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RESTING STATE EEG RHYTHM CHARACTERISTICS ASSOCIATED WITH READINESS FOR DIVERGENT THINKING

CECHY RYTMU EEG W SPOCZYNKU ZWIĄZANE Z GOTOWOŚCIĄ DO MYŚLENIA ROZBIEŻNEGO

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zaplanowanie badań
B. Data collection/entry
zebranie danych
C. Data analysis/statistics
dane – analiza i statystyki
D. Data interpretation
interpretacja danych
E. Preparation of manuscript
przygotowanie artykułu
F. Literature analysis/search
wyszukiwanie i analiza literatury
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Summary

Background. Local synchronization of the electrical activity of the cerebral cortex at rest with eyes open in persons with different levels of divergent thinking were studied.
Material and methods. 95 men and 98 women aged 18-21 with different levels of divergent thinking were studied. The power of the EEG at rest with eyes closed and open was analyzed.
Results. There were established differences in the extent of the depression depth, as well as in the activation of the EEG alpha rhythm, which is related to gender and level of productivity. Women have a greater depth of alpha rhythm depression than men. In subjects with high and medium levels of divergent thinking, alpha-rhythm depression was of a generalized nature, and in subjects with low levels of divergent thinking – local and topographically non-specific.
Conclusions. These results indicate that the EEG response of readiness to perceive stimuli, which provides either very high or very low productivity of divergent thinking, is manifested in the dynamics of the biopotential power in the EEG alpha range.

Keywords: alpha rhythm, electroencephalogram, brain

Streszczenie

Wprowadzenie. Badanie obejmowało szczegóły lokalnej synchronizacji aktywności elektrycznej w korze mózgu w spoczynku z otwartymi oczyma u osób o różnym poziomie myślenia rozbieżnego.
Materiał i metody. Przebadano 95 mężczyzn i 98 kobiet w wieku 18-21 lat o różnym poziomie myślenia rozbieżnego. Analizie poddano moc EEG w spoczynku z oczyma zamkniętymi i otwartymi.
Wyniki. Ustalono różnice w głębokości depresji oraz w aktywacji rytmu alfa podczas EEG, co jest związane z płcią i produktywnością. Kobiety mają rytm alfa w głębszej depresji niż mężczyźni. Osoby z wysokim i średnim poziomem myślenia rozbieżnego wykazały zgeneralizowaną depresję fal alfa, zaś osoby o niskim poziomie myślenia rozbieżnego – lokalną i niespecyficzną pod względem topografii.
Wnioski. Uzyskane wyniki sugerują odpowiedź EEG opierającą się na gotowości na odebranie stymulacji, która generuje bardzo wysoki lub bardzo niski poziom produktywności w zakresie myślenia rozbieżnego, która objawia się w dynamice biopotencjałów mocy w zakresie alfa podczas badania EEG.

Słowa kluczowe: rytm alfa, elektroencefalogram, mózg

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Introduction

Approaching the problem of creativity from the standpoint of cognition means trying to understand the mental mechanisms, representations, and processes that underlie creative thought. With the suggestion of Guilford, within the framework of the psychometric approach, the creative process is considered the interaction of two opposite types of thinking: divergent (associated with the generation of a set of solutions) and convergent (associated with the generation of a single solution) [1].

When considering the stages of the creative process, the authors of different approaches are based on Wallas's idea of its four stages: preparation, incubation, aha reaction (insight), and development. At the stage of preparation, a conscious study of the problem is carried out. In the incubation stage, there is a break in conscious work and the energy of the subconscious is used. The solution appears quite suddenly after the incubation period and is verified in the last stage [2].

When looking at the correlation between attention and the creative process, it is necessary to highlight defocused (distributed) attention, which means attention distributed between its focus and the periphery [3]. The research of this phenomenon in foreign cognitive psychology is based on connectionism's notions of primary (free associations, concrete thinking, and thinking by analogy) and secondary (abstractness, consistency, and orientation towards the demands of reality) cognitive processes [4]. Defocused attention refers to primary cognitive processes, and focused attention refers to secondary cognitive processes.

