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Study of EEG characteristics during the observation of an educational material

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ABSTRACT

In this paper we applied analysis of multivariate time series for detection of changes in functional relations in brain during observation of educational material. Applied method is based on definition of mutual interdependence of processes and is known as Recurrent Measure of Dependence. In the paper we analyzed multichannel EEG signals obtained during experiments with observation of educational material by human subjects. We applied the method to EEG signals and showed qualitative changes in brain dynamics during educational process in comparison to dynamics of background activity.

Keywords: Electroencephalogram, education, connectivity analysis, network reconstruction

1. INTRODUCTION

Understanding of brain mechanisms and cognitive functions is one of the most relevant topics in modern science. At the same time there is a need for application of new obtained knowledge from this sphere in order to enhance quality of education.[1] These studies provide possibility to modify educational process with help of neuro- and cognitive science.[2]

One of the most interesting tasks is to study methods and conditions of education and to find ones that provide optimal mastering of new information. These studies combine approaches of neuroscience, pedagogy and psychology, that are aimed to find new technical means and methods for qualitative modernisation of educational process. For example, neurophysiological studies on electroencephalogram (EEG) revealed influence of musical education on work of the whole brain.[3] Another EEG-based resarch showed effectiveness of podcasting as educational instrument.[4]

Success of these studies is mostly explained by application of interdisciplinary methods and approaches. At this context statistical physics and nonlinear dynamics can enhance mathematical apparatus in sphere of big data analysis and help to reveal new features of brain activity dynamics. Wide variety of mathematical methods are aimed to reconstruct functional relations between different areas of brain.[5] One of the most used methods are Granger causality method,[6] evaluation of nonlinear associations,[7] wavelet bicoherence.[8]

In present work we applied new method (Recurrent Measure of Dependence)[9] for analysis of multivariate time series of EEG obtained during experiments with observation of educational material by human subjects. We applied the method to EEG signals and showed qualitative changes in brain dynamics during educational process in comparison to dynamics of background activity.

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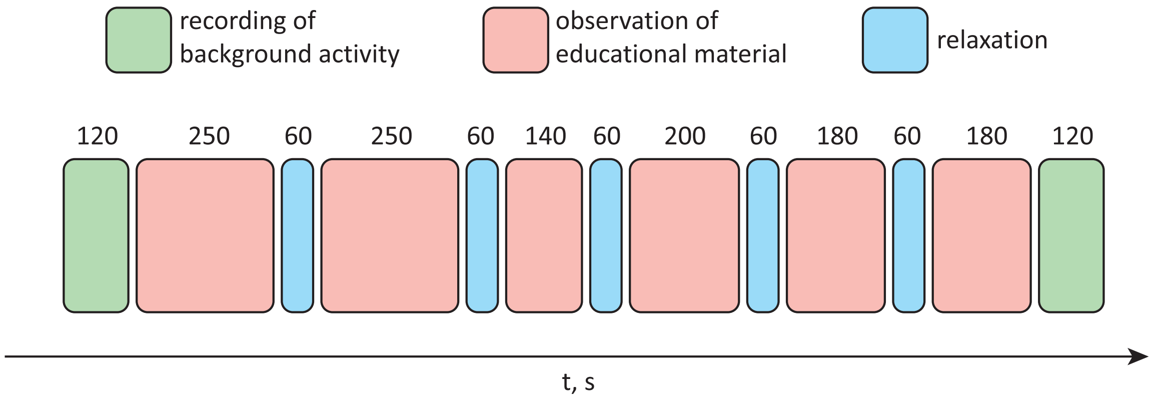

Figure 1. Scheme of experiment; coloured blocks correspond to different stages of experiment: recording of backfround EEG activity, observation of educational material, relaxation. Number near each block reflect its duration in seconds.

2. METHODS

In our work we used multichannel EEG data obtained in experiments with observation of educational material.

This experimental work was held for 3 healthy subjects – students – in the age of 20-22. All students study in Yuri Gagarin State Technical University of Saratov and have high average grade. All participants provided informed written consent before the experiment.

Experimental work was held in the first half of day. Experimental design is illustrated on Fig. 1. During the experiment subjects observed consequent visual stimuli such as bistable images. The task of participant was to perceive large number of sequentially displayed images and to make decision on each image. These actions were used to test concentration of subject's attention and to monitor changes in level of attention.

In the experiment the subjects were comfortably sitting at a 7080 cm distance from a 24 LCD monitor with an approximately 0.25 rad visual angle. During one experimental session several educational videos with duration 98-250 s and 60 s pauses between then were demonstrated on the monitor with a spatial resolution of 1920 1080 pixels and a 60-Hz refresh rate.

Before and after active experiment we recorded background EEG activity for 120 s in order to compare back ground activity with EEG signasl during experiment.

To register the EEG data, we used electroehcephalograph "Encephalan-EEGR-19/26" by Medicom MTD (Taganrog, Russia) with 19 EEG channels. For EEG signal recording the cup adhesive Ag/AgCl electrodes (one for each channel) were placed on the scalp with the help of "Tien20" paste. Before the experiment, we put the abrasive "NuPre" gel on the scalp to increase the skin conductivity. After the electrodes were placed, we monitored the impedance to get best possible quality of EEG recordings. The ground electrode N was located above the forehead, and the reference electrodes A1 and A2 were attached to the mastoids. For filtering the EEG signals, we used a band-pass filter with cutoff points at 0.016 Hz and 70 Hz, as well as a 50-Hz Notch filter.

Method used for EEG analysis supposes following steps.

