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The use of multiple regression analysis to study the relationship between the amplitudes of EEG rhythms within one derivation with mental retardation

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Abstract

Using the calculation of coefficients of multiple linear regression and two-dimensional correlation, we studied the mutual influence (functional connectivity) between the amplitudes of EEG rhythms within one lead in mentally retarded persons. Multiple regression equations were geometrically interpreted using polycyclic multigraphs. As a result of the studies and calculations, it was revealed that with mental retardation, the number of regression coefficients is determined more than in the norm. In the control group of sinistrals, more regression coefficients were detected between the amplitudes of EEG rhythms within one lead than in dextrals. Apparently, the results obtained reflect the features of the network semantic-topological brain. A greater number of regression coefficients within the full lead in dextrals, under normal conditions, was expressed in the sinister hemisphere, and sinistrals in the dextral one. In mentally retarded persons, on the contrary, during the reign, a greater number of regression coefficients appeared in the dextral hemisphere, and in sinistrals (although not

significantly) in the sinistral. It can also be assumed that the connections-relationships found in the leads reflect projections in these leads of the EEG rhythm generators. The foregoing makes it possible to consider the regression connections-relations calculated in the analysis of the relationship between the amplitudes of EEG rhythms as units of neurophysiological activity.

Key words: mental retardation; multiple regression; polycyclic multigraphs; interhemispheric differences in EEG rhythm amplitudes within one lead.

Introduction. The modern stage of development of science is characterized by the development of algorithms for analyzing the activity of complex multilevel systems, which include the brains of animals and humans. The main subject of these studies are not material objects as such, but the connections and relationships that form the systems of the world around us.

One of the basic problems of electroencephalography is the study of the nature and mechanisms of the generation of rhythmic activity. This problem is being investigated not only by various neurophysiological methods, but also by mathematical modeling methods [5]. The greatest attention is paid to the alpha rhythm, which is associated not only with rhythmic, but also with cognitive processes [3, 13, 14]

Several theories of the origin and localization of alpha activity generators are considered “Optional pacemaker theory” laid down by P. Anderson, et al. It is based on the localization of the central mechanism of alpha rhythm generation in the thalamic nuclei, which affect neuronal activity in the corresponding cortical areas [11, 12].

The model of cortical and thalamic generators proposed by F. Lopez da Silva et al. [19] is based on the existence of relatively independent generators located both in the nuclei of the thalamus and in the cortex.

The theory of Basar E [13, 14], which states the existence of a multitude of multifunctional alpha-rhythm generators selectively distributed throughout the brain, forming a diffusely distributed alpha-system.

Earlier, using multiple regression analysis, we established mutually oriented (vector) mutual influences between the indices of amplitudes of ECoG rhythms. These results are consistent with general ideas about the functioning of the forebrain as a whole. The distributed nature of the source of the alpha rhythm of the electroencephalogram (EEG) made it possible to put forward a hypothesis about the existence of multiple discrete sources of alpha range oscillations - “alphons” [24]. We suggested that in a similar way in the cerebral cortex there are hypothetical generators of beta-2, beta-1-, theta- and delta-rhythms [4, 6].

There are ideas that dynamic functional connections between different parts of the cortex and subcortical structures should play a leading role in the functioning of the brain [1, 23].

According to modern ideas, EEG rhythms are generated by the corresponding generators. By studying the connectivity (mutual influence) of the amplitudes of different EEG rhythms, we are actually studying the connectivity of the operation of various generators of EEG rhythms. The presence of connections-relations between the amplitudes of EEG rhythms within one lead indicates the presence of control mechanisms between them. There is no information in the literature about the functional connectivity (mutual influence) of individual EEG rhythms with each other.

It was shown that the initial locations of the generators of electroencephalogram frequency rhythms differed significantly in vertical and anteroposterior measurements, which, as the authors believe, indicates that the EEG rhythms recorded during one EEG epoch are generated by nerve populations located in different parts of the brain [21]. Therefore, by studying the relationship (mutual influence) of the amplitudes of different EEG frequency bands, one can get an idea of the relationship between nerve populations located in different parts of the brain and generating EEG rhythms.

There are also ideas that different EEG rhythms are generated by a common or similar source [10].

Studied by Michel C.M. (1992) [21] localization of sources of delta-, theta-, alpha- and beta-frequency ranges of EEG using the fast Fourier transform dipole approximation and three-dimensional dipole modeling. The analysis showed that the location of the sources of EEG frequency bands in the subjects differed significantly in the vertical and anterior-posterior dimensions. The source of delta was deepest and most anterior, theta more posterior and shallower, alpha the most posterior and highest in vertical dimension, beta-1 deeper and slightly forward than alpha, and beta-2 again earlier and deeper than beta. -1. Thus, source depth was not linearly related to temporal frequency. The sources of all 5 bands were oriented in the sagittal direction. The results show that different EEG frequency bands during a given EEG epoch are generated by neuronal populations in different locations in the brain.

Studies [16] found two sources of alpha rhythm generation located in the thalamic structures of the brain and operating in a narrow-band frequency range with maximum resonant response frequencies of 10.1 and 10.5 Hz.

It has been shown that each delta-, theta-, alpha- and beta-rhythm of the traditional EEG occurs in several anatomically different brain structures. The results of these studies imply the presence of distributed regional sources of brain rhythms and support the view that during preparatory attention modulation of brain sources occurs, generating alpha and beta brain rhythms [20].

