The European Proceedings of
Social & Behavioural Sciences
EpSBS

ISSN: 2357-1330

DOI: 10.15405/epsbs.2019.11.75

10th ICEEPSY 2019
International Conference on Education and Educational Psychology

THE DYNAMICS OF EEG POWER SPECTRUM IN THE PROCESS OF CHEMICAL CONCEPT FORMATION

Dmitry Talantov (a)*
*Corresponding author

(a) Institute Psychology, Russian Academy of Sciences, Moscow, Russia. E-mail: dtalant@yandex.ru

Abstract

The solution of one of the paradoxical situations of modern education is the legislative reducing mandatory disciplines to reduce training overloads of students and at the same time a catastrophic increase in student overloads, directly related to modern variations of the neuroefficiency hypothesis, in particular, the ratio of information and energy characteristics of mental activity. The purpose of the study was to examine the dynamics of inter-level changes in the EEG power spectrum when performing varying complexity differentiations of chemical compounds. Twenty-nine psychology students aged 18-23 took part in the study. The EEG power spectrum indices were recorded before and after the formative experiment. The data obtained testify in favor of the hypothesis of neuroefficiency: the formation of concepts that represent the subject area of activity causes not only high accuracy, speed, but also ease of performing activities, which is manifested in the reduction of energy consumption in terms of EEG indicators. A psychological interpretation of the EEG spectrum frequency ranges was suggested based on a comparison of the behavioral characteristics of the respondents at all stages of the experiment (fatigue, interest, ease, anxiety), objective psychological indicators of the concept Substance formation (accuracy and choice reaction time) and objective physiological indicators (EEG power spectrum):

Delta-rhythm is an indicator of effort to achieve a result;

Theta-rhythm is an indicator of concentration / generalization of nerve processes;

Beta-rhythm is an indicator of fatigue, familiarity / subjective ease of activity;

Gamma-rhythm is an indicator of highly complex cognitive activities.

Keywords: Concept, reaction time, power spectrum.

https://doi.org/10.15405/epsbs.2019.11.75
Corresponding Author: Dmitry Talantov
Selection and peer-review under responsibility of the Organizing Committee of the conference
eISSN: 2357-1330

1. Introduction

The problem of the effectiveness of cognitive processes is directly related to variations of the neuroefficiency hypothesis, describing the feedback of cognitive success with the level of brain activation (Neubauer & Fink, 2009; Basten, Stelzel, & Fiebach, 2013; Costanzo et al., 2016; Causse, Chua, Peysakhovich, Del Campo, & Matton, 2017). While solving mental tasks, more successful subjects demonstrate less brain activation than less successful ones (Rypma et al., 2006; Dunst et al., 2014). Studies have noted the nonlinear nature of the relationship between the physiological reactions of the body and the observed results of mental activity. In this regard, of interest is the problem of the relationship of psychological and physiological "costs" and the success of thinking, which can be considered from the standpoint of operational efficiency (Balin, 1971).

The term “efficiency” allows us to describe the process of mental activity in the context of the level of success and the psychophysiological “price” of such activity, as well as the specification of the psychophysiological mechanisms that underlie this ratio.

Studies performed in the framework of the differential-integration approach to mental development showed that the formation of mature concepts representing the subject area of activity determines not only high accuracy, speed, but also ease of implementation activities, which can lead to a decrease in fatigue in terms of reducing energy costs for its implementation. However, empirical data confirming the reduction in energy consumption in terms of EEG indicators are not presented.

2. Problem Statement

The main disadvantage of modern education is that the increasing complexity of cognitive activity leads to mental and physical exhaustion of students, which is directly related to modern variations of the neuroefficiency hypothesis, in particular, the ratio of information and energy characteristics of mental activity.

3. Research Questions

It is assumed that the targeted formation of the multi-level organization of the «substance» concept can lead to a reduction in energy costs in terms of indicators of brain activity in solving chemical problems.

4. Purpose of the Study

The goal of the study is to explore the dynamics of EEG power spectrum in respondents before and after the chemical concept formation.

5. Research Methods

In order to compare the indicators of brain bioelectrical activity (BEA) during cognitive activity, the Encephalan-EEGR-19/26 computerized portable electroencephalograph-recorder in the Mini version was synchronized with the Chemical Differentiation diagnostic software. Registration was carried out in

https://doi.org/10.15405/epsbs.2019.11.75
Corresponding Author: Dmitry Talantov
Selection and peer-review under responsibility of the Organizing Committee of the conference
eISSN: 2357-1330

the telemetry mode - into the computer's memory via the Bluetooth interface by the following leads: EEG_C3_O1, EEG_C4_O2 with sensitivity settings of 70 μV / mm and a sweep speed of 30 mm / sec. The frequency step was 0.25 Hz.

The EEG record was automatically scanned for artifacts that were eliminated using a regression procedure. Areas with an amplitude of more than 180 μV within a 650 ms window were noted as a bad channel, areas with an amplitude of more than 140 μV were considered as a motor artifact, and more than 60 μV - as a visual and muscular artifact. The choice of EEG data was carried out according to epochs corresponding to the execution of tasks. For each epoch, a spectrogram was calculated (the square of the Fourier transform module).