In the state of rest, closed and open eyes are characterized by different brain organization as evidenced by the results of numerous studies [5-7], it is not only due to the presence or absence of visual information but also due to the change in general focus: from intra-oriented in the state of closed eyes to the outward-oriented in the setting of eyes open. Boitsova and Danko [7] consider that changes in the EEG pattern during the transition from rest with eyes closed to rest with eyes open reflect the process of restructuring the functional systems of the brain, due to the transition from interoceptive to exteroceptive focus.

In psychophysiology, the functioning of the brain's modulatory systems is based on the generalized tonic activation of the brain, associated levels of wakefulness, and local phase activations that determine the selective nature of attention [8]. Among neurophysiological models of attention, Posner's model is of special interest, which considers attention as a system of mental process control [9]. The researcher distinguished the anterior and posterior morphofunctional systems of attention. The anterior system is a system of arbitrary, controlling attention, and target detection. It is represented by the anterior cingulate gyrus and dorsolateral prefrontal cortex, which are associated with the basal ganglia, limbic, and thalamic nuclei. The posterior system of involuntary attention and orientation includes the parietal cortex, the pad of the visual cortex, and the upper tubercles of the corpora quadrigemina. According to Posner's theory, both systems of attention are influenced by the ascending reticular activating system. The orienting of attention and controlling (executive attention) the different types of attention are referred to as alerting attention. In such phenomena, those specific for the concrete current tasks of phasic attention (task-specific phasic alertness) are distinguished from those of general specific readiness (intrinsic alertness). Changes in EEG power in the alpha-1 range of the parietal and central zones are associated with the direction of general cognitive-specific readiness [10,11].

In the work of Livanov and co-authors, the concepts of "level of readiness" and "focuses of maximum synchronicity (FMS)" were formulated. In accordance with this idea, the level of biopotentials during neocortex synchronization with the parameters of their spectral power and coherence generally characterizes the degree of a person's readiness to perceive and process information and implement programmed behavioral acts. According to some [12], "the main condition for the successful course of activity is the strengthening not of global synchronization, but intensity of the local synchronization addressed to the zones involved into this act". In this case, the NREM sleep phase can take place both in the background of a global increase or decrease in the synchronization of brain biopotentials.

While the extent of spacious synchronization of the brain's electrical activity cannot be adequately measured for the activation of cerebral structures. The researchers believe that the electrical activity optimal for the passage of the certain type of activity and the extent of readiness fostering the effective carrying out of an activity should to be studied in detail using empirical methods. Therefore, our study aims to discover the particularity of EEG rhythms in the rest condition, as a manifestation of reactionary readiness to intellectual activity of the divergent type.

Material and methods

Participants

The study included 95 men and 98 women aged 18-21. The study was conducted in accordance with generally accepted bioethical standards, following review of relevant international regulations on experimental work and clinical tests (Council of Europe Convention on the Protection of Human Rights and Human Dignity in Respect of Biological and Medical Achievements, Convention on Human Rights and Biomedicine (ETS No. 164) of 04.04.1997, and the Helsinki Declaration of the World Medical Association (2008)). Study participants (volunteers) signed a written consent to participate in the experiment. The examinations were conducted on weekdays from 10:00 to 13:00. The female participants underwent examinations during the follicular phase of their menstrual cycle.

Groups for the analysis of data were formed by gender and by level (low, medium, high) of efficiency during the performance of divergent type tasks. The particular divergent type task was selected from a book [13] by a group of independent experts (students of psychological, mathematical, and geographical faculties), for example: "13 million date palms are growing in Bangladesh. During the season, each palm tree can produce 240 liters of juice, which is later used to make palm sugar. But to collect this juice, an incision in the trunk under the crown at a height of 20 m must be made". The participants were then advised to suggest as many ways as possible to make the incision. The text for the task was shown on a computer screen. Two minutes were given to accomplish each task. Tasks were performed mentally. The results were recorded after the registration of electroencephalograms. The guideline to create an original product was not given. The efficiency of divergent task performance was evaluated by the number of suggested answers. To rank efficiency indicators, the 25-a and 75-a percentiles were determined for all subjects. 2-3 answers and performance indicators that fell in the range from the 25-a percentile to the 75-a, were considered as average. Values that failed to meet or exceeded these limits were evaluated as low and high efficiency, respectively. As a result, 6 groups of test subjects were formed (Table 1).