In recent years, the role of neural networks in the structure of brain activity has become more and more obvious [22].

Interest in network sciences has increased significantly over the past decades. Network models have been recognized as a crucial tool in the analysis of the dynamics of complex systems. Networks appear to be ubiquitous and have some special properties that make them very suitable for brain modeling [17]

The formation of neural networks is possible on the basis of system analysis. Graph theory, as an example of such a systematic approach, turns out to be a useful tool for network analysis of various neuroimaging data (EEG, MEG, fMT) [15].

Therefore, the construction of visualizing oriented polycyclic multigraphs, i.e. connections-relationships (semantic cases) directed from one indicator of the amplitude of the EEG frequency range to another can contribute to the expansion of our understanding of the functional state of the CNS [2].

The aim of our work was:

1. To investigate the EEG in the mentally retarded using a half-cycle analysis.

2. Using multiple regression analysis to investigate the relationship between the EEG amplitudes of different EEG frequency ranges within one lead, in all leads in mental retardation in comparison with the control.

3. Build polycyclic multigraphs that reflect the relationship between EEG rhythms within each lead and analyze them.

4. To study the functional interhemispheric asymmetry of the EEG rhythm amplitudes in mentally retarded persons using multiple regression analysis.

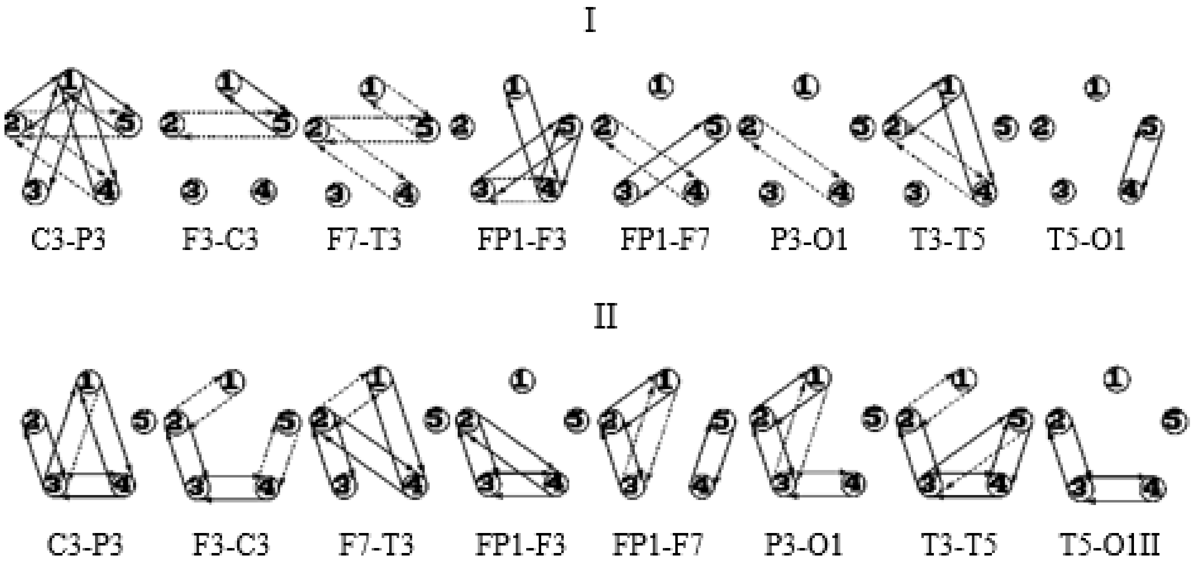
Materials and methods. We examined 65 mentally retarded patients (ICD-10 heading F70) aged 16-18 years old - the main group. They were on inpatient examination and treatment at the Communal Non-Commercial Enterprise "Odessa Regional Mental Health Center" of the Odessa Regional Council (Ukraine). The control group consisted of 34 persons aged 16 - 24 who were on a stationary examination in connection with the call to the Armed Forces of Ukraine. The EEG was recorded in a state of calm wakefulness with closed eyes on the Neuron-Spectrum-2 electroencephalograph at a quantization frequency of 500 Hz using a montage: bipolar ring 16. The electrodes were placed according to the "10-20%" system (9) in l6 cortical zones. The EEG was recorded from the frontal (F3, F4), central (C3, C4), parietal (P3, P4), occipital (01, 02), anterior temporal (F7, F8), middle temporal (T3, T4) and posterior temporal (T5, T6) cortical zones (odd numbers indicate areas of the sinister hemisphere, even numbers - dexter). Bandwidth 0.5-35 Gi, sampling frequency 500 Hz. The analysis was performed using periodometric analysis in five standard frequency ranges: σ 0.5–4 Hz. Θ 4-8 Hz,. α 8 \u003d 13 Hz, β1 13-20 Hz, β2 20-32 Hz.

Each of the set of indicators of the amplitude of EEG rhythms selected for analysis) was considered as a target feature (Y-s), and the remaining indicators were considered as influencing variables (sets of X-s) and equations of multiple linear regression of the form were constructed:

$Y1 = a0 + b1X1 + b2X2 \ldots + bnXn,$

where a0 is a free member, coefficients b1,b2…., bn are regression indicators reflecting the degree of influence on the analyzed indicator of the remaining elements of the set, x1, x2…, xn indicators. The probability of manifestation of influence, i.e., the adequacy of the regression coefficients, was assessed using the sigmal deviations of the regression coefficients, and the effectiveness of the regression as a whole was assessed by calculating the multiple correlation coefficient [7]. The task of synthesizing objects of multidimensional research was implemented using the geometric interpretation of multiple linear regression equations using polycyclic multigraphs [2].