Fourier transform decomposes the signal into a series of harmonic components without any loss of information. Each harmonic includes three parameters: amplitude, initial phase and frequency. The dependence of the amplitude and phase of the harmonics on the frequency is called the spectrum (Kulachev, 2007). Noisy epochs reduced.

5.1. Participants

29 second-year students of the psychological department of the State Academic University of Humanitarian Sciences aged 18 to 23 years old took part in the experiments (34% were men; 66% were women). Significant differences in the indicators of the formal-dynamic properties of individuality according to the results of the OFDSI test (Rusalov, 2012) were not found between boys and girls, which indicates the possibility of combining respondents into one sample. All subjects were right-handed.

5.2. Measures

At the first stage, data were collected about the features of mental resources (Diagnostic complex rapid assessment of mental resources of individuality, Rusalov, Volkov) and the organization of the concept “substance” (ChemicalDifferentiation, Volkova, Nilopets) from respondents. EEG recording was performed during cognitive load, which consists of performing cognitive tasks at three levels of complexity - global (Figure 1) (distinguishing simple and complex compounds), basic (Figure 2) (distinguishing oxides, acids, bases and salts) and detailed (Figure 3) (more complex differentiation within classes of compounds). Formulas of chemical compounds appeared randomly on the screen. Respondents were offered three types of tasks, each of which contained 42 specific tasks.

https://doi.org/10.15405/epsbs.2019.11.75
Corresponding Author: Dmitry Talantov
Selection and peer-review under responsibility of the Organizing Committee of the conference
eISSN: 2357-1330

Figure 1. Global level

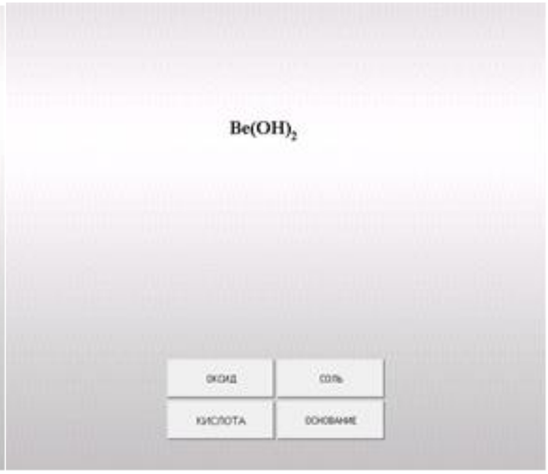

Figure 2. Basic level

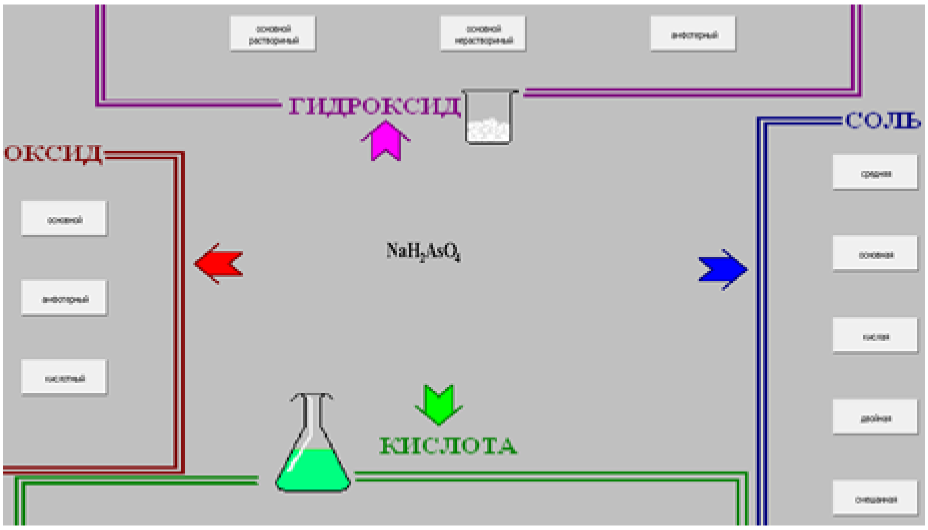

Figure 3. Detailed level

At the second stage, a learning experiment was implemented aimed at the formation of the chemical aspect of the “substance” concept (Volkova, 2011). The respondents had the opportunity to study in accordance with the zone of their closest opportunities in the GreatChemist computer program complex both in small groups and individually. Stimulus material was selected in such a way that relations on the basis of belonging to a certain group of compounds contradicted known test rules. Thus, a hydrogen atom (H) was present in acids (HBr), acid salts (KHCO3), ammonium salts (NH4Br), bases (NaOH). The hydroxyl group (OH) can be seen in organic acids (CH3CH2COOH), bases (KOH), basic salts (Al (OH) 2NO3). A more detailed description of the features of the thought processes involved in performing chemical differentiations is presented in the work of Volkova (2008). The researchers created a situation of competition between the respondents, reporting the best performance at different levels of differentiation and such criteria of concept formation as accuracy (more than 95%), the standard task execution time and the sustainability of the results obtained.

https://doi.org/10.15405/epsbs.2019.11.75
Corresponding Author: Dmitry Talantov
Selection and peer-review under responsibility of the Organizing Committee of the conference
eISSN: 2357-1330

At the third stage, under the condition that the respondents of the concept “substance” were formed, the EEG was recorded again during the execution of the “Chemical Distribution” test. The criterion for the formation of a concept was the adequacy indicators (a measure of recognition of stimulus-objects with a certain degree of accuracy); maturity (a measure of the differentiation-integration of the invariant features of an object, in particular, the constant of the operational threshold for discrimination); the form of orderliness of structures (the number of levels of generality, features of their integration); the speed and ease of concept formation, stability and speed of its actualization (Volkova, 2011).

