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Revealing True and False Brain States Based on Wavelet Analysis of Electroencephalogram

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Abstract

Statement of the Problem: As you know, there exist two different states in the brain's mental activity: true and false. In recent years, a progressive method of wavelet transformation of the electroencephalogram (EEG) has been developed, which enabled us to establish the fundamental possibility of direct objective registration of the human brain's mental activity. Earlier, we created an experimental model and software for recognizing true and false mental responses of a person based on the EEG wavelet transformation and described it in the article. The developed experimental model and information software made it possible to compare the two mental states of brain activity by electroencephalographic indicators, one of which is false and the other is true. **The goal** is to develop a fundamentally new information technology for recognizing true and false states in the brain's mental activity based on the wavelet transformation of the electroencephalogram. **Results:** It was revealed that the true and false states of the brain can be distinguished using the method of continuous wavelet transformation and calculation of the EEG wavelet energy. It is shown that the main differences between true and false mental responses are observed in the delta and alpha ranges of the EEG. In the EEG delta rhythm, the wavelet energy is reliably higher in case of a false answer compared to a true one. In the EEG alpha rhythm, the wavelet energy is significantly higher with a true answer than a false one. **Practical significance of the research:** The data obtained open up the fundamental possibility of identifying true and false mental states of the brain on the basis of continuous wavelet transformation and calculation of the EEG wavelet energy.

Keywords

Information Technology, Electroencephalogram (EEG), Continuous EEG Wavelet Transformations, Mental Activity of the Brain, Consciousness, Truth and Falsehood

1. Introduction

A polygraph or a lie detector is a technical tool for conducting instrumental psychophysiological studies widely used in the practice of criminal investigation and in professional selection to test false and true human responses [1] [2] [3].

The fundamental disadvantage of polygraphic testing is that the assessment of the result is based on the registration of psychophysiological indicators, which only indirectly reflect the subjective state of the individual and are not indicators of the true or false mental state of the subject's brain.

In a number of countries, data obtained through psychophysiological surveys are not considered as evidence (in Germany, Poland, USA).

The limitations of the polygraphic method are associated with the fact that the mental activity of the human brain reflecting its false or true state is not directly recorded.

The brain is a unique organization in living nature that has the ability for mental activity, which manifests itself in consciousness, thoughts, feelings, emotions, *i.e.* in a person's subjective perception of himself and the world around him [4]-[16].

In recent years, progressive methods of wavelet transformation of electroencephalogram (EEG) have been developed [17] [18] [19] [20]. Using this method, we established the fundamental possibility of direct objective registration of the human brain's mental activity [21] [22] and created an experimental model and software for recognizing true and false mental responses based on the analysis of electroencephalogram [23] [24], which opened the prospect for identifying false and true mental states of the human brain.

The aim of the work is the development of a fundamentally new information technology for the recognition of true and false states of the brain in mental activity based on the wavelet transformation of the electroencephalogram.

2. Methods

We described an experimental model and software for recognizing true and false mental responses based on the analysis of continuous wavelet transformation (CWT) of electroencephalogram in the article [23] [24].

CWT is a convolution of the studied signal $x(t)$ (EEG) and a set of some basis functions $\varphi_{s,\tau}$:

$$W(s,\tau)=\int_{-\infty}^{+\infty}x(t)\varphi_{s,\tau}^{*}(t)\mathrm{d}t$$

Each basis function $\varphi_{s,\tau}$ can be obtained from one function φ_0 called the mother wavelet:

$$\varphi_{s,\tau}(t)=\frac{1}{\sqrt{s}}\varphi_0\left(\frac{t-\tau}{s}\right)$$

In the present study, we used the maternal Morlet wavelet which has shown its effectiveness in the time-frequency analysis of EEG signals:

$$\varphi_0(\eta) = \pi^{-\frac{1}{4}} e^{j\omega_0\eta} e^{-\frac{\eta^2}{2}}$$

The most common way to obtain information on the time-frequency composition of a signal using CWT is to consider the so-called wavelet spectra, which represent the projection of the three-dimensional surface of the wavelet transformation energy $E(s, \tau)$ onto the plane (t, f) ("time-frequency"), where

$$E(s,\tau) = |W(s,\tau)|^2$$

The wavelet spectrum can be viewed and averaged over characteristic frequency ranges—for example, alpha, beta, gamma, etc. The averaged wavelet energy for the characteristic frequency range F is calculated as follows:

$$E_F(t) = \frac{1}{\Delta f_F} \int_{f \in f_F} E(f,t)\,df ,$$

where Δf_F is the width of the frequency range F.

We used the multivariate analysis of variance ANOVA [25] to calculate the wavelet energy for various EEG rhythms: in the delta, theta, alpha, beta ranges and averaged it over 10 EEG derivations in two series of testing of the subjects: during the demonstration of the image and mental true and false answers.