Own research and discussion. In multiple regression analysis of the relationships of amplitudes



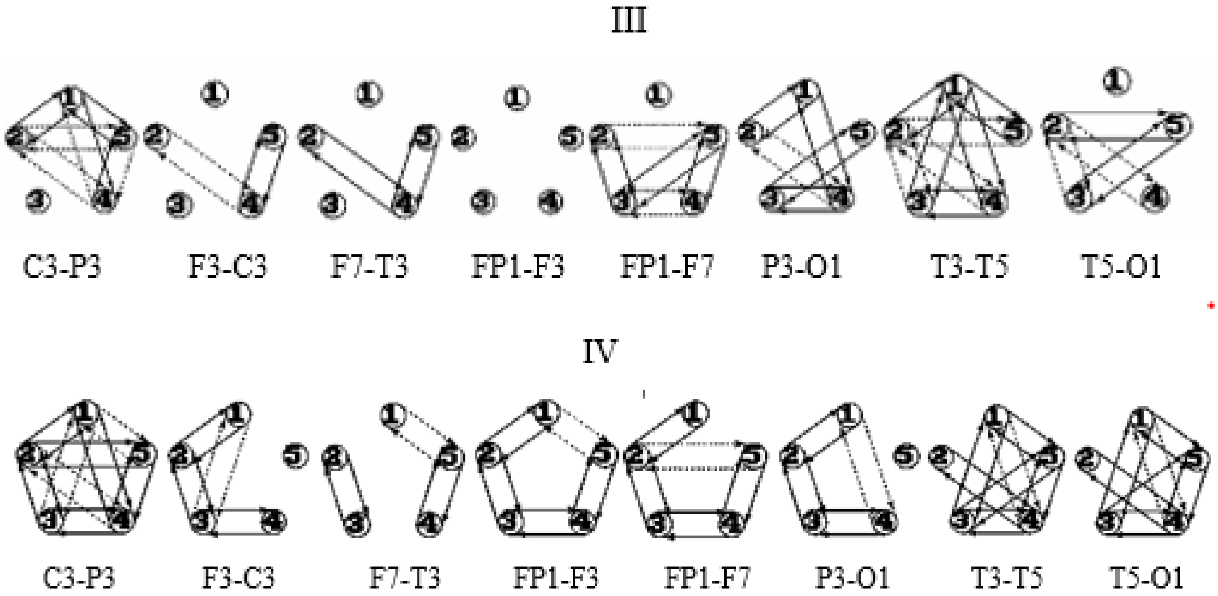


Fig. 1. Polycyclic multigraphs reflecting the relationship between the amplitudes of EEG rhythms, within the same lead, in the control group and in the mentally retarded in the sinister hemisphere

Notation: I - Dextrals, control; II - Dextrals, mentally retarded; III - Sinistrals, control; IV - Sinistrals, mentally retarded. Leads: C3-P3 Central-parietal, F3-C3 Frontal-central F7-T3 Temporal-central, FP1-F3 Frontal, FP1-F7 Anterior-temporal, P3-O1 Parietal-occipital, T3-T5 Posterior-temporal, T5- O1 Temporoccipital.

EEG rhythms: 1-delta, 2-theta, 3-alpha, 4-beta-low frequency, 5-beta-high frequency. Solid lines are positive influences, dashed lines are negative EEG rhythms in different frequency ranges within one lead were revealed (Fig. 1, 2, 3); than in the dextral hemisphere. In sinistrals, under normal conditions, a greater number of connections-relations by 1.16 times is detected in the dextral hemisphere. It should be noted that the number of connections-relationships in sinistrals was greater than in dextrals: in the sinistral hemisphere by 1.53 times, and in the dextral hemisphere by 2.47 times.

In mentally retarded persons, dextrals, more connections-relationships were determined in the dextral hemisphere by 1.43 times than in the sinistral. In mentally retarded persons, a greater number of connections - relationships (albeit slightly) were determined in the sinistrals' hemisphere by 1.02 times than in the dextrals (Fig. 1, 2, 3).