Techniques and equipment used:

1. The questionnaire of the formal-dynamic properties of individuality for the diagnosis of the properties of the “subject-activity” (psychomotor and intellectual spheres) and “communicative” aspects of temperament (Rusalov, 2012).

2. Electroencephalograph-recorder, computerized portable “Encephalan-EEGR-19/26” in the modification “Mini” (European certificate CE 538571 of the British Standards Institute, BSI) for stationary use of the patient's ABP-10.

3. Diagnostic software package "ChemicalDifferentiation" (Certificate of state registration of computer programs No. 20166661340). The respondents on the screen in a random order were presented formulas of chemical compounds, which should be divided as quickly as possible and correctly into groups in accordance with the specified instruction. The reaction time of a difficult choice and the number of correct answers were measured. During the assignments, videotaping was made to record external behavioral manifestations.

4. Computer software complex “GreatChemist” (Certificate of State Registration of Computer Program No. 2006614415). The GreatChemist test is based on the same methodological principles as ChemicalDifferentiation, but includes a wider range of basic conceptual relationships that form the foundation of modern chemistry.

5.3. Analysis

Statistical data processing was implemented on the basis of standard IBM SPSS Statistics 22 programs. The spectral power parameters were calculated over the entire EEG frequency range (0-40 Hz). To identify inter-level differences in the EEG power spectrum, the nonparametric Wilcoxon test was used for dependent samples, since the average power spectrum did not match the normal distribution (the Shapiro – Wilk test).

6. Findings

The results of the comparison of the reaction time of a complex choice, the number of correct answers and changes in the EEG power spectrum at different levels of cognitive load are presented. The dynamics of inter-level changes in the indices of the reaction time of a complex choice and the EEG power spectrum before and after the forming experiment is considered.

https://doi.org/10.15405/epsbs.2019.11.75
Corresponding Author: Dmitry Talantov
Selection and peer-review under responsibility of the Organizing Committee of the conference
eISSN: 2357-1330

Comparison of the reaction time of a difficult choice, the number of correct answers among respondents before and after the formative experiment (see Table 1):

Table 1. Comparative analysis of indicators * differentiation of chemical objects before and after the formative experiment

		Averange values		**The value of the Wilcoxon test**	**Asim. significance (2 sided)**
		Before the formative experiment	**After the formative experiment**		
Global level	T1. ms	66	29	-4.23	0.00
	N1	8	1	-4.20	0.00
Basic Level	T2. ms	84	42	-3.83	0.00
	N2	22	3	-4.29	0.00
Detailed level	T3. ms	86	42	-3.63	0.00
	N3	35 (83.33%)	18 (42.85%)	-4.29	0.00

* T - reaction time of a difficult choice; N - the number of errors from 42 presentations of tasks

The data obtained in the present formative experiment to a certain extent agree with the data of the forming experiment of Volkova (2008) (see Table 2) on chemistry-capable students namely: 1) the higher the level of complexity, the longer the reaction time of a difficult choice; 2) in the process of the formative experiment, the accuracy and speed of the activity is increased.

Table 2. The data of the forming experiment of E.V. Volkova on chemistry-capable students.

		Averange values	
		Results of the formative experiment (psychologists)	**Results of the formative experiment (students capable of chemistry)**
Global level	T1. ms	29	31
	N1	1	0.5
Basic Level	T2. ms	42	47
	N2	3	0.83
Detailed level	T3. ms	42	147
	N3	18 (42.85%)	4 (9.5%)

* T - reaction time of a difficult choice; N - the number of errors from 42 presentations of tasks

Inter-level changes in the EEG power spectrum of respondents before the formative experiment:

Let us consider the differences in inter-level changes in the power spectrum of the respondents prior to the formative experiment. According to the data presented in Table 3, the average indices of the power spectrum in the delta range when performing more complex differentiations are higher compared with the average indices of simpler differentiations. Significant differences were found in the average indices of the power spectrum in the delta range at frequencies: 1.71 Hz, 1.95 Hz, 3.91 Hz.

With increasing information complexity (basic vs detailed), the average power spectrum increases even more and the number of significant differences in the delta range at frequencies: 0.24 Hz, 0.49 Hz, 0.73 Hz, 0.98 Hz, 1.22 Hz, 1.46 Hz, 2.20 Hz, 2.69 Hz (table 4).

https://doi.org/10.15405/epsbs.2019.11.75
Corresponding Author: Dmitry Talantov
Selection and peer-review under responsibility of the Organizing Committee of the conference
eISSN: 2357-1330

Table 3. Delta-range of the spectrum (global vs basic).

