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MODELING OF MULTIFACTOR REGRESSION OF THE SYNCHRONIZATION PERIOD FOR AN INDIVIDUAL PATTERN OF THE HUMAN BRAIN NEURAL NETWORK

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We consider multifactor model of the human brain synchronization depending on external factors (frequency and index of alpha rhythm, interhemispheric asymmetry and type of neural network of the head brain). All statistical data were obtained with the help of device Neuron-Spectrum (Neurosoft, Russia), which carried out multichannel registration of EEG (electroencephalogram) by 8 cup electrodes connected with ear electrodes and localized in accordance with the system 10 – 20. We consider the following two groups of subjects: people who regularly practice psycho-physical relaxation (meditation) and aged 22 – 34, and people who do not practice psycho-regulation and aged 22 – 38. The testing of the constructed models for the Control group proves an importance of all investigated factors and gives a mean absolute percentage error 0.53%. Also, the coefficient of determination showed that 99.9% of dispersion of the investigated feature is explained by the considered external factors. For the PPR (psycho-physical relaxation) group, we prove an importance of only one of the considered factors (frequency of alpha rhythm). Therefore, for this group, an additional research is needed to search for more significant external factors.

Keywords: multifactor model; synchronization of the head brain; interhemispheric asymmetry; type of neural network of the head brain; frequency of alpha rhythm; index of alpha rhythm; modeling; electroencephalogram.

Introduction

Nowadays, the problem of diagnosing the current state and changes in the human body becomes actual. Therefore, physiological methods of diagnosis functional states are identified in a special class of methodical techniques and indicators.

Recently, there are more and more data that even short-term fluctuations in EEG (electroencephalogram), especially in the alpha band of its frequency spectrum, in many cases reflect fluctuations in the level of functional state of the brain. In particular, the level determines an efficiency of sensorimotor activity and some sides of mental activity [1].

Space-time organization of bioelectric activity of the brain and its dynamics are closely related to the features of functional states of the brain. Therefore, along with an evaluation of individual rhythmic EEG components, the characteristics of their space-time relations, in particular indicators of coherence, are used. An average level of coherence can be determined for individual frequency ranges (for example, alpha or beta) and for two power spectra over all frequencies taken together. Also, a good indicator of the normal state of the brain is an average level of coherence for individual spectral components (delta, theta, alpha and beta).

In this case, the greater a probability that interactions between cortex sections appear in the alpha range, the higher a plasticity of the neurodynamic processes. Enough large local unions of nervous cells functionally connected by a common task, i.e. neural ensembles, are formed, when individual operations are performed in natural neural networks.

It is obvious that one of the main mechanisms to combine neurons functionally is the synchronization of their activity. Moreover, as a rule, the synchronization is rhythmic. In order to study in detailes a role of the synchronization mechanism in mobilization of optimal functional state, it is necessary to know features of synchronization of the neural networks in the alpha range.

1. Research Method

In the study, we consider the following two groups of subjects:

1. PPR group, i.e. people who regularly practice psycho-physical relaxation (meditation) and aged 22–34.
2. Control group, i.e. people who do not practice psycho-regulation and aged 22–38.

With the help of device Neuron-Spectrum (Neurosoft, Russia), we carried out multichannel registration of EEG (electroencephalogram) by 8 cup electrodes connected with ear electrodes and localized in accordance with the system 10-20. We took several functional samples: background record (BR), relaxation state of persons who practice PPR, execution of local load (LL) alternately with the right and left hand on the ergograph before fatigue (failure to work) and background record of recovery period after each load. Frequency of EEG quantization was 250 Hz. Computer electroencephalography included spectral and correlation analysis, which was carried out with the help of software of developer company.

The aim of the study is to construct a model of synchronization period for each group of subjects taking into account the following external factors:

1) neural network type;
2) alpha-rhythm frequency, Hz;
3) alpha-rhythm index, %;
4) interhemispheric asymmetry, %.

Therefore, we consider the following actual and, at the same time, poorly understood problem. We analyse dynamics of human brain activity based on estimates of synchronism of the moments of sharp changes in EEG characteristics, and first of all alpha-activity.

Also, at this stage, the problem requires a significant amount of methodological work and basic experimental studies.

