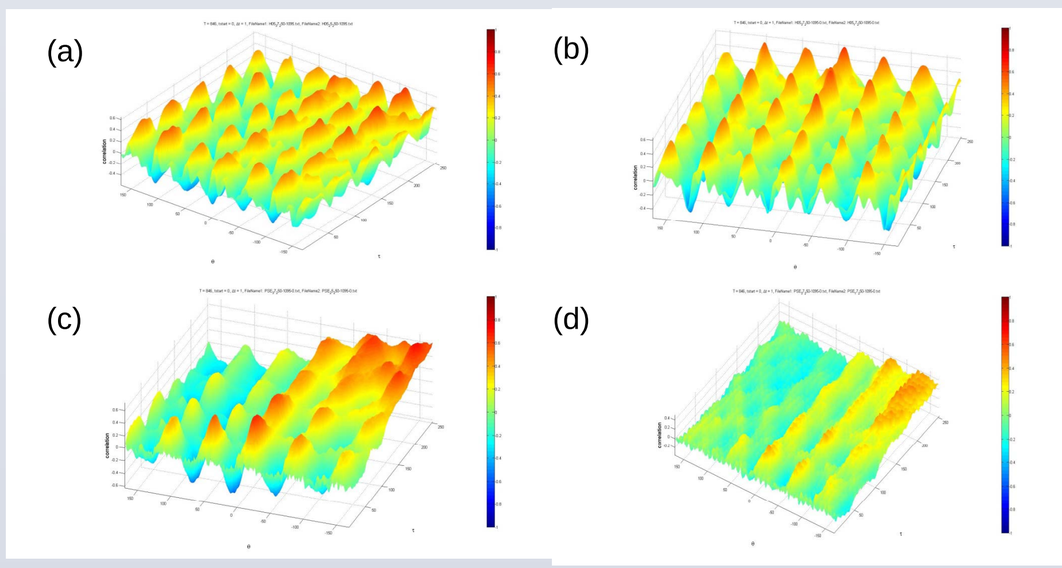


Cross-correlation $q_{10\text{-}54}(\tau; \theta_{10\text{-}54})$, 10 (frontal zone) - 54 (occipital zone), Healthy-6th (*a*) and 1st (*b*) control subjects, and patient (*c*) (R-B stimuli)

The current study demonstrates that the breakdown of frequency-phase synchronization is not always associated with the onset and amplification of high-frequency (50÷100 *Hz*) neuromagnetic responses. For example, sensors 37, 25 (left temple area) and 30 (left parietal area) show a disruption in natural cortical rhythms not because of high-frequency resonances (50÷100 *Hz*) but due to a higher intensity of high-frequency stochastic components. To characterize the intensity of stochastic components, we use the "spikiness" parameter [1, 2], which is defined in FNS as the power spectrum value at the frequency corresponding to the characteristic time of loss of correlations in the series of high-frequency irregularities. We report that for the patient the values of spikiness factor at sensors 25, 30, 37 and the anomalous sensors are 3 or more (up to 10) times higher than the maximum values of ~ 150 $fTl^2/f_d cm^2$ for control subjects.

N sensor	25	37	30	17	10	59
Patient	956	579	1474	777	156	169.5
Healthy-1st	8.6	79	36.2	7.1	87.2	8.4
Healthy-5th	44.9	19.8	12.7	38.4	9.2	7.14
Healthy-6th	5.0	168	29	0.13	11.1	108.7

Table 1. The values of the "spikiness" parameter ($fTl^2/f_d cm^2$) of the MEG signals in different cortex areas for several healthy subjects and patient



Cross-correlation $q_{37\text{-}25}(\tau; \theta_{37\text{-}25})$ (*a*, *c*) and $q_{37\text{-}30}(\tau; \theta_{37\text{-}30})$ (b, d) for the 5th healthy control subject (*a*, *b*) and the patient (*c*, *d*); R-B stimuli

Conclusions

This study as well as our previous studies [3-5] show that the identification of the level of breakdown in frequency-phase synchronization of MEG and EEG signals in different cortex areas using FNS cross-correlation function (1) may be used not only as a diagnostic sign of neurodegenerative diseases and psychiatric disorders but also to assess the effectiveness of therapeutic actions. The tendency of the organism to restore the synchronization to its normal levels is considered as the cornerstone of the analysis. We believe that a similar cross-correlation analysis based on appropriate biomedical signals may be used to assess the effectiveness of medical treatment for other diseases and conditions.

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