Frequency Range (Hz)	Differentiation		The value of the Wilcoxon test	p
	Global level	Basic level		
	Average power spectrum (μV2)			
1.71	6.65	7.71	-3.17	0.00
1.95	5.90	6.60	-2.48	0.01
3.91	3.78	4.32	-2.44	0.02

Table 4. Delta-range of the spectrum (basic vs detailed).

Frequency Range (Hz)	Differentiation		The value of the Wilcoxon test	p
	Basic level	Detailed level		
	Average power spectrum (μV2)			
0.24	8.60	10.34	-2.07	0.04
0.49	14.95	18.87	-2.76	0.01
0.73	16.20	20.32	-2.78	0.01
0.98	13.14	16.38	-3.21	0.00
1.22	10.39	12.48	-3.90	0.00
1.46	8.71	9.82	-2.22	0.03
2.20	5.97	6.37	-2.02	0.04
2.69	5.16	5.56	-2.51	0.01

A similar pattern was found when comparing the average performance of the power spectrum in the theta range, namely, significant differences between the global and basic levels of complexity were found at frequencies: 4.64 Hz, 4.88 Hz, 5.13 Hz, 5.37 Hz, 5.61 Hz, 5.86 Hz, 6.10 Hz, 6.35 Hz (table 5); between basic and detailed - 4.15 Hz, 4.39 Hz, 4.64 Hz, 4.88 Hz, 5.13 Hz, 5.61 Hz, 5.86 Hz, 6.10 Hz, 6.35 Hz, 6.59 Hz, 6.83 Hz, 7.08 Hz, 7.32 Hz, 7.57 Hz, 7.8 Hz, 8.06 Hz, 8.30 Hz (table 6). The average indices of the power spectrum in the theta range when performing more complex differentiations as well as in the delta range are higher compared to simpler differentiations. However, the number of significant differences is greater: there are 8 significant differences between the global and base levels in the theta range, and 3 in the theta range; there are 17 significant differences between the basic and detailed in theta range, and 8 in the delta range.

Table 5. Theta-range of the spectrum (global vs basic).

Frequency Range (Hz)	Differentiation		The value of the Wilcoxon test	p
	Global level	Basic level		
	Average power spectrum (μV2)			
4.64	3.30	3.71	-2.13	0.03
4.88	3.17	3.60	-2.77	0.01
5.13	3.09	3.58	-2.04	0.04
5.37	3.11	3.70	-3.08	0.00
5.61	3.04	3.55	-3.62	0.00
5.86	2.82	3.36	-3.24	0.00
6.10	2.44	3.12	-4.44	0.00
6.35	2.44	2.98	-3.34	0.00

Table 6. Theta-range of the spectrum (basic vs detailed).

Frequency Range (Hz)	Differentiation		The value of the Wilcoxon test	p
	Basic level	Detailed level		
	Average power spectrum (μV2)			
4.15	4.12	4.59	-2.07	0.04
4.39	3.93	4.20	-2.68	0.01
4.64	3.71	4.09	-2.27	0.02
4.88	3.60	4.18	-2.79	0.01
5.13	3.58	3.92	-2.64	0.01
5.61	3.55	4.07	-2.87	0.00
5.86	3.36	4.09	-3.75	0.00
6.10	3.12	3.47	-2.48	0.01

It should be noted that when comparing the average performance of the power spectrum in the alpha range, no significant differences between the global and the base level of complexity were found; between basic and detailed, there is only one significant difference at a frequency of 11.96 Hz (Table 7), which seems to confirm that the alpha rhythm is not specific for cognitive load, since it reflects the rhythm of the idling of neurons (Kropotov, 2005) that reproduce impulses from the reticular nucleus of the thalamus.

Table 7. Alpha-range of the spectrum (basic vs detailed).

Frequency Range (Hz)	Differentiation		The value of the Wilcoxon test	p
	Basic level	Detailed level		
	Average power spectrum (μV2)			
11.96	2.22	2.30	-2.27	0.02

According to the data presented in Table 8, the average performance of the power spectrum in the beta range when performing more complex differentiations is higher compared to the average indicators of simpler differentiations. However, in the high frequency range of 25.63 Hz, the average power spectrum decreases. Significant differences were found in the average power spectrum indices in the beta range at frequencies: 16.11 Hz, 16.60 Hz, 25.63 Hz.

With increasing information complexity (basic vs detailed), the average power spectrum increases even more and the number of significant differences in the beta range increases at frequencies: 14.40 Hz, 14.89 Hz, 16.84 Hz, 17.82 Hz, 18.06 Hz, 18.31 Hz, 19.28 Hz, 20.02 Hz, 20.50 Hz, 21.72 Hz, 22.70 Hz, 23.43 Hz, 23.68 Hz, 24.41 Hz, 25.39 Hz, 25.63 Hz, 25.87 Hz, 26.36 Hz, 28.32 Hz, 28.80 Hz, 29.29 Hz, 30.02 Hz (table 9).