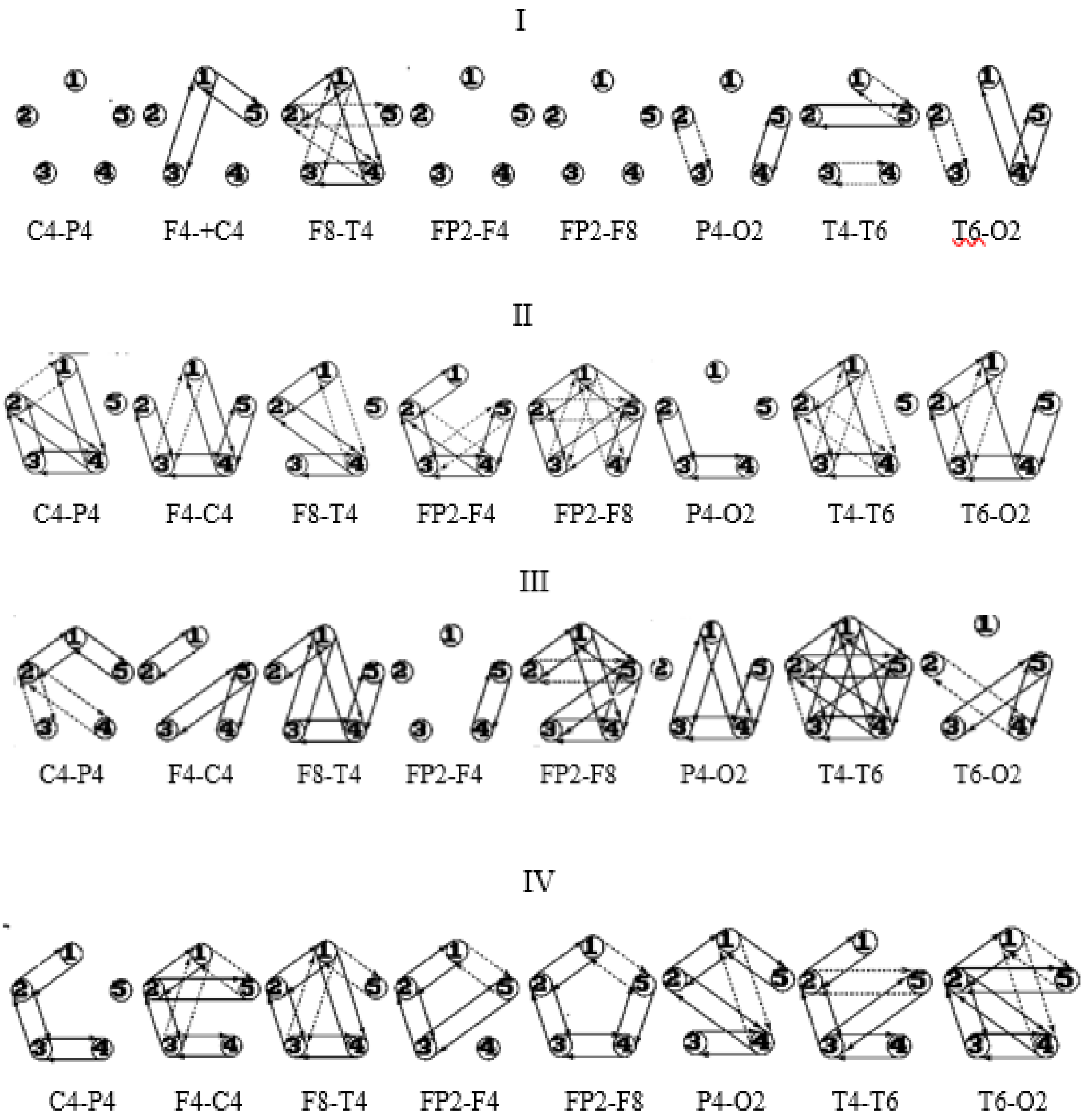


Fig. 2. Polycyclic multigraphs reflecting the relationship between the amplitudes of EEG rhythms in the control group and in the mentally retarded in the dextral hemisphere

Notation: I - Dextrals, control; II - Dextrals, mentally retarded; III - Sinistrals, control; IV - Sinistrals, mentally retarded.

Leads: C4-P4 Central-parietal, F4-C4 Frontal-central F8-T4 Central temporal, FP2-F4 Frontal, FP2-F8 Anterior-temporal, P4-O2 Parietal-occipital, T4-T6 Posterior-temporal, T6-O2 Temporoccipital.

EEG rhythms: 1-delta, 2-theta, 3-alpha, 4-beta-low frequency, 5-beta-high frequency.

Solid lines are positive influences, dashed lines are negative ones.

In mentally retarded persons, the number of regression saint-relations was determined to be greater than under normal conditions: in dextrals in the sinister hemisphere by 1.43 times, in the dextralr hemisphere by 2.87 times; in sinistrals in the sinistral hemisphere by 1.31 times, and in the dextral by 1.11 times.

The greatest number of connections-relationships in dextrals in the sinister hemisphere under normal conditions was determined in the C3-P3 lead central parietal - 12, and in the dextral hemisphere in the F8-T4 lead temporally central also 12. hemisphere under normal conditions was determined in the P3-O1-parietal-occipital lead, and T5-O1-temporal-occipital, two connections - relationships.

The largest number of connections-relations in the sinistrals in the sinister hemisphere under normal conditions was determined in the T3-T5 posterotemporal lead - 16, and in the dexter hemisphere also, in the posterotemporal T4-T6 lead - 20. The least number of connections-relations in the sinistrals in the sinistral hemisphere, under normal conditions, it was determined in lead FP1-F3 - frontal-0, and in the dextral hemisphere also, in lead Fp2-F4 frontal - 2.

The largest number of connections-relationships in mentally retarded dextrals persons in the sinistrals hemisphere was determined in the T3-T5 posterior temporal lead -10, and in the dextral hemisphere in the FP2-F8 anterior temporal lead - 18. Apparently, the regions of these leads are more activated, than others. The smallest number of connections - relationships in mentally retarded dextrals in the sinister hemisphere was determined in lead T5-O1 temporo-occipital - 4, and in the dextral hemisphere in lead P4-O2 parietal-occipital - 4. Apparently, the regions of these leads are less activated than other.