Table 1. Groups of test subjects

Group of test subjects	Characteristics of groups	Number of subjects
1	Males with high productivity of divergent thinking	33
2	Males with average performance of divergent thinking	44
3	Males with low productivity of divergent thinking	18
4	Females with high productivity of divergent thinking	19
5	Females with average performance of divergent thinking	56
6	Females with low productivity of divergent thinking	23

Procedure

Electrical activity in the cerebral cortex at rest with closed and open eyes was recorded. The duration of EEG recording in both experimental situations was 60 seconds (s). The electrical activity of the cerebral cortex was recorded monopolarly from 19 leads according to the international system 10/20 (Fp1, Fp2, F3, F4, F7, F8, Fz, C3, C4, Cz, T3, T4, T5, T6, P3, P4, Pz, O1, O2) with the help of the hardware and software complex "Neurocom", developed by the scientific and technical center of radio-electronic medical devices and technologies "KHAI-Medica" (certificate of state registration No. 6038/2007 of January 26, 2007). Artifact activity rejection of the native EEG was carried out by applying ICA-analysis (Independent Component Analysis).

EEG power and coherence indicators were analyzed in the frequency ranges of Δ (0.5-4.0 Hz), θ, α1, α2, α3, β, and γ (35-40 Hz). Determination of frequency limits θ, α1, α2, α3, and β were carried out based on the individual frequency of the α-rhythm of each subject [14]. According to these values for each homogeneous group, the frequency limits of the alpha rhythms were calculated (Table 2) according to the following principle: the lower limit of alpha-1 is the value of the individual frequency minus 4, the upper limit of alpha-1 is the individual frequency minus 2; upper limit of alpha-3 is the individual frequency plus 2 [14]. Based on this data, the frequency limits of theta and beta rhythms were determined.

Table 2. Frequency limits of rhythms, Hz

Individual frequency of the α-rhythm, Hz	Theta	Alpha-1	Alpha-2	Alpha-3	Beta
9	4.0-5.0	5.0-7.0	7.0-9.0	9.0-11.0	11.0-35.0
9.5	4.0-5.5	5.5-7.5	7.5-9.5	9.5-11.5	11.5-35.0
10	4.0-6.0	6.0-8.0	8.0-10.0	10.0-12.0	12.0-35.0
10.5	4.0-6.5	6.5-8.5	8.5-10.5	10.5-12.5	12.5-35.0
11	4.0-7.0	7.0-9.0	9.0-11.0	11.0-13.0	13.0-35.0
11.5	4.0-7.5	7.5-9.5	9.5-11.5	11.5-13.5	13.5-35.0
12	4.0-8.0	8.0-10.0	10.0-12.0	12.0-14.0	14.0-35.0

Statistical analyses were carried out using Statistica 10.0 multi-factor ANOVA and MegaStat. Values where $p<0.05$ were considered statistically significant. The accuracy of differences between EEG indicators, in the case of parametric sampling, was determined using Student's t-test, and for variable samples without normal distribution, the nonparametric Wilcoxon test was used [15].

Results and Discussion

Changes in the electrical activity of the brain occur as a result of the transition from a state of rest with eyes closed to a state of rest with eyes open. In our opinion, this provides a certain level of anticipatory attention, i.e. the appropriate level of readiness for activity. The analysis of the results shows that the changes in EEG power indicators had several features related to gender and the intensity of divergent thinking.