Table 8. Beta-range of the spectrum (global vs basic).

Frequency Range (Hz)	Differentiation		The value of the Wilcoxon test	p
	Global level	Basic level		
	Average power spectrum (μV2)			
16.11	1.32	1.60	-2.34	0.02
16.60	1.27	1.45	-2.58	0.01
25.63	1.28	1.10	-1.96	0.05

https://doi.org/10.15405/epsbs.2019.11.75
Corresponding Author: Dmitry Talantov
Selection and peer-review under responsibility of the Organizing Committee of the conference
eISSN: 2357-1330

Table 9. Beta-range of the spectrum (basic vs detailed)

Frequency Range (Hz)	Differentiation		The value of the Wilcoxon test	p
	Basic level	Detailed level		
	Average power spectrum (μV2)			
14.40	1.53	1.70	-2.61	0.01
14.89	1.56	1.70	-2.60	0.01
16.84	1.43	1.62	-2.46	0.01
17.82	1.36	1.61	-3.07	0.00
18.06	1.35	1.64	-2.52	0.01
18.31	1.31	1.55	-3.01	0.00
19.28	1.37	1.56	-2.11	0.04
20.02	1.37	1.60	-2.00	0.05
20.50	1.36	1.64	-2.13	0.03
21.72	1.27	1.70	-2.24	0.03
22.70	1.27	1.71	-2.57	0.01
23.43	1.18	1.49	-2.52	0.01
23.68	1.23	1.46	-2.37	0.02
24.41	1.15	1.44	-3.24	0.00
25.39	1.11	1.44	-2.64	0.01
25.63	1.10	1.41	-2.77	0.01
25.87	1.19	1.42	-2.66	0.01
26.36	1.15	1.38	-2.08	0.04
28.32	1.21	1.44	-2.80	0.01
28.80	1.22	1.38	-2.21	0.03
29.29	1.26	1.38	-2.06	0.04
30.02	1.24	1.42	-2.31	0.02

It should be noted that when comparing the average indices of the power spectrum in the gamma range, no significant differences were found between the global and the base level of complexity; between basic and detailed - 32.47 Hz, 32.95 Hz, 33.20 Hz, 33.44 Hz, 35.15 Hz. (Table 10).

Table 10. Gamma-range of the spectrum (basic vs detailed)

Frequency Range (Hz)	Differentiation		The value of the Wilcoxon test	p
	Basic level	Detailed level		
	Average power spectrum (μV2)			
32.47	1.23	1.45	-2.28	0.02
32.95	1.11	1.34	-2.08	0.04
33.20	1.14	1.35	-2.13	0.03
33.44	1.14	1.36	-2.51	0.01
35.15	1.02	1.25	-2.14	0.03

Inter-level changes in the EEG power spectrum of respondents after a formative experiment:

After the formative experiment, when comparing the average indices of the power spectrum of the global and basic level of complexity, significant differences were found only in the beta-range at frequencies of 23.19 Hz, 29.78 Hz (Table 11). The number of significant differences in the beta range was also significantly reduced when comparing the baseline and detailed level (2 vs 22) (Table 12). At frequencies of 23.19 Hz, 29.78 Hz, 18.06 Hz, the average indices of the power spectrum decreased.

https://doi.org/10.15405/epsbs.2019.11.75
Corresponding Author: Dmitry Talantov
Selection and peer-review under responsibility of the Organizing Committee of the conference
eISSN: 2357-1330

Table 11. Beta-range of the spectrum (global vs basic)

Frequency Range (Hz)	Differentiation		The value of the Wilcoxon test	p
	Global level	Basic level		
	Average power spectrum (μV2)			
23.19	1.44	1.24	-2.31	0.02
29.78	1.47	1.27	-2.63	0.01

Table 12. Beta-range of the spectrum (basic vs detailed)

Frequency Range (Hz)	Differentiation		The value of the Wilcoxon test	p
	Basic level	Detailed level		
	Average power spectrum (μV2)			
15.38	1.45	1.56	-1.98	0.05
18.06	1.52	1.34	-2.00	0.05

The expansion of the delta-range of the power spectrum is observed at frequencies of 0.24 Hz, 0.49 Hz, 0.73 Hz, 0.98 Hz, 1.22 Hz, 1.46 Hz, 1.71 Hz, 2.93 Hz, 3.42 Hz, 3.66 Hz, 3.91 Hz (8 vs 11) (table 13) , on which significant differences are found in the case when the detailed level has not yet been fully formed, but the speed and accuracy of the differentiation of chemical stimulus-objects has increased significantly; Of particular interest is that this expansion of the frequency range of the spectrum of inter-level differences (basic vs detailed) is realized by including the frequencies of inter-level differences unformed global vs basic and basic vs detailed levels.

Table 13. Delta-range of the spectrum (basic vs detailed).

