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ORIGINAL ARTICLE

Individual electroencephalogram pattern and regulatory processes of the brain

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ABSTRACT

BACKGROUND: The aim of the research was to reveal the individual features of synchronization of neuronal networks in people with different level of self-regulation of the functional state of the CNS.
METHODS: The research sample included 38 athletes, meditation practitioners, and people with increased anxiety aged 20-40. We analyzed the baseline EEG record with opened eyes for 30-60 minutes, test with eyes closed for 10-30 minutes, and mental calculation test. EEG sampling rate was 250 Hz.
RESULTS: It was possible to distinguish the areas (epochs of analysis) of synchronization at one dominant frequency of the alpha rhythm in the group of leads individually for each participant. The analysis of synchronized leads allowed us to find four different individual patterns. The regular synchronization of fronto-centro-temporal leads was typical of athletes and meditators. People with increased anxiety levels had synchronization of centro-occipital and temporal leads accompanied by asymmetry between left and right hemispheric leads.
CONCLUSIONS: The obtained data make it possible to determine the current type of individual EEF pattern, predict the capacity of regulation of one's functional state, and be used as a scientific basis of developing means for correction of the functional state of the nervous system and for training of self-regulation skills.

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Key words: Athletes - Electroencephalography - Nervous system.

Functional disorders of the central nervous system (CNS) affect cerebral connections, which makes the full-scale self-regulation and adaptive activity impossible.[1, 2] The main regulator of biorhythms and related vital process is the association of the pineal gland and the hypothalamus, and the key part in the functional state regulation is played by the thalamus.[3]

Cerebral biorhythm is associated with individual features of self-regulation mechanisms and the flexibility of neurodynamic processes.[4-7] The more the number of interactions between cortical areas in the alpha wave band is the higher the flexibility of neurodynamic processes is. Implementation of individual operations by natural neuronal networks causes the formation of neuronal ensembles – relatively large populations of nervous system cells involved in a particular neural computation.[8]

It is obvious that one of the main mechanisms of functional associations of neurons is the synchronization of their activity. As a rule, such synchronization is rhythm-related. The leading part in the organization of neuronal ensembles is probably played by the alpha rhythm. It is established that the "functional core" organizing bioelectrical activity of the brain in other bands is formed by alpha oscillations.[9, 10] Though there are many studies dedicated to the alpha rhythm and its role in regulatory processes, the mechanisms of interaction and synchronization of neuronal networks, individual as well, are under-investigated. The study of synchronization of neuronal networks will help in better understanding the mechanisms of their functional organization in regulatory activity and achievement of the planned results.

The aim of the research was to reveal the individual features of synchronization of neuronal networks in people with different level of self-regulation of the functional state of the CNS.

Materials and methods

Thirty-eight students and postgraduates of South Ural State University, aged 20 to 40 (mean age 26±4), were recruited as participants for the series of electroencephalographic studies. The participants were divided into three groups: the 1st group, or group I, included athletes (N.=14) engaged in acyclic sports (First-Class and Masters of Sport); the 2nd group, or group II, included the participants of the same age (N.=12) regularly practicing psychophysical self-regulation (PPR); the 3rd group, or group III, included the participants of the same gender (N.=12), aged 23-40, who had depression with expressed anxiety for over 6 months (mental stress group – MSG).

Electroencephalogram (EEG) was recorded with the help of 8 and 16 cup electrodes connected with ear-clip electrodes and located in accordance with the 10-20 system. We analyzed the baseline record with opened eyes for 30-60 minutes (BR), test with eyes closed for 10-30 minutes (CE), and mental calculation test (CC). EEG sampling rate was 250 Hz. Computer-aided electroencephalography included spectral, period, and correlation analysis performed with the help of developer' software.

Results

Using the period analysis we assessed spectral and frequency characteristics of theta, alpha and beta rhythms on electroencephalograms. The spectral analysis of the alpha activity in the participants revealed that throughout the whole EEG record it was possible to distinguish the areas (epochs of analysis) of synchronization at one dominant frequency of the alpha rhythm in the group of leads. The detailed examination of the large array of data on the spectral analysis of EEG revealed the following features of synchronization between leads.

Both in the baseline record and in other tests of each participant there was a regular synchronization at a dominant frequency of the alpha activity in 50% of leads (or more). It was noted that synchronization was observed between the certain set of leads (8-10 leads of 16), *i.e.* there was a pattern (picture) of synchronization between the groups of leads of the cerebral cortex. Each participant had his own repeated pattern of alpha rhythm synchronization.