Firstly, gender-related features that women, compared to men, had a more intense alpha-1,2,3-rhythm at rest with eyes closed and a greater extent of depression reflected in these rhythms in the course of transition to calm contemplation. In addition, it should be noted that the groups were different in the depression reaction of the alpha rhythm. The depressive reaction of alpha-rhythms in groups of men and women with an average level of divergent thinking effectiveness had a generalized specificity in all three frequency ranges of alpha-rhythms (Figure 1).

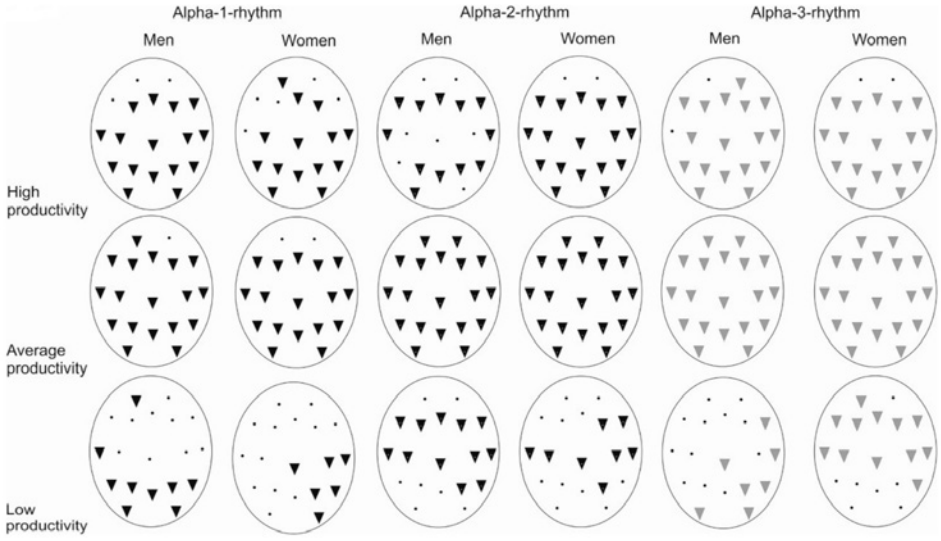

Figure 1. Changes ($p<0.05$) of power indicators in the range of alpha frequencies in rest condition with eyes open compared to rest condition with eyes closed in groups with different levels of effectiveness in task performance related to the divergent type

Notes: A triangle with the top down indicates a decrease in rhythm power.

The nature of alpha-rhythm depression can be called generalized in groups with high productivity in performing a divergent task. In groups with low productivity, depression of the alpha rhythm was manifested locally and had its topographic differences in the frequency sub-bands of the alpha rhythm and in different groups selected by sex (Figure 1).

The depth of depression (extent of power reduction) of the alpha rhythm also fluctuated in different groups. Intergroup differences in the depth of depression can be associated with the fact that the performance of a divergent task was more pronounced in male subjects (Figures 2, 3, 4). According to this indicator, the group with an average level of productivity was clearly distinguished among men. It was in this group that the depth of depression was greatest amongst all frequency ranges of the alpha rhythm.