Frequency Range (Hz)	Differentiation		The value of the Wilcoxon test	p
	Basic level	Detailed level		
	Average power spectrum (μV2)			
0.24	6.57	8.73	-3.45	0.00
0.49	13.24	17.98	-3.41	0.00
0.73	16.29	20.96	-2.89	0.00
0.98	12.85	16.95	-3.34	0.00
1.22	10.58	12.90	-3.23	0.00
1.46	8.26	10.25	-3.90	0.00
1.71	7.30	8.24	-2.56	0.01
2.93	4.81	5.27	-2.32	0.02
3.42	4.34	4.90	-2.10	0.04
3.66	3.80	4.55	-3.70	0.00
3.91	3.77	4.30	-2.40	0.02

Concept formation The substance is accompanied by a narrowing of the theta range of the spectrum (global vs base - 8 vs 0; base vs detailed - 17 vs 9) (table 14), which retains significant differences in power spectrum indices when performing tasks at different levels of complexity; It should be emphasized that the narrowed frequency range of the base vs of the detailed level includes the same invariant frequency spectrum set (4.64 Hz, 4.88 Hz, 5.13 Hz, 5.61 Hz, 5.86 Hz, 6.10 Hz, 6.35 Hz), found

https://doi.org/10.15405/epsbs.2019.11.75
Corresponding Author: Dmitry Talantov
Selection and peer-review under responsibility of the Organizing Committee of the conference
eISSN: 2357-1330

in the case of unformed concept levels Substance. A decrease in the average power spectrum indices was observed only at a frequency of 8.79 Hz.

Table 14. Theta-range of the spectrum (basic vs detailed).

Frequency Range (Hz)	Differentiation		The value of the Wilcoxon test	p
	Basic level	Detailed level		
	Average power spectrum (μV2)			
4,64	3,51	4,02	-2,16	0,03
4,88	3,19	3,79	-2,55	0,01
5,13	3,03	3,95	-3,08	0,00
5,37	3,25	4,08	-3,06	0,00
5,61	2,99	3,85	-4,24	0,00
5,86	2,98	3,66	-3,19	0,00
6,10	2,87	3,51	-3,32	0,00
6,35	2,79	3,19	-3,07	0,00
8,79	2,88	2,55	-2,28	0,02

Table 15. Gamma-range of the spectrum (basic vs detailed).

Frequency Range (Hz)	Differentiation		The value of the Wilcoxon test	p
	Basic level	Detailed level		
	Average power spectrum (μV2)			
35,15	1,22	0,98	-2,02	0,04
35,39	1,29	0,93	-2,27	0,02
40,52	0,37	0,32	-2,09	0,04

When comparing the basic and detailed level of complexity after the formative experiment, significant differences in the average power spectrum indices were revealed in the gamma range at frequencies: 35.15 Hz, 35.39 Hz, 40.52 Hz (see table 15). Average power spectrum declined.

Table 16. The number of significant differences in the performance of the power spectrum at different levels of cognitive complexity before and after the formative experiment.

Frequency Range (Hz)	Before the formative experiment		After the formative experiment	
	global – basic level	basic – detailed level	global – basic level	basic – detailed level
Delta (0-3 Hz)	3	8	0	11
Theta (4-8 Hz)	8	17	0	9
Alpha (9-13 Hz)	0	1	0	0
Beta (14-30 Hz)	3	22	2	2
Gamma (31-40 Hz)	0	5	0	3

According to Chuprikova (2019) the reaction time of differentiation, especially the reaction time of subtle differentiations, as well as the number of errors, can serve as an indicator of the brain to discriminate ensembles of excitations caused by different stimuli. The more concentrated, independent and delimited are the ensembles of nervous excitations, the shorter the time of differentiation reactions and the higher the accuracy of the response (Boyko, 2002; Chuprikova, 2004). Developed discriminative ability of the brain is needed for the organization of complex differentiated and multi-level cognitive components that reflect the intellectual ability of a person.

https://doi.org/10.15405/epsbs.2019.11.75
Corresponding Author: Dmitry Talantov
Selection and peer-review under responsibility of the Organizing Committee of the conference
eISSN: 2357-1330

In studies Volkova (2011) showed that the most important psychological condition for the development of general and special abilities is the formation of conceptual structures relevant to the subject area of activity: the higher the measure of compliance of these structures with the object, the more productive the activity of the subject. The most important physiological condition for the formation of these structures is the discriminative ability of the brain to concentrate and delineate the foci and fluxes of nervous excitations in the corresponding nervous structures. Conceptual structures have a complex hierarchical structure, each of the levels is characterized by a certain number of distinguished and coded features of the object, and, consequently, its own frequency characteristics. The higher the level of generalization, the higher the degree of ordering of the system, the measure of which is the change in the entropy of the system. However, entropy leads to equalization of probability and the elimination of differences between levels of generalization, certain energy costs are necessary. As noted Vekker (1976), to separate the levels of generalization of the features of an object and maintain invariance between them requires certain energy costs, a certain work, the most accessible indicator of which is the time for distinguishing the stimulus-objects. Thus, the higher the level of generalization (level of complexity) of the conceptual structure, the more energy must be required to maintain the differences between the levels and, therefore, there must be more difficult choice time. The data presented in Table 16 confirm this theoretical conclusion: prior to the formative experiment, the response time of the detailed level of complexity is longer than the response time of the base level and global. However, after the formative experiment, the execution time of complex and complex differentiations was 42 ms. As we can see, as a result of the experiment aimed at the formation of the concept Substance, the speed of the task is significantly increased, which is reflected in a decrease in the reaction time of a complex choice, and the accuracy of its implementation increases. It should be noted that despite the high motivation of the research participants, the detailed level of the concept Psychology students could not be formed (the number of classification errors is 42.85%).