A long-term EEG recording (over 30 minutes) allowed us to distinguish a criterion of synchronization pattern which could be described as synchronization appearing at one frequency of the alpha rhythm in 45% of EEG leads (Table I). Such synchronization reflected the circuit of neuronal network, and this picture was repeated throughout the EEG record of each participant. This recurrent picture of synchronization received a name of "synchronization pattern".

Thus, it was revealed that each participant both in the baseline record and at functional tests had a regular synchronization between the certain leads specific for the participant (Table II). The repeated pattern involved synchronization in more than 45% of leads. The rate of recurrence of such synchronization varied within the range of 5 to 70 seconds, depending on the participant and the functional test. In the baseline records the mean rate of recurrence of "synchronization pattern" was within the limits of 10 to 40 seconds. Along with that, the minimal period of the synchronization pattern recurrence was observed in the group of athletes being equal to 10 ±5 seconds at the average, and the maximal period was observed in the MSG – 30 ±7 seconds at the

Table I.—*Synchronization pattern in the baseline record (9.8 Hz). Participant Gre-ov, 33 years old. Spectrum and frequencies (alpha) 38s, epoch 4.*

Lead	A max	S max	A mean	S mean	A full	S full	F dominant	F mean	Index
Fp1A1	1.5	2.3	0.89	0.91	12	12	9	9.4	20
Fp2A2	1.6	2.4	0.79	0.81	11	11	9	10.2	18
F3A1	2.0	4.1	0.91	1.1	12	15	9.8	9.8	13
F4A2	1.7	2.7	0.78	0.91	10	12	9.8	9.8	16
C3A1	2.1	4.4	1.0	1.3	14	18	9.8	9.4	25
C4A2	2.0	3.9	0.9	1.2	12	17	9.8	9.8	26
P3A1	2.5	6.2	1.1	1.6	15	22	9.8	9.4	17
P4A2	1.9	3.6	1.	1.4	13	20	9.8	9.8	21
O1A1	2.0	4.1	1.3	2.0	18	27	10.9	10.9	25
O2A2	2.9	8.6	1.4	2.6	20	35	10.2	10.2	10
F7A1	1.8	3.1	0.8	0.84	11	11	9.8	9.8	20
F8A2	1.5	2.3	0.7	0.77	9.8	10	10.9	10.2	10
T3A1	1.7	2.8	0.81	0.88	11	12	9.8	9.8	24
T4A2	1.6	2.7	0.75	0.82	10	11	9.8	9.8	14
T5A1	1.6	2.4	0.85	0.83	11	11	10.9	10.9	19
T6A2	1.3	1.7	0.71	0.65	9.9	9.1	9	10.2	24

A: spectrum amplitude, µV/s; S: spectrum power, µV ^2/s^2; F: frequency; Hz: Index of the rhythm - %.

Table II.—*Synchronization pattern in the baseline record (9.8 Hz). Participant Gre-ov, 33 years old. 623 s, epoch 114, mental calculation test.*

Lead	A max	S max	A mean	S mean	A full	S full	F dominant	F mean	Index
Fp1A1	1.7	3.0	0.83	0.88	11	12	9.8	9.8	11
Fp2A2	1.2	1.5	0.6	0.43	8.3	6.0	9.8	9.8	11
F3A1	1.9	3.4	0.86	0.92	12	12	9.8	9.8	4
F4A2	1.1	1.3	0.68	0.51	9.5	7.1	9.8	10.2	5
C3A1	1.7	3.1	0.94	1.1	13	14	9.8	10.2	19
C4A2	1.4	1.9	0.68	0.54	9.5	7.5	9.8	9.8	13
P3A1	1.7	2.9	0.97	1.1	13	15	11.7	10.5	10
P4A2	1.4	1.9	0.68	0.59	9.5	8.2	9.8	9.8	10
O1A1	2.5	6.1	1.2	1.8	16	25	11.7	11.3	31
O2A2	1.6	2.6	0.78	0.76	10	10	11.7	10.9	3
F7A1	1.4	2.0	0.79	0.76	11	10	9.8	10.2	15
F8A2	1.2	1.5	0.53	0.36	7.4	5.1	9.8	9.8	10
T3A1	1.4	2.0	0.81	0.77	11	10	11.3	11.3	18
T4A2	1.2	1.5	0.45	0.27	6.2	3.8	9.8	9.8	7
T5A1	1.9	3.7	0.92	1.0	12	14	11.3	11.3	24
T6A2	1.3	1.6	0.46	0.3	6.4	4.2	9.8	9.8	9

A: spectrum amplitude, µV/s; S: spectrum power, µV ^2/s^2; F: frequency; Hz: Index of the rhythm - %.

average, which was two times higher than in the groups of athletes and relaxation exercise practitioners.