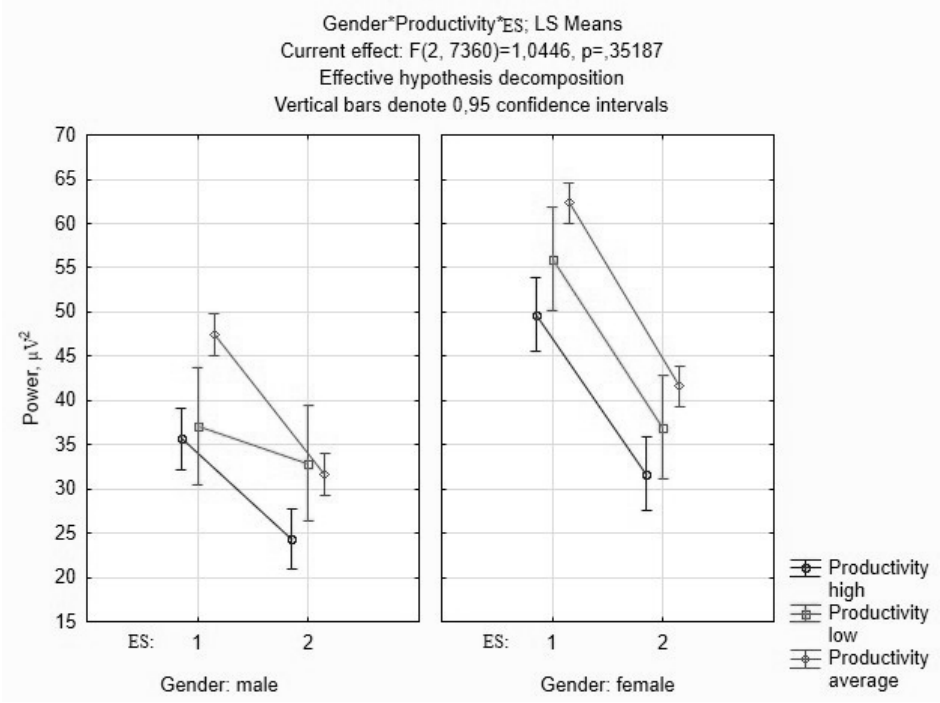

Figure 2. The depth of depression of the alpha-1-rhythm in the groups based on productivity of divergent thinking
Notes: ES – experimental situations (1 – state of rest with eyes closed, 2 – state of rest with eyes open).

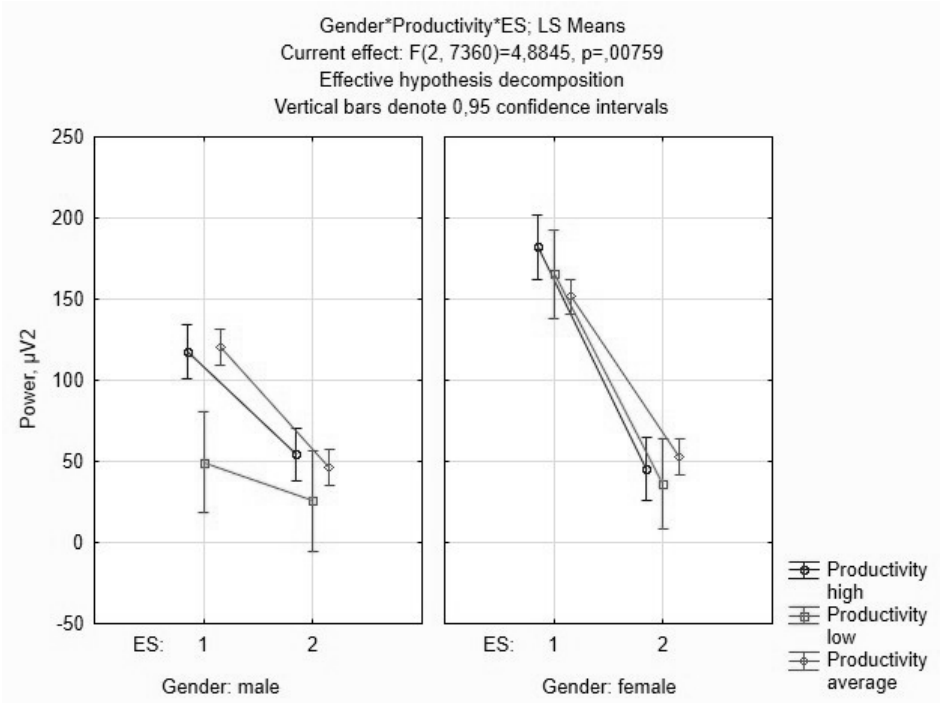

Figure 3. The depth of depression of the alpha-2-rhythm in the groups based on productivity of divergent thinking
Notes: ES – experimental situations (1 – state of rest with eyes closed, 2 – state of rest with eyes open).