The largest number of connections-relationships in mentally retarded sinistrals in the sinistral hemisphere was determined in the C3-P3 lead in the central parietal -16, and in the dextral hemisphere, in the lead T6-O2 in the temporoccipital region - 14. It can be assumed that in mentally retarded sinistrals these leads are more activated than the others. The smallest number of connections-relationships in mentally retarded sinistrals in the sinister hemisphere was determined in the temporally central lead F7-T3 - 6, and in the dextral hemisphere, in the central-parietal lead C4-P4 - 6. It can be assumed that in mentally retarded sinistrals the regions leads are less activated than others.

In leads F3-C3 fronto-central, F7-T3 temporo-central, P3-O1 parietal-occipital, T3-T5 posterior-temporal, T5-O1 temporo-occipital in dextrals under normal conditions in the sinistral hemisphere, the relationship-relationship to the indicator of the amplitude of the alpha rhythm from other indicators of the amplitudes of the EEG rhythms was not determined

(Fig. 1, I). In the dextral hemisphere, under normal conditions in dextrals, to the alpha-rhythm amplitude indicator, the relationships-relationships were not determined in leads C4-P4 ventral-parietal, FP2-F4 frontal, FP2-F8 anterior-occipital (Fig. 2, III).

In sinistrals under normal conditions in the sinistral hemisphere in leads C3-P3 central-parietal, F3-C3 fronto-central, F7-T3 temporo-central, FP1-F3 frontal, to the alpha-rhythm amplitude indicator, the connections-relationships were not determined in the dextral hemisphere to relation-relationships were not determined in terms of the amplitude of the alpha rhythm. Only in the lead FP2-F4 frontal.

In mentally retarded persons, both extrals and sinistrals, in both hemispheres, correlations to the alpha rhythm amplitude index from other indicators of the EEG rhythm amplitudes were determined (Fig. 1, 2).

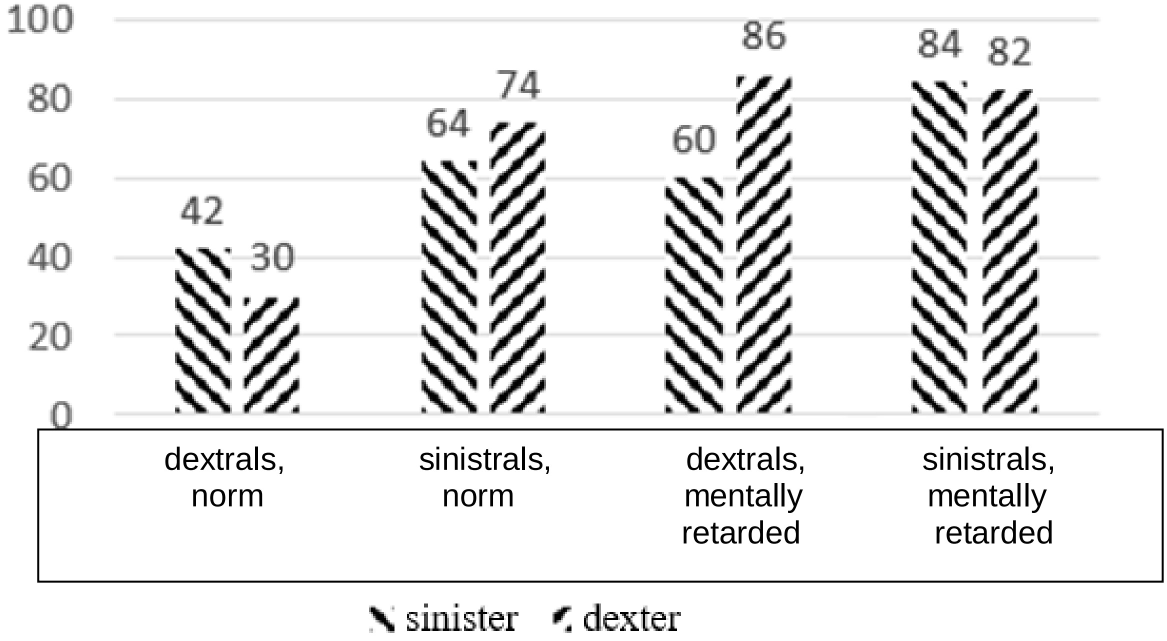
In the delta range, under normal conditions, in dextrals, a greater number of regression relationships-relations were determined in the sinistral hemisphere, and in sinistrals - in the dextral one. In the mentally retarded, a greater number of regression relationships, both in dextrals and sinistrals, was determined in the dextral hemisphere.

In the theta range, under normal conditions, in dextrals and sinistrals, a greater number of regression relationships-relations were determined in the sinistral hemisphere, in mentally retarded dextrals and sinistrals - in the dextral one.

In the alpha-rhythm range under normal conditions in dextrals and sinistrals, a greater number of regression connections-relations were determined in the dextral hemisphere. In mentally retarded dextrals, a greater number of regression connections-relations were determined in the dextral hemisphere, and in deviant women, the number of regression connections-relations in both hemispheres was determined the same.

In the beta-low-frequency range, under normal conditions, in dextrals, a greater number of regression relationships-relations were determined in the sinistral hemisphere, and in dextrals - in dextral one. In mentally retarded dextrals, a greater number of regression connections-relations were determined in the dextral hemisphere, and in sinistrals - in the sinistral.