The survey involved 10 first-year volunteer students of the medical, preventive medicine and pediatric faculties of the I.M. Sechenov First MSMU (17 - 20 years old men) who gave informed consent to the processing of personal data and participation in the work. The study on students was approved at a meeting of the local ethics committee of the I.M. Sechenov First Moscow State Medical University on N˚ 10 - 18 from 05.12.2018.

The experimental model and research procedure that we described in articles [23] [24] includes several stages.

Before testing, electrodes are fixed on the surface of the test person's head to record the EEG in different leads. 10 EEG channels (O2, O1, P4, P3, C4, C3, F4, F3, T4, T3) are used, located throughout the head in accordance with the international scheme "10 - 20".

The experimenter gives instructions to the test person as following. Different images will successively appear on the monitor screen in front of the subject with the following question: "What is shown in the figure?", and the subject knows the answer exactly. The time of presenting the image with a question to the subject for observation is 3 sec. After the image on the screen has disappeared, the subject gives a true or false mental answer.

Depending on the question posed, the answer can be laconic, such as "Yes" or "No". Or the answer can be expanded, for example: the image shows the "Elephant" and the question is "What is this?"—The answer may be true—"This is an elephant"; or false—"This is a fly." The specified time for a mental response is 3 seconds.

Two consecutive series of tests were carried out. According to the instructions, **in the first series, the subject gives mental truthful answers, in the**

second series, the subject gives false mental answers. 10 subjects participated in two series; in each series, the subject was presented with 30 images, a total of 60 images.

During the entire testing period, EEG registration and recording is carried out [25]. All files with EEG recording were analyzed using the method of continuous wavelet transformation [17] [18] [19] [20], the corresponding wavelet spectra were constructed and the wavelet energy was calculated. Statistical analysis of wavelet energy was carried out using multivariate analysis of variance ANOVA [26].

The experimental model and information software made it possible to compare two mental states of brain activity by electroencephalographic indicators, one of which is false and the other is true.

3. Results

The wavelet spectrum was calculated and analyzed in four EEG frequency ranges: delta (1 - 4 Hz), theta (4 - 8 Hz), alpha (8 - 14 Hz) and beta (15 - 30 Hz), for 10 EEG channels, in two intervals of recording: during the direct presentation and perception of the image by the subject and during the mental true or false response of the subject.

As a result, after each test, the following data were obtained: averaged wavelet energies over the duration of EEG recording fragments (3 s) for each subject in the delta/alpha/beta/gamma EEG ranges while viewing the image and during mental response.

Wavelet spectra are shown in Figure 1, which shows the presence of characteristic components with high energy, both during the presentation of the question and during the mental response of the subject in different frequency ranges of the EEG.

Designations. The vertical dashed line indicates the end of the image demonstration and the beginning of the subject's mental response. Horizontal: time in seconds, total 6 seconds. Vertical: f-EEG rhythm frequency. On the right, there is a vertical color diagram E reflecting wavelet energy (in dimensionless units).

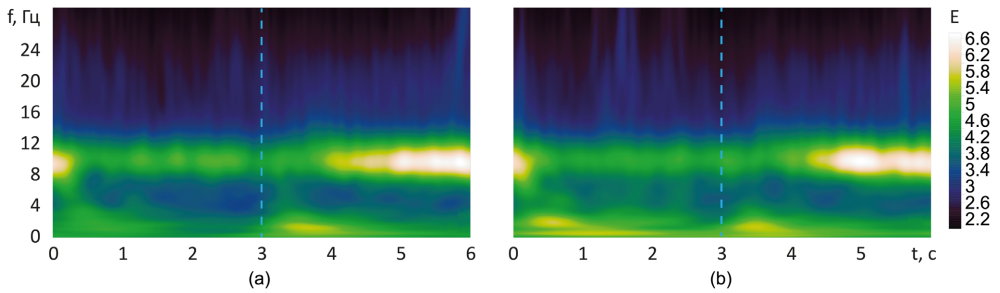

Figure 1. Wavelet spectra of EEG recording fragments: 3 sec during image demonstration and 3 sec during mental response, averaged over 10 EEG channels and 60 tests, presented to 10 subjects in total in the first and second series of testing. Record "(a)" is the first series, record "(b)" is the second series.

Figure 1 shows that the main changes in the EEG wavelet spectra occur in the delta and alpha rhythm, both during the demonstration of the image and during the mental response.

Table 1(a) and Table 1(b) and Table 2(a) and Table 2(b) show the calculation of the wavelet energy for various EEG rhythms: in the delta and alpha ranges, in two series of testing of subjects: during the demonstration of the image and with mental true and false answers.