Based on the data on the reduction of the reaction time of a complex choice as a result of the formation of a concept, an increase in the neuroefficiency of the activity is postulated, however, no empirical data on the change in energy consumption in terms of the power spectrum indices of the EEG were presented. Therefore, the next task was to study the dynamics of the EEG power spectrum indices in the process of forming the multi-level organization of the Substance concept.

Information and energy characteristics of cognitive activity can be judged by the power spectrum of amplitude-time indicators of bioelectric activity, which are associated with energy in the recorded areas of the cerebral cortex, due, according to Danilova (1992) systems of nonspecific and specific brain activation,

The inter-level differences in the EEG power spectrum are understood to be differences in the power spectrum indices when the respondents carry out differentiations of chemical stimulus of objects at different levels of complexity: global vs basic and basic vs detailed.

The real psychological and physiological content of the frequency ranges of the power spectrum, its boundaries is one of the most controversial issues.

https://doi.org/10.15405/epsbs.2019.11.75
Corresponding Author: Dmitry Talantov
Selection and peer-review under responsibility of the Organizing Committee of the conference
eISSN: 2357-1330

The formation of the “Substance” concept is accompanied by a change in the whole complex of objective psychological and physiological indicators, behavioral characteristics of the respondents at all stages of the study, subjective experiences of success / failure to solve problems.

Comparison of the EEG power spectrum indices during the formation of the “substance” concept and the dynamics of its formation in terms of the reaction time of a complex choice, analysis of the experiment video recordings can allow the following psychological interpretation of the frequency ranges to be advanced:

Delta (0-3 Hz)

a) the disappearance of significant inter-level differences in the EEG power spectrum (3 vs 0) in the case of the formation of a global and basic level of the Substance concept, i.e. high stable speed and stable accuracy of performing tasks of distinguishing simple / complex compounds and distinguishing classes of inorganic compounds; which opens the way for restructuring education and reducing school overload.

b) expansion of the frequency range of the power spectrum (8 vs 11), which reveals significant differences in the case when the detailed level is not yet fully formed, but the speed and accuracy of differentiation of chemical stimulus-objects has significantly increased; Of particular interest is that this expansion of the frequency range of the spectrum of inter-level differences (basic vs detailed) is realized by including the frequencies of inter-level differences unformed global vs basic and basic vs detailed levels. This explains the cause of the overload - the lack of conceptual systems.

Theta (4-8 Hz)

a) the disappearance of significant interlevel differences in the EEG power spectrum (8 vs 0) in the case of the formation of a global and basic level of the Substance concept;

b) concept formation the substance is accompanied by a narrowing of the frequency range, where significant differences in the power spectrum indices are maintained when performing tasks at different levels of complexity; It should be particularly emphasized that the narrowed frequency range of the base vs of the detailed level includes the same invariant frequency spectrum set, found in the case of unformed levels of the Substance concept.

Alpha (9-13 Hz)

a) in the case of an unformed concept, the only significant inter-level difference in the alpha spectrum of the EEG power was revealed in the case of complex and complex processing of information (basic vs detailed level);

b) the absence of any significant cross-level differences in the case of both the global and the base levels, and in the case of the unformed detailed level.

Beta (14-30 Hz)

a) an extremely sharp increase in the number of significant inter-level differences in the EEG power spectrum with increasing complexity of information processing (from complex to complex) in the case of an unformed Substance concept (3 vs 22) and only 2 reliable inter-level differences in both the formed (global and basic) and case of unformed (detailed) concept levels. Analysis of video surveillance, interviews with respondents and literature (Polikanova & Leonov, 2016) suggests that such changes in the power spectrum can act not only as markers of fatigue, but also familiarity / subjective ease of performing tasks.

Gamma (31-40 Hz)

a) the absence of significant differences when comparing the EEG power indices of the spectrum during the execution of simple and complex differentiations, both in the case of the formed global and basic level of the Substance concept, and in the case of the unformed;

b) narrowing of the frequency range where significant differences in inter-level differences in power spectrum indices are preserved when performing tasks at a high level of complexity when the detailed level is not yet fully formed, but the speed and accuracy of differentiation of chemical stimulus objects has increased significantly. Apparently, the gamma range is “sensitive” only to the most complex information (Danilova, Bykova, Anisimov, Pirogov, & Sokolov, 2002).

7. Conclusion

1) in the case of an unformed substance concept, the higher the level of complexity of the processed information, the more significant inter-level differences in the EEG power spectrum and the wider the frequency range over which these significant differences appear; those. the increase in the complexity of the processed information leads to the need to increase the activation of brain structures, which is manifested in an increase in significant inter-level differences in the EEG power spectrum and in the expansion of its range.

2) conceptualization the substance is accompanied by a decrease in significant inter-level differences in power spectrum indices and a narrowing of the frequency range (excl. delta, complex information), on which these differences are revealed, which is in favor of the neuroefficiency hypothesis.