These facts comply with the theory of regular activation of cortical neuronal network via thalamo-cortical connections involving the striatum.[11] The thalamus serves as a filter of the flow of mode-specific impulses.

The frequency of the alpha rhythm mainly associated with synchronization pattern was individual for each participants; it was changing both at the implementation of any functional test and at transition to another test (Figure 1) and corresponded to the dominant frequency oscillations.

Discussion

The same character of oscillations of synchronizations between EEG leads was observed for alpha, theta, and even beta bands, but only for the alpha rhythm it was regular

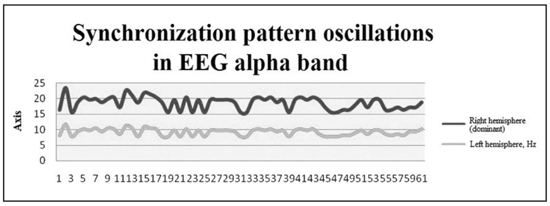

Figure 1.—Changes in the frequency of the alpha rhythm associated with synchronization patterns in 1-hour EEG record.

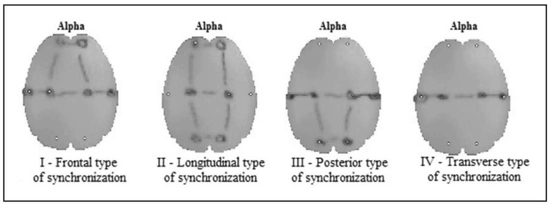

Figure 2.—Types of regular alpha synchronization of leads.

and stable throughout the EEG record. For that reason, we performed the analysis of alpha synchronization patterns.

Further study of synchronization between EEG leads in the participants revealed that the observed variations of alpha synchronization could be classified into four different individual types of patterns.

The first type of pattern was presented by synchronization between fronto-centro-temporal cortical leads (“frontal type” of synchronization pattern, Figure 2). The second type of pattern was associated with regular interaction of fronto-centro-occipital leads at the same frequency of the alpha rhythm (“longitudinal type” of pattern). The third type was characterized by the regular synchronization between centro-temporo-occipital leads (“posterior type” of pattern). The fourth type was associated with synchronization between centro-temporal leads with occasional involvement of frontal or occipital leads (“transverse type” of pattern).

It should be noted that each type of pattern involved synchronization between leads on somatosensory zone of the cortex – the projection of conduction tracts from thalamus cores. The essential role of the caudo-thalamo-cortical system in the functional state regulation was argued by many scientists [12, 13] who also underlined the capacity of this system in distribution of the local activation of neocortex via activating effects of the thalamus.

The analysis of the results showed that the first type of synchronization between fronto-centro-temporal leads was the most common (22 participants of 38, or 58%). The second most common type was synchronization of fronto-centro-occipital leads; this pattern was observed in 8 participants (21%). The rarest types were synchronization between centro-temporo-occipital leads (5 participants, 13%) and synchronization of temporo-central leads (3 participants, 8%).

Interestingly, the similar distribution of synchronization patterns was observed in the groups of athletes and meditators (practitioners of relaxation exercises on visualization and concentration of attention). In these groups, approximately 80% of the participants had the pattern of synchronization between fronto-centro-temporal leads, and the remaining 20% - the patterns of synchronization between fronto-centro-occipital leads or between centro-fronto-occipital leads.

In contrast, the MSG (mental stress group) almost did not have the pattern of synchronization of fronto-centro-temporal leads (1 case of 12), while the most common pattern was a regular synchronization between fronto-centro-occipital leads (5 of 12 participants); there were also patterns of synchronization between centro-temporo-occipital leads (3 of 12 participants) and between temporo-central leads (3 of 12 participants).

Speaking of the common pattern of synchronization between fronto-centro-occipital leads (longitudinal type of pattern) in the MSG and the common pattern of synchronization between fronto-centro-temporal leads (frontal type of pattern) in the groups of athletes and meditators it should be noted that the index of the alpha rhythm in frontal and temporal leads of the frontal type of synchronization pattern was at the average by 50% than the index of the alpha rhythm in the longitudinal type of pattern.