Table 1. (a) Wavelet energy in the EEG delta range in subjects during the **demonstration of the image** in 2 series: the first one where the subject gives a true mental answer; the second one where the subject gives a false mental answer; (b) Wavelet energy in the EEG delta range in subjects during **mental responses** in 2 series: the first one where the subject gives a true mental answer; the second one where the subject gives a false mental answer.

(a)

Trial Subject No.	Wavelet energy in the 1st series.	Wavelet energy in the 2nd series.
1	54.5354	55.3867
2	29.1812	30.9614
3	46.7598	56.7436
4	37.5352	39.4898
5	43.8911	50.4258
6	61.096	76.2829
7	51.6958	49.7955
8	32.6052	42.689
9	47.2556	54.1128
10	44.0797	59.6733

(b)

Trial Subject No.	Wavelet energy in the 1st series.	Wavelet energy in the 2nd series.
1	71.2926	76.5373
2	35.4006	31.9026
3	50.8322	47.9359
4	32.0606	33.0923
5	49.951	44.7927
6	62.5786	75.7395
7	48.8731	55.4987
8	35.7703	34.4211
9	50.8717	48.7566
10	40.1075	43.0883

Table 2. (a) Wavelet energy in the EEG alpha range in subjects during the **image demonstration** in 2 series: the first one where the subject gives a true mental answer; the second one where the subject gives a false mental answer; (b) Wavelet energy in the EEG alpha range in subjects during **mental responses** in 2 series: the first one where the subject gives a true mental answer; the second one where the subject gives a false mental answer.

(a)

Trial Subject No.	Wavelet energy in the 1st series.	Wavelet energy in the 2nd series.
1	34.2514	33.8205
2	26.9776	32.2151
3	61.3891	52.2307
4	23.6984	24.7679
5	28.9997	28.4213
6	62.3025	64.7821
7	66.9808	67.6739
8	41.0498	39.4804
9	55.143	54.3847
10	32.8821	35.3724

(b)

Trial Subject No.	Wavelet energy in the 1st series.	Wavelet energy in the 2nd series.
1	39.8181	39.2663
2	31.735	35.6505
3	63.6879	57.0833
4	24.7511	25.8803
5	31.9963	31.3882
6	73.1894	70.9788
7	84.6141	83.9917
8	46.1339	46.9017
9	68.4828	71.4698
10	31.847	31.8577

Significant differences were revealed in the EEG delta range between the wavelet energy values in the first (true) and second (false) series of testing, both at the stage of image observation and at the stage of true or false mental responses ($F(1.9) = 8$, $p = 0.018$). It has been shown that in general, the wavelet energy in the EEG delta range is higher in case of a false answer than a true one.

When analyzing the wavelet energy in the theta range of the EEG, no significant effects were found in the subjects both during the **image demonstration** and during the **mental responses** in 2 series of testing.

In the EEG alpha range, it was revealed that the value of the wavelet energy has significant differences in true and false mental responses ($F(1.9) = 7$, $p = 0.024$). During the image observation, the wavelet energy is higher in the first test series when the subject is set to a true answer, and lower in the second test series when the test is set to a false answer. During a mental response, the wavelet energy is higher with a true response than a false one. In this case, the energy is higher during mental responses than during the previous image observation, regardless of whether the test was given a true or false answer.

When analyzing the wavelet energy in the theta range of the EEG, no significant effects were found in the subjects during the **image demonstration** or during **the mental responses** in 2 series of testing.

4. Conclusions

Thus, it was found that true and false states of the brain can be distinguished using the method of continuous wavelet transformation and calculation of the EEG wavelet energy. It is shown that the main differences between true and false mental responses are observed in the delta and alpha ranges of the EEG.

In the EEG delta rhythm, the wavelet energy is reliably higher in case of a false answer compared to a true one. In the EEG alpha rhythm, the wavelet energy is significantly higher with a true answer than a false one.

It should be noted that even during the image demonstration, the EEG activity of the brain may indicate the subject's intention to lie or tell the truth. At the stage of **image observation**, the wavelet energy in the EEG alpha range is higher when the subject is set for a true response, and lower when the subject is set for a false response, and in the delta EEG range the same is higher in case of a false response than a true one.

When subjects observe an image, high wavelet energy in the low-frequency delta range and low wavelet energy in the alpha range may indicate the subject's intention to give a false answer.

According to the instructions, in the first series of testing the subject has a mindset for a correct, honest mental answer; in the second series of testing, the subject was set to false answer. During the period of image observation, along with the comprehension of the image content, the subject is mentally tuned in advance to give a true or false mental answer. At this time, formation of a true or false state of the brain occurs, which is then realized during mental responses.

The data obtained open up the fundamental possibility of identifying true and false mental state of the brain on the basis of continuous wavelet transformation and calculation of the EEG wavelet energy. At the same time, in order to develop a practical test method and identify true and false mental states of the brain, further detailed analysis of the EEG of individual cortical structures of the brain is necessary, which is our immediate task.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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