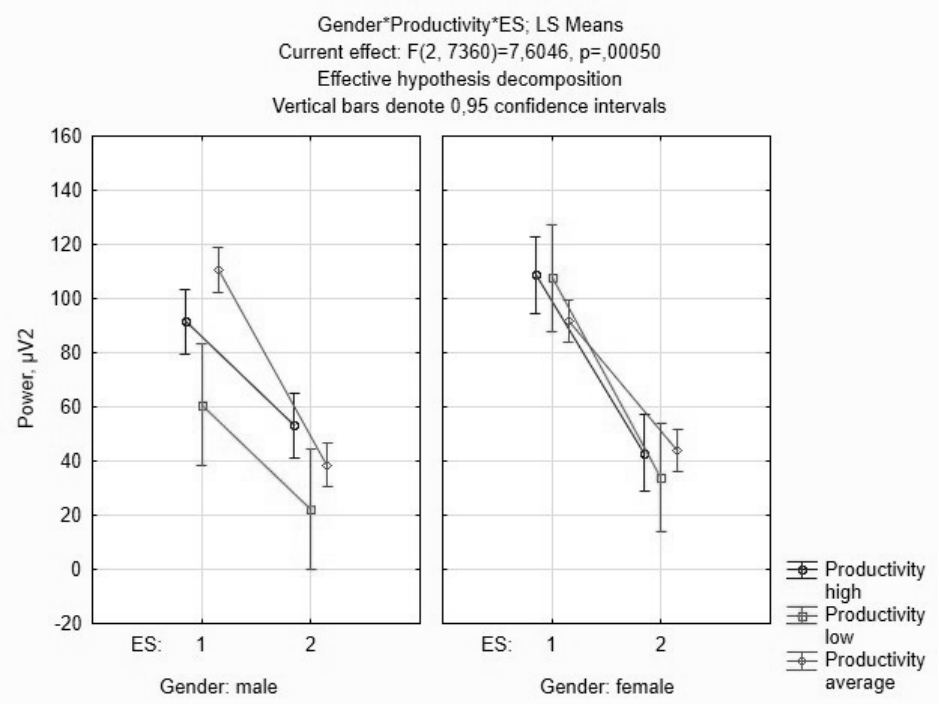

Figure 4. The depth of depression of the alpha-3-rhythm in the groups based on productivity of divergent thinking
Notes: ES – experimental situations (1 – state of rest with eyes closed, 2 – state of rest with eyes open).

Among women, intergroup differences in the depth of depression were not so pronounced. When compared with men all women, regardless of the level of productivity of divergent thinking; the depth of depression of the alpha-1 and alpha-2 rhythms were greater (Figures 2, 3, 4).

It is quite natural that the differences in the depth of depression associated with the gender of the subjects were manifested to a greater extent in the alpha-1 and alpha-2 range, which today are associated with the conscious expectation of a stimulus, i.e. with arbitrary, focused, and supportive attention (or involuntary attention), respectively [14]. Therefore, we can say that the level of attention in men and women differed significantly. It is in the alpha-1 and alpha-2 range in women that we observed higher intensity indicators than in men at rest with eyes closed. According to [16], the higher the power of the alpha rhythm at rest with eyes closed the better the prognosis for differentiation of external stimuli. Women at rest with a closed visual sensory channel had a lower level of activation than men and therefore attempted to increase it through outward attention. This was achieved due to the greater, compared to men, depth of the alpha rhythm depression. Our results are confirmed by the following psychological characteristics of women: they focus on details [17] and try to obtain comprehensive information to make a decision [18].

Readiness for activity and the activity itself can be ensured by reducing power in different frequency bands: in alpha – to obtain visual information from the outside [19], in both alpha and beta – for active information processing [20], and in theta – in anticipation of the stimulus [14,16]. Moreover, one of these mechanisms is often enough to achieve the optimal level of attention required for adequate perception of stimuli and effective mental activity. The dynamics of EEG power established in our study indicates that in all subjects the transition to calm contemplation was accompanied by a decrease in beta-rhythm power. In groups with medium and low productivity of divergent thinking, it presented more widely on the scalp (Figure 5).