Changes in the bioelectric activity of the brain by mental activity, as a rule, have zonal specificity. In other words, EEG rhythms in different areas of the cortex are different during solving problems. There are several ways to evaluate character of space-time organization of the EEG during solving problems.

One of the most common methods is research remote synchronization of biopotentials and coherence of spectral components of the EEG in different regions of the brain. It is known that for a state of rest, usually there is a certain average level of synchronization and coherence of the EEG, which reflects an active maintenance of interzonal connections and tone of cortex areas at rest. These interzonal relations are typical for the rest and essentially changed, when a task appears.

It is established that mental activity dramatically increases the number of cortex sites such that a correlation between the sites on various components of the EEG shows high statistical significance. However, interzonal relationships depend on the nature of the problem and selected indicator and can be different. For example, consider the solving of verbal and arithmetic problems. In this case, the degree of remote synchronization of biopotentials in the frontal and central departments of the left hemisphere increases. In addition, solving mathematical problems gives an additional focus of activation in parietal-occipital departments.

Also, the changes in degree of spatial synchronization of biopotentials depend on the degree of action algorithmization. If the performed action has easy algorithm, then the degree of synchronization in back parts of the left hemisphere increases. If the performed algorithm of action is difficult, then the activation focus moves to the front zones of the left hemisphere.

Previous researches propose four types of neural networks of the brain. Certain sets of other indicators correspond to each type, see Fig. 1.

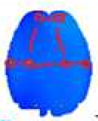
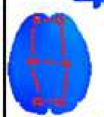
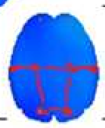
Type of neural network	Type of synchronization	Alpha-rhythm index of BR , %	Interhemispheric asymmetry, %	Synchronization period, s
	Front	28±8	14±3	13±3
	Longitudinal	14±4	18±3	26±7
	Back	19±5	16±3	19±6
	Transverse	12±3	30±5	22±5

Fig. 1. Average indicators for different types of neural networks of the brain

The alpha rhythm is a rhythmic component of the EEG with frequency in the range 8-13 Hz (some authors propose the lower limit be 7.5 or even 7 Hz, and the higher limit be from 12 to 14 Hz) and having maximum amplitude in the occipital area of the cortex. Usually, any EEG components with similar characteristics are also called «alpha rhythm», even if they are not rhythmic, but are, for example, individual waves. In this case, an alternative term is "alpha-activity".

There are no clear boundaries between pronounced alpha-rhythm and alpha-like activity. Therefore, most researches, especially early ones, do not distinguish alpha-rhythm and alpha-like activity. Additional term problem is an existence of EEG components, which are closed to alpha-rhythm by frequency and other characteristics, and differ from the alpha-rhythm by degree of expression in different areas of the cortex and connections with different analyzers. For example, well-known mu-rhythm is registered under certain conditions in central areas [2]. Sometimes, these components are also called "alpha-rhythm". Nevertheless, an activity corresponded to area of EEG spectrum having frequency 10 Hz, is often called "alpha-activity".

2. Modeling of Synchronization Period for Each Group

According to empirical data, we carry out multiple regression analysis for each group of subjects. Also, we compile and analyze matrices of multicollinearity. For each constructed model, we use the following variables:

1) y is a synchronization period, sec;
2) x_1 is a frequency of alpha rhythm, Hz;
3) x_2 is an index of alpha rhythm, %;
4) x_3 is an interhemispheric asymmetry, %.

The type of neural network is a qualitative indicator, therefore the model has corresponding dummy variable:

$$z_1 = \begin{cases} 1, & \text{first type.} \\ 0, & \text{not first type;} \end{cases}$$

$$z_2 = \begin{cases} 1, & \text{second type,} \\ 0, & \text{not second type;} \end{cases}$$

$$z_3 = \begin{cases} 1, & \text{third type,} \\ 0, & \text{not third type.} \end{cases}$$

If the variables z_1, z_2, z_3 are zero, then there is the forth type of neural network.

We evaluate quality of the constructed models by the coefficient of multiple correlation. The coefficient is a measure of connection between the dependent variable and the whole set of independent variables. The coefficient of determination shows dispersion of dependent variable determined by the combined effect of all factors included in the model.