In the beta-high-frequency range, under normal conditions, in dextrals, a greater number of regression relationships-relations were determined in the sinistral hemisphere, and in dextrals - in the dextral one. In mentally retarded dextrals, a greater number of regression connections-relations were determined in the dextral hemisphere, and in sinistrals - in the sinistral one.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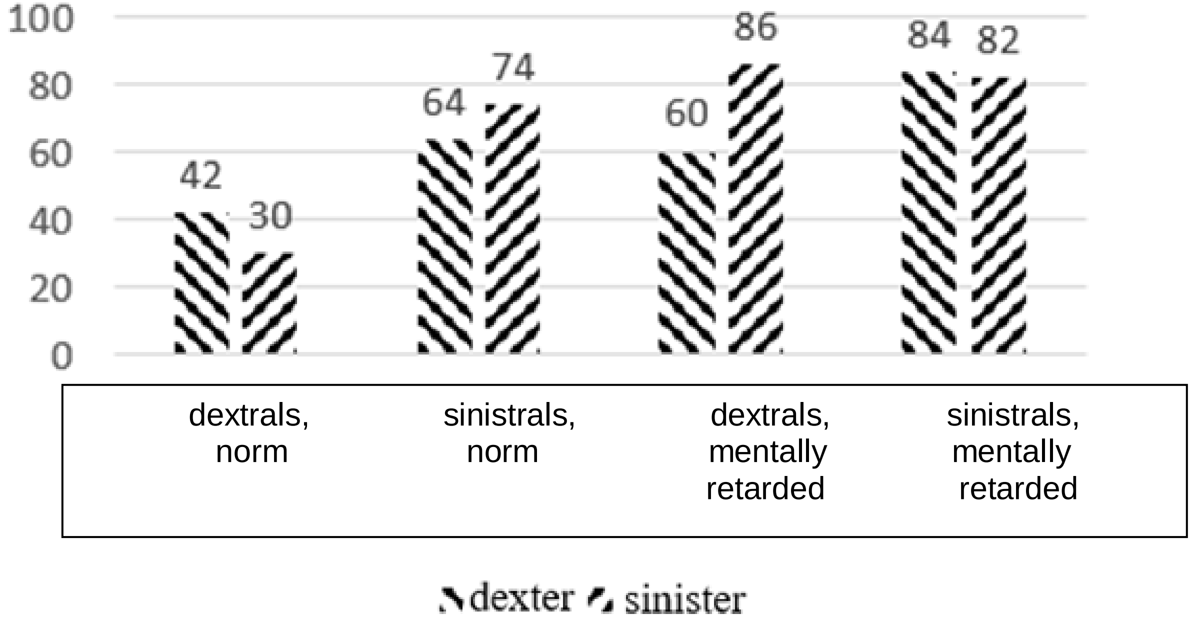
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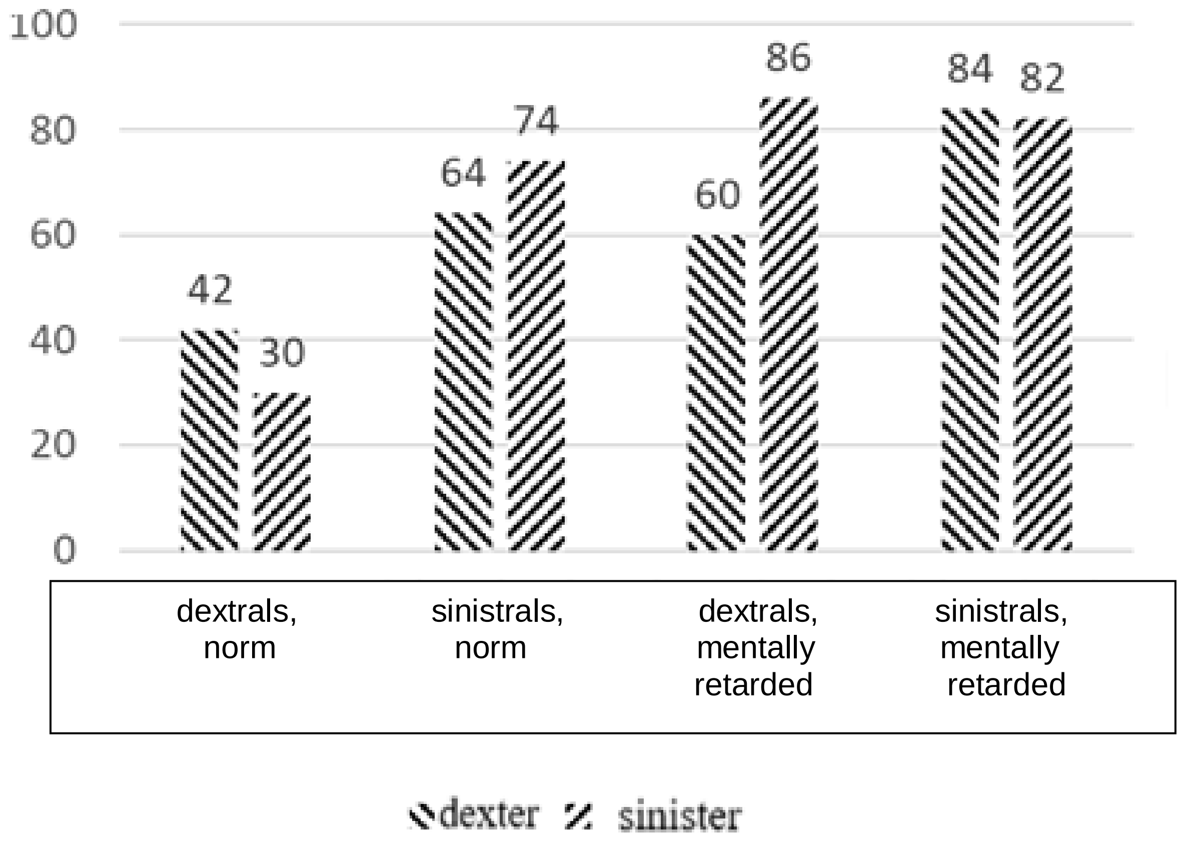