Interestingly, the first type of pattern was mainly expressed in the athletes and relaxation exercise practitioners, *i.e.* people who could control their emotions. Some experts [14-17] note the correlation between the frontal alpha rhythm power with emotional stability. Our findings on the strength of fronto-temporal alpha band connections prove this assumption.

All the participants of the MSG had an expressed asymmetry of synchronization pattern involving shift and reduction of boundaries towards the left or right hemisphere. In other words, the MSG group had synchronization between symmetric leads less often than the groups of athletes and meditators.

Some authors [18, 19] argue that people with expressed neuroses or increased anxiety have a prominent hemispheric asymmetry (over 25%) associated with partial disturbances both of thalamo-cortical and interhemispheric functional connections. Our findings indicate the asymmetry of thalamo-cortical connections between the left and right hemispheres associated with excitability of subcortical structures and the limbic system.

In the baseline record with opened eyes hemispheric asymmetry in the group of athletes was 15-20%, in the group of meditators – 10-15%, and in the MSG – over 30% (Table III). With eyes closed hemispheric asymmetry of the alpha rhythm power in the MSG was less than 20% approximating to 10-15% of the groups of athletes and meditators.

TABLE III.—*Asymmetric synchronization pattern in the baseline record. Spectrum and frequencies (alpha), 184 s, epoch 31. Participant E-va, 24 years old.*

Lead	F dominant	F mean	Index
Fp1A1	9.4	9.8	14
F3A1	9.4	9.4	11
C3A1	9.4	9.4	18
P3A1	9.8	9.8	31
O1A1	9.4	9.8	18
Fp2A2	9.4	11.3	11
F4A2	9.4	9.8	22
C4A2	9.4	9.8	28
P4A2	9.8	9.8	38
O2A2	10.5	10.5	24
F7A1	9.4	9.4	11
T3A1	9.4	9.4	17
T5A1	9.8	9.8	17
F8A2	12.9	10.5	7
T4A2	8.2	8.2	13
T6A2	10.5	10.5	33

A: spectrum amplitude, µV/s; S: spectrum power, µV ^2/s^2; F: frequency; Hz: Index of the rhythm - %.

Considering the increased excitability of the limbic system (tonsils, striatum) observed in such people [20-22] it may be assumed that the striatum increases excitability of the thalamus and functionally related cortical areas changing the normal succession of inhibition-excitement cycles in the caudo-thalamo-cortical system.

The findings of our electroencephalographic studies indicate that functional cyclicality is typical of the body both at rest and during adaptive and compensatory transformations. The obtained results suggest the presence of individual, probably genetically determined mechanisms for the central organization of adaptation processes.

The recurrent generalization of the alpha rhythm following the synchronization pattern at the frequency close to the pattern frequency, *i.e.* synchronization at one frequency of more than 90% of leads, apparently indicates the low-frequency rhythmic activity of reticular function (RF). The RF is known to provide the generalized activation of vast cortical areas; working at a low frequency the RF contributes to the formation of resting condition.[23, 24]

Thus, our studies confirm the idea of the central organization of functional states different in people with different physical fitness levels.[25]

Conclusions

The detailed studies of long-term electroencephalogram record allowed us to specify and describe the individual features of central mechanisms. For instance in the groups of athletes and meditators we observed, both at rest and more rarely at functional testes, cyclic changes of activity of the thalamo-cortical and the stem modulation systems of the brain at the frequency of the alpha rhythm. The observed regular synchronization of more than 50% of EEG leads with domination of fronto-central cortical areas in athletes and meditators is combined with a high level of self-regulation and better performance both of cognitive tasks and at exercising involving small groups of muscles.

The low-frequency activity of the reticular function is observed at the frequency of the alpha rhythm, which is typical for the thalamo-cortical system; along with that, this system provides the realization of “filtering mechanism” for processing of specific cognitive information while solving the set task of for processing of the information on the internal environmental condition. At the frequency over 9.5 Hz, so-called “sounding” mechanism for control of the body condition and its relations with the environment may be initiated.

In the MSG the change of synchronization pattern occurs 2-3 times more rarely as compared to the group of athletes and meditators. Less coordinated interaction of two modulation systems and larger level of their activity resulting in domination of beta and theta rhythms over the alpha rhythm also indicate the low level of self-regulation of the functional state of the CNS in such people. It is combined with the sensitivity to stress factors and increased anxiety.

The obtained data make it possible to determine the current type of individual EEF pattern, predict the capacity of regulation of one’s functional state, and be used as a scientific basis of developing means for correction of the functional state of the nervous system and for training of self-regulation skills.

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