Comparing the behavioral characteristics of the respondents at all stages of the study (fatigue, interest, lightness, anxiety), objective psychological indicators of the formation of the Substance concept (accuracy and reaction time of a difficult choice) and objective physiological indicators (EEG spectrum power) can be assumed:

1) a change in the frequency range of significant inter-level differences of the delta rhythm may indicate a change in the effort expended to achieve the required accuracy of the task and reduce the time for its implementation;

2) a change in the frequency range of the theta rhythm may indicate concentration / generalization of the nervous processes, the degree of the formation of the concept Substance;

3) a change in the frequency range of significant inter-level differences of the beta rhythm may indicate fatigue, familiarity / subjective ease of performing tasks;

4) a change in the frequency range of significant inter-level gamma-rhythm differences is manifested only when performing complex and complex tasks.

Acknowledgments

The authors express gratitude to T.A. Dudnikova and I.O. Fedulova for helping in gathering the data.

https://doi.org/10.15405/epsbs.2019.11.75
Corresponding Author: Dmitry Talantov
Selection and peer-review under responsibility of the Organizing Committee of the conference
eISSN: 2357-1330

References

Balin, V. D. (1971). On the ratio of background EEG activation indicators and some indicators of the productivity of mental activity. *Experimental and Applied Psychology* (pp. 42-52). Leningrad: Leningrad State University. (In Russian).

Basten, U., Stelzel, C., & Fiebach, C. J. (2013). Intelligence is differentially related to neural effort in the task-positive and the task-negative brain network. *Intelligence*, *41*(5), 517-528.

Boyko, E. I. (2002). The mechanisms of mental activity. *Izb. psychol. Proceedings*. In A.V. Brushlinsky, & T. N. Ushakova (Eds.). Moscow; Voronezh. (In Russian).

Causse, M., Chua, Z., Peysakhovich, V., Del Campo, N., & Matton, N. (2017). Mental workload and neural efficiency quantified in the prefrontal cortex using fNIRS. *Scientific reports*, *7*(1), 5222.

Chuprikova, N. I. (2004). The psyche is the subject of psychology in the light of the achievements of modern neuroscience. *Questions of Psychology, 2,* 104-118. (In Russian).

Chuprikova, N. I. (2019). *Human reaction time: Physiological mechanisms, verbal-semantic regulation, connection with intelligence and properties of the nervous system.* Moscow: Publishing House Jask. (In Russian).

Costanzo, M. E., VanMeter, J. W., Janelle, C. M., Braun, A., Miller, M. W., Oldham, J., ... & Hatfield, B. D. (2016). Neural efficiency in expert cognitive-motor performers during affective challenge. *Journal of motor behavior*, *48*(6), 573-588.

Danilova, N. N, Bykova, N. B, Anisimov, N. V, Pirogov, Yu. A., & Sokolov, E. N. (2002). The gamma rhythm of the electrical activity of the human brain in sensory coding. *Biomedical Radioelectronics*. *3*, 34-42. (In Russian).

Danilova, N. N. (1992). Psychophysiological diagnosis of functional conditions: Textbook. allowance for biol., psychol. and honey. specialist. universities. Moscow: Publishing House of Moscow State University. (In Russian).

Dunst, B., Benedek, M., Jauk, E., Bergner, S., Koschutnig, K., Sommer, M., ... & Freudenthaler, H. (2014). Neural efficiency as a function of task demands. *Intelligence*, *42*, 22-30.

Kropotov, Yu. D. (2005). *Modern diagnostics and correction of attention deficit disorder.* St. Petersburg: Albi. (In Russian).

Kulachev, A. P. (2007). *Computer electrophysiology and functional diagnostics.* (4th Ed., rev. and add.) (p. 178-230). Moscow: INFRA-M. (In Russian).

Neubauer, A. C., & Fink, A. (2009). Intelligence and neural efficiency: Measures of brain activation versus measures of functional connectivity in the brain. *Intelligence*, *37*(2), 223-229.

Polikanova, I. S., & Leonov, S. V. (2016). Psychophysiological and molecular genetic correlates of fatigue. *Modern foreign psychology*, *5*(4), 24-35. (In Russian).

Rusalov, V. M. (2012). *Temperament in the structure of human personality: differential-psychophysiological and psychological research.* Moscow: IP RAS. (In Russian).

Rypma, B., Berger, J. S., Prabhakaran, V., Bly, B. M., Kimberg, D. Y., Biswal, B. B., & D'Esposito, M. (2006). Neural correlates of cognitive efficiency. *Neuroimage*, *33*(3), 969-979.

Vekker, L. M. (1976). Mental processes. Volume 2. Thinking and intelligence. L: Publishing house of Leningrad State University. (In Russian).

Volkova, E. V. (2008). The general universal law of development, the development of cognitive structures of chemical knowledge and chemical abilities. Yekaterinburg: Publishing House of the Ural University. (In Russian).

Volkova, E. V. (2011). *Psychology of special abilities: differentiation-integration approach*. Moscow: Publishing House "Institute of Psychology RAS". (In Russian).