1. Control Group

The coefficient of multiple correlation R is 0.917. Therefore, there is very strong relationship between all factors and synchronization period. The mean absolute percentage error (MAPE) for current values is 0.526 %.

The multiple regression equation takes the form:

$$y = 17.63 + 2.28 \cdot z_1 + 4.42 \cdot z_3 - 0.93 \cdot x_1 - x_2 + 1.18 \cdot x_3.$$

The coefficient of determination R^2 is 0.999. It means that 99.9% of dispersion of dependent variable is determined by the combined effect of all factors included in the model.

Fig. 2 shows real and model data for the Control group.

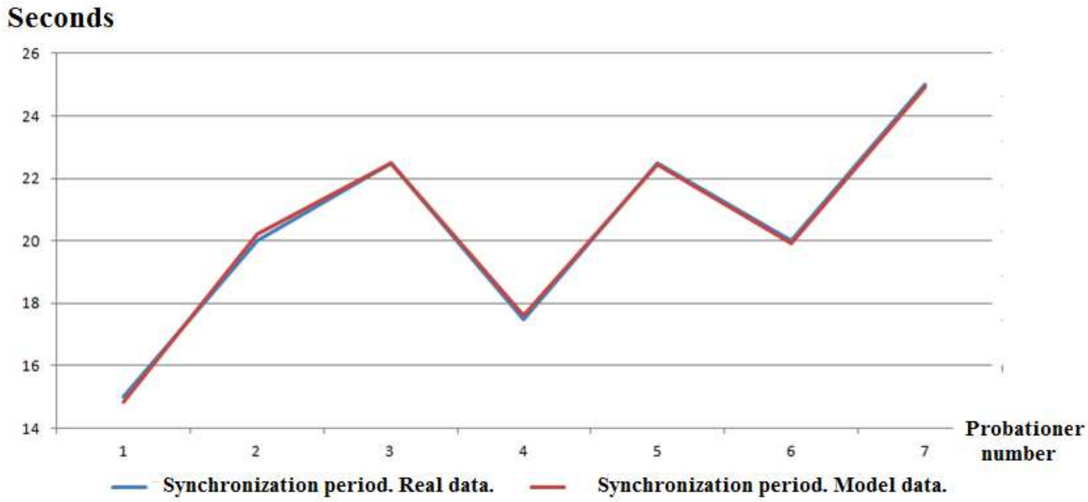


Fig. 2. Real and model data for the Control group

MAPE of the obtained model is 0.53%.

2. PPR Group

The independent variable x_2 (frequency of the alpha rhythm, Hz) is given by range of values, which are also replaced by mean values. Total number of observations is 9. For each pair of factors, the correlation coefficients are less than 0.7. Therefore, it is not necessary to exclude any factor.

The coefficient of multiple correlation R is 0.918. The coefficient of determination R^2 is 0.843. It means that 84.3% of dispersion of dependent variable is determined by the combined effect of all factors included in the model.

The regression equation takes the form:

$$y = 107.123 + 1.197 \cdot z_1 - 9.763 \cdot x_1 + 0.006 \cdot x_2 + 0.201 \cdot x_3.$$

Fig. 3 shows real and model data for the PPR group.

Despite a high coefficient of determination, the study of t-statistics shows that all coefficients of factors are insignificant, expect the alpha-rhythm frequency. This fact is explained by a high coefficient of the correlation between synchronization period and