Signals, that describe processes X and Y, are used to reconstruct trajectories in phase space $\mathbf{x} = \{x_1, x_2, .., x_N\}$ and $\mathbf{y} = \{y_1, y_2, .., y_N\}$ correspondingly. For each trajectory reccurent matrices are calculated as:

$$\mathbf{R}^X_{i,j} = H(\varepsilon - |x_i - x_j|), \quad (1)$$

$$\mathbf{R}^Y_{i,j} = H(\varepsilon - |y_i - y_j|), \quad (2)$$

where $H(\bullet)$ – Heaviside fuction, ε – size of reccurent area in phase space. With help of these matrices we can calculate probability of following: event X possesses value x_i as $P^X(x_i) = 1/N \sum_{j=1}^{N} \mathbf{R}_{i,j}^X$, and the same for event Y: $P^Y(y_i) = 1/N \sum_{j=1}^{N} \mathbf{R}_{i,j}^Y$.

Also we calculate mutual reccurent matrix as:

$$\mathbf{JR}_{i,j} = \mathbf{R}_{i,j}^X \mathbf{R}_{i,j}^Y, \tag{3}$$

and with help of it we can calculate conditional probability that event X possesses value x_i while event Y possesses value y_i as $P^{XY}(x_i, y_i) = 1/N \sum_{j=1}^{N} \mathbf{JR}_{i,j}$.

In order to find how independent events X and Y at time moment i we calculate Recurrent Measure of Dependence (RMD):

$$RMD_i = P^{XY}(x_i, y_i)/(P^X(x_i)P^Y(y_i)). \tag{4}$$

Calculation of RMD allows to analyze connection with respect to delay time τ.[10] In this case we have:

$$RMD(\tau) = \log_2 \left(\frac{1}{N'} \sum_{i=1}^{N'} RMD_i(\tau) \right). \tag{5}$$

where $N' = N - \tau$ and $RMD(\tau)$.

3. RESULTS

Fig. 2 illustrates resuts of analysis of functional connections in brain of subjects during background activity and during observation of educational material. Presented results were averagen over certain stages of experimental session. From Fig. 2a,c one can see, that in case of background activity the most significant connections are between areas in occipital and parietal cortex of left hemisphere and partially in frontal cortex.

However, picture changes during observation of educational material: there is significant increase in connection in right hemisphere (see Fig. 2b,d). It can be seen, that the most increse in connection is between occipital and parietal cortex . One can alse see a hub – O2 channel with 4 significant connections.

Appearance of such hub can be related to processes of perception and processing of external visual information and to increased concentration of attention. These results fit modern theories about work of human brain. However, such localization of brain area related to perception and analysis of visua information can be useful in development of "brain-computer" interface or devices for evaluation of attention level.

4. CONCLUSION

In present work we applied new method (Recurrent Measure of Dependence) for analysis of multivariate time series of EEG obtained during experiments with observation of educational material by human subjects. We applied the method to EEG signals and showed qualitative changes in brain dynamics during educational process in comparison to dynamics of background activity.

Obtained results can be helpful in development of "brain-computer" interface or devices for evaluation of attention level.

5. ACKNOWLEDGMENTS

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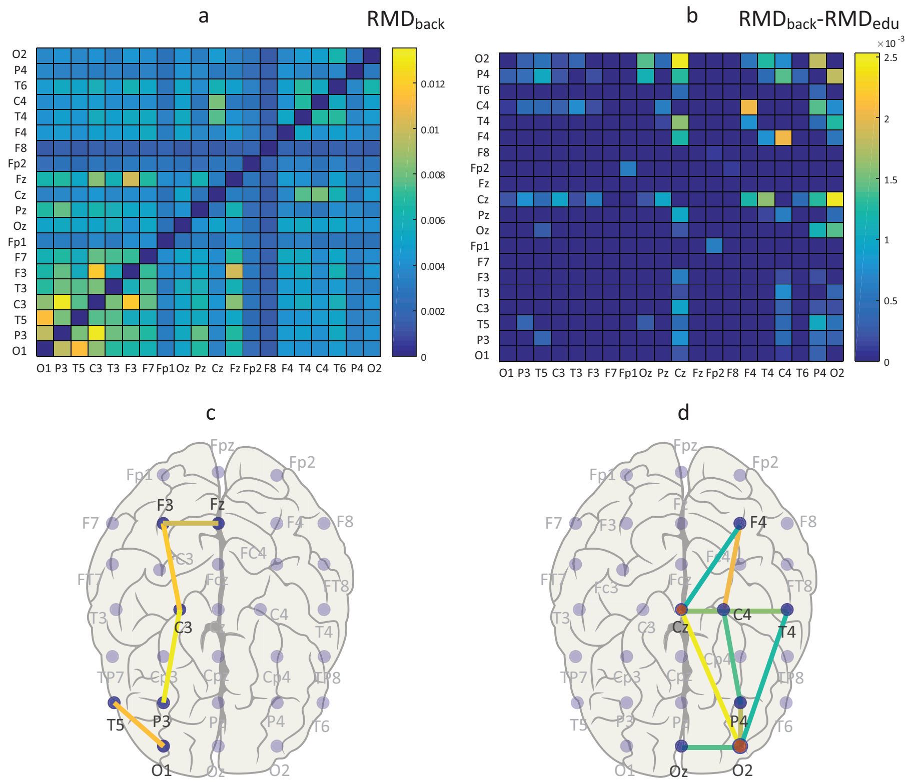

Figure 2. Results of analysis: matrix of connections between areas of brain during background activity (a) and during observation of educational material (b), visualization of significant connections during background activity (c) and during observation of educational materia (d).

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