Fig. 3. Statistically significant regression coefficients reflecting the relationship between the amplitudes of EEG rhythms determined within one lead.

Notation: Sinistral -Sinistral Hemisphere, Dextral-Dextral Hemisphere.

Table 1

Statistically significant regression coefficients between the amplitudes of EEG rhythms in frequency ranges within one lead

EEG rhythms	Norm				Mentally retarded			
	Dextrals		Sinistrals		Dextrals		Sinistrals	
	Hemispheres							
	Sinistral	Dextral	Sinistral	Dextral	Sinistral	Dextral	Sinistral	Dextral
Delta	**18**	12	18	**30**	20	**34**	32	**38**
Theta	**20**	12	**32**	24	30	**36**	36	**40**
Alpha	6	12	20	**26**	36	**4+0**	36	36
Beta low frequency	**22**	14	32	**34**	26	**42**	**40**	26
Beta high frequency	**20**	12	26	**32**	8	**16**	**26**	24

Table 2.

Coefficients of interhemispheric asymmetry of the number of coefficients of multiple regression between the amplitudes of EEG rhythms

EEG rhythms	Norm		Mentally retarded	
	Dextrals	Sinistrals	Dextrals	Sinistrals
Delta	20,00	-25,00	-25,93	-8,57
Theta	25,00	14,29	-9,09	-5,26
Alpha	-33,33	-13,04	-5,26	0,00
Beta low frequency	22,22	-3,03	-23,53	21,21
Beta high frequency	25,00	-10,34	-33,33	4,00

In the study of lateralization, coefficients of interhemicap asymmetry (CMA) of indicators + multiple regression oriented to EEG rhythms within one lead, i.e. their representation in the sinistral and dextral hemispheres (Table 2) revealed that in dextrals people under normal CMA conditions, the EEG delta, theta, beta-low-frequency and beta-high-frequency rhythms are oriented to the sinistral hemisphere, and the alpha of the rhythm is oriented to the dextral.

In sinistrals under normal conditions the CCAs are oriented in the delta, alpha, beta-high- and low-frequency ranges and are oriented to the dextral hemisphere, while the theta rhythm is oriented to the sinister. In mentally retarded dextrals, the CCAs of all EEG rhythms were oriented to the dextral hemisphere. In mentally retarded sinistrals, CMA delta and theta rhythms were oriented to the sinistral hemisphere, and beta rhythms were oriented to the dextral. KMA alpha rhythm was not determined.

Discussion. In a multiple regression analysis of the relationships between amplitudes in the subjects of retardants, the number of regression coefficients was greater than in normal conditions, both in sinistrals and dextrals. It should be noted that under the normal conditions, sinistrals showed more regression coefficients between the amplitudes of EEG rhythms within one lead than dextrals.

Similar relationships were also revealed in the analysis of relationships between the amplitudes of EEG rhythms within the same EEG rhythm, but in different leads [18]. Apparently, the results obtained reflect the features of the network semantic-topological brain.

A greater number of regression coefficients, within the limits of the full lead in dextrals, under normal conditions, was detected in the sinister hemisphere, and in sinistrals in the dextral one. In mentally retarded persons, on the contrary, in dextrals, a greater number of regression coefficients were detected in the dextral hemisphere, and in sinistrals (albeit not significantly) - in the sinistral one.

According to the ideas of Rusinov's school [19], an increase in the number of correlations between various EEG and ECoG components reflects an increase (in general) in cortical tone, and a decrease reflects a decrease in this tone. Therefore, it can be assumed that, according to the regression analysis of the relationship between the amplitudes of EEG rhythms within one lead, in dextrals under normal conditions, the cortical tone of the sinister hemisphere is higher than that of dextral, and in sinistrals, on the contrary, the cortical tone of the dextral hemisphere is higher than that of the sinistral one.

In mentally retarded persons, dextrals, the tone of the cortex of the dextral hemisphere is higher than that of the sinistrals, and in sinistrals, on the contrary, the tone of the cortex of the sinistral hemisphere slightly predominates over the tone of the cortex of the dextral one.

In different leads, both in sinistrals and dextrals, under the conditions of the norm, in mentally retarded individuals, a different number of relationships was determined. The resulting differences may indicate that the level of activity of different regions of the brain is not the same. Under normal conditions in dextrals in the sinistral hemisphere in the central-parietal lead C3-P3, and in the dextral hemisphere in the temporo-central lead F8-T4, the level of activity is higher than in other regions. In sinistrals, the most activated leads were T3-T5 posterotemporal, and in the dextral hemisphere, in lead T4-T6 posterotemporal.