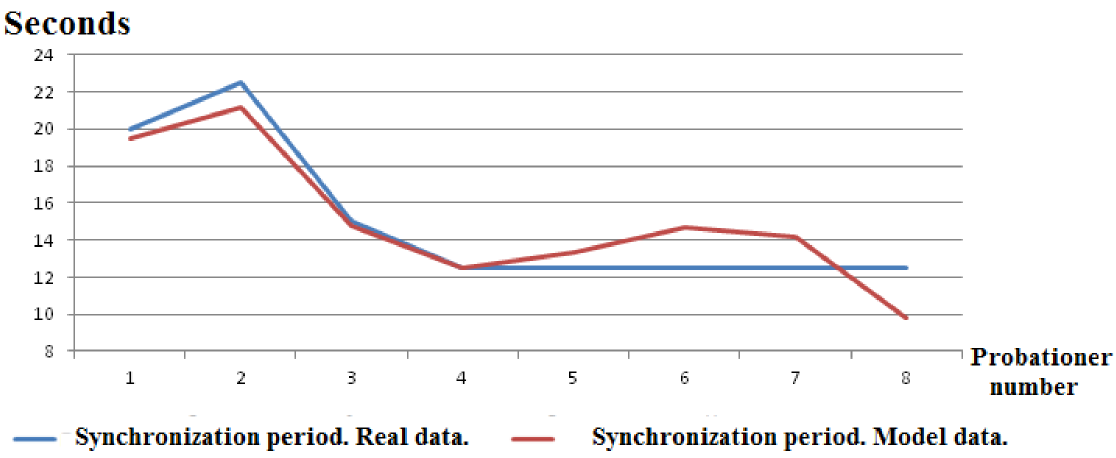


Fig. 3. Real and model data for the PPR group

frequency of the alpha-rhythm, specifically for the considered group (-0.87). MAPE of the obtained model is 8.68%.

Therefore, we construct a pair-regression model of synchronization period for the PPR group taking into account only the alpha-rhythm frequency. We exclude all factors having not significant coefficients. Then the model takes the form:

$$y = 99.91 - 8.62 \cdot x_1.$$

The coefficient of determination of the obtained model is 0.76, and MAPE is 11.94 %.

Therefore, for a group of people who regularly practice psycho-physical relaxation, the frequency of alpha rhythm has the greatest influence among the considered factors. An adequacy of the model decreased (but not significantly), when we exclude all other factors from the model. This means that it is necessary to find other influential factors and use them in the model.

Conclusion

The mechanisms of human alpha-rhythm generation are not completely clear. In particular, this can be explained by the fact that the human alpha-rhythm has some differences from the close to it alpha-like activity of animals (which is often also called alpha-rhythm), and the results of the research on animals can be only partially generated to the human brain [2].

In the study, we consider the following two additional groups.

1. Sport Group, i.e. people who are engaged in acyclic sports (martial arts) and aged 21–28.

2. NPS group, i.e. people with an increased level of anxiety (neuropsychic stress) and aged 23–40.

For these groups, there is no single-valued relationship between synchronization period and considered factors. Therefore, additional research is necessary.

For two main groups of people, we proved the following. A multifactor model should include all initial factors in the case of people who do not practice psycho-regulation. An additional research is required to find more significant external factors in the case of people who regularly practice psycho-physical relaxation (meditation).

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МОДЕЛИРОВАНИЕ МНОГОФАКТОРНОЙ РЕГРЕССИИ ПЕРИОДА СИНХРОНИЗАЦИИ ГОЛОВНОГО МОЗГА ЧЕЛОВЕКА

Ю. И. Корюкалов, Н. С. Софьина, Д. В. Софьин, Н. А. Лебедева

В статье рассмотрена многофакторная модель синхронизации головного мозга человека в зависимости от внешних факторов (частота альфа-ритма, индекс альфа-ритма, межполушарная ассиметрия и тип нейросети головного мозга). Все статитстические данные получены при помощи прибора Нейрон-Спектр (Нейрософт, Россия) осуществляли многоканальную регистрацию ЭЭГ (электроэнцефалограмма) с 8 чашечных электродов, соединенных с ушными электродами и локализованных в соответствии с системой 10 – 20. В рассмотрение были взяты 2 группы испытуемых: люди, регулярно практикующие психо-физическую релаксацию (медитация), возраста 22 – 34 года, и люди, не практикующие психо-регуляцию, возраста 22 – 38 лет. При тестировании построенных моделей для группы Контроль была доказана значимость всех исследуемых факторов и достигнута средняя ошибка аппроксимации 0,53%, а коэффициент детерминации показал, что 99,9% дисперсии исследуемого признака объясняется взятыми внешними факторами. Для группы ПФР (психо-физическая релаксация) доказана значимость только одного из исследоуемых факторов (частота альфа-ритма), поэтому для данной группы требуются дополнительные исследования для поиска более значимых внешних факторов.

Ключевые слова: многофакторная модель; синхронизации головного мозга; межполушарная ассиметрия; тип нейросети головного мозга; частота альфа-ритма; индекс альфа-ритма; моделирование; электроэнцефалограмма.

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