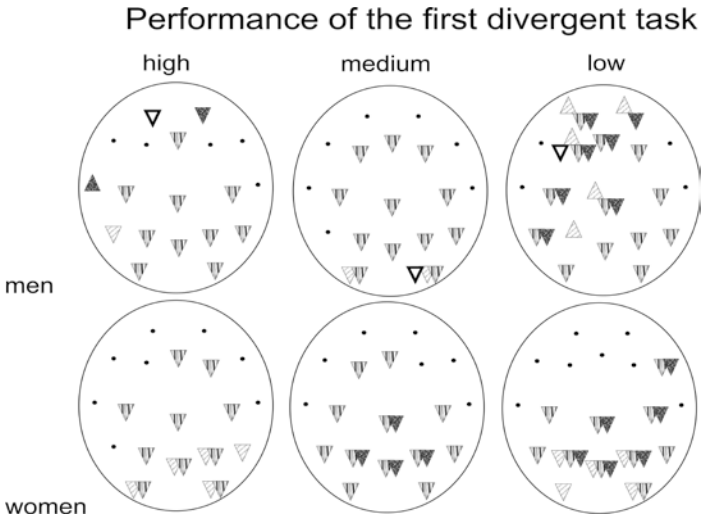

Figure 5. Changes in delta, theta, beta, and gamma rhythms at rest with eyes open compared to rest with eyes closed in subjects with different performances on divergent-type tasks

Notes: A triangle with the top up indicates an increase in the power of the rhythm, with the top down – a decrease; △ – delta activity, △ – theta rhythm, △ – beta rhythm, △ – gamma rhythm.

Simultaneous decreases in the power of alpha and beta rhythms are considered a reflection of the process of active information processing [21]. In our study, such a decrease was obtained during the opening of the eyes and calm contemplation which can be interpreted as a greater readiness to process information. Changes in delta power and theta activity were much less pronounced and their topography changed depending on the selected group and the effectiveness in performance on the first or second divergent type task. This, obviously, should be taken as a fact of the "non-involvement" of slow EEG waves in the process of tune-up to mental activity.

Changes in the power of the gamma rhythm at rest with eyes open compared to at rest with eyes closed had a fairly clear topographic timing only in groups with low productivity of divergent thinking. In particular, there was a decrease in gamma rhythm power in F1, F2, F3, Fz, C3, Cz, and T5 in men and F8, C4, Cz, P3, P4, and Pz in women. A more detailed analysis showed that such topographic changes in gamma-ray power are manifested only in those subjects in whom the productivity of divergent thinking varied in the first and second tasks from medium to low or from low to medium. Therefore, these results cannot be directly related to the low productivity of divergent thinking.

Conclusions

We can assume that the above-described pattern of changes in power indicators (primarily in the range of alpha frequencies), which we interpreted as a mechanism of preparation for mental activity, maybe an EEG marker of divergent thinking effectiveness. In summary, we observed that there is a certain EEG reaction of readiness to perceive stimuli, which provides either very high or very low productivity in divergent thinking manifested in the dynamic biopotential power of the EEG's alpha range.

The alpha rhythm performs the function of time scanning ("reading") of information and is closely related to the mechanisms of perception and memory [22]. It is suggested that the alpha rhythm reflects the reverberation of excitations that encode intracerebral information and create an optimal background for the reception and processing of afferent signals. Its role is in the functional stabilization of the brain and ensuring readiness to respond. It is also assumed that the alpha rhythm is associated with the action of selective mechanisms of the brain, which performs the function of a resonant filter and thus regulates the flow of sensory impulses. The general readiness or general activation state is reflected in the indicators of a low-frequency alpha rhythm, which was approximately identical in all subjects. According to [14], alpha-1 is associated with a conscious expectation of a stimulus, i.e. arbitrary, directed attention. And, since all respondents knew that they would be performing intellectual tasks, they were all waiting for these tasks, i.e. waiting for incentives. Peculiarities related to the performance of divergent thinking are expressed in the range of alpha frequencies, in the dynamic electrical activity of the cerebral cortex, and indicate a better readiness for stimuli which determines the effectiveness of divergent type mental activity.

Disclosures and acknowledgments

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