The largest number of connections-relationships in mentally retarded dextrals in the sinistral hemisphere was determined in the T3-T5 posterior temporal lead -10, and in the dextral hemisphere in the FP2-F8 anterior temporal lead - 18. Apparently, the regions of these leads are more activated, than others.

The smallest number of connections-relationships in mentally retarded dextrals in the sinistral hemisphere was determined in the T5-O1 temporo-occipital lead - 4, and in the dextral hemisphere in the lead P4-O2 parietal-occipital - 4. Apparently, the regions of these leads are less activated than others.

The largest number of connections-relationships in mentally retarded sinistrals in the sinistral hemisphere was determined in the C3-P3 lead in the central parietal, and in the dextral hemisphere, in the lead T6-O2 in the temporo-occipital. It can be assumed that in mentally retarded sinistrals, the regions of these leads are more activated than others. The smallest number of connections-relationships in mentally retarded sinistrals in the sinistral hemisphere was determined in the F7-T3 lead temporally central, and in the dextral hemisphere, in the lead C4-P4 central-parietal. It can be assumed that in mentally retarded sinistrals, the regions of these leads are less activated than others.

It can also be assumed that the connections-relationships revealed in the leads reflect the projection of the EEG rhythm generators into these leads.

The foregoing, apparently, can serve as a confirmation of the correctness of considering the regression connections-relations calculated in the analysis of the relationship between the amplitudes of EEG rhythms as units of neurophysiological activity. “In the presence of a simple unit, complex phenomena can be described as being regularly composed of simple parts. This is the essence of an extremely effective strategy called "scientific analysis" [8].

When analyzing the number of connections-relations oriented to EEG rhythms, it was revealed that in dextrals, both in the norm and in mentally retarded persons, a greater number of connections-relations are oriented in the dextral hemisphere, while in sinistrals, the localization of orientation was blurred.

The given polycyclic multigraphs describing the relationship of rhythm amplitudes within the same rhythm in different leads, as well as those previously given by us in [18] (Fig. 5, A) and different rhythms within the same lead (Fig. 5, B) are given in this work, describe a network semantic-topological model of brain electrogenesis.

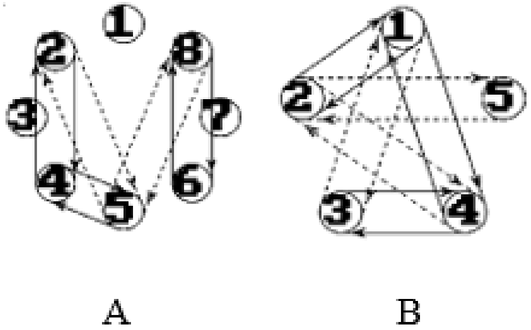

Fig. 5. Polycyclic multigraphs describing the relationship of rhythm amplitudes within the same rhythm of different leads (A) and different rhythms within the same lead (B)

Notation: A- 1- C3-P3 Central-parietal, 2-F3-C3 Fronto-central 3-F7-T3 Temporal-central, 4-FP1-F3 Frontal, 5-FP1-F7 Anterior-temporal, 6-P3-O1 Parietal-occipital, 7-T3- T5 Posterior-temporal, 8-T5-O1 Temporoccipital. Solid lines are positive influences, dashed lines are negative.

B-1-delta, 2-theta, 3-alpha, 4-beta-low frequency, 5-beta-high frequency. Solid lines are positive influences, dashed lines are negative ones.

Conclusions

1. When calculating the coefficients of multiple regression between the amplitudes of EEG rhythms in mentally retarded persons, a larger number of coefficients of multiple

regression was revealed. Perhaps this is due to the formation of a system of compensatory neurophysiological mechanisms in mentally retarded persons.

2. When calculating the coefficients of multiple regression between the amplitudes within one lead in the control group of sinistrals, the multiple regression coefficients were determined more than in the control group of dextrals. It can be assumed that in sinistrals, in comparison with dextrals, the tone of the cortex is increased.

3. The results presented in paragraphs 1 and 2 were also obtained when calculating the coefficients of multiple regression between the amplitudes of EEG rhythms within the same frequency range. The results obtained can be considered as a feature of the network semantic-topological brain.

4. In various leads, both in sinistrals and dextrals, under normal conditions and in mentally retarded persons, a different number of connections-ratios was determined. The resulting differences may indicate that the level of activity of different regions of the brain is not the same.

5. A network semantic-topological model of brain electrogenesis in mentally retarded persons is described.

Author Contributions

Lobasyuk B. A. -.Conceptualization,; methodology; writing—review and editing,
Bartsevich L. B. - formal analysis, investigation, writing—original draft preparation;
Zamkovaya A. V. - project administration, original draft preparation..
All authors have read and agreed to the published version of the manuscript.

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Institutional Review Board Statement

The study was conducted in accordance with the Declaration of Helsinki and approved by the Institutional Review Board (or Ethics Committee) of the Odessa National Medical University (protocol No. 124 from 02.02.2017)

Informed Consent Statement

Informed consent was obtained from all subjects involved in the study.

Data Availability Statement

The data presented in this study are available on request from the corresponding author.

Conflicts of Interest

The authors declare no conflict of interest.

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