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Bioelectrical activity of the brain during performance of manipulative movements in women with different modal alpha-frequencies

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An important component of the general biological problem of coordinated activity of the brain's motor systems and of the executive apparatus during the implementation of motor functions is the question of the interconnection of electroencephalogram (EEG) rhythm characteristics, above all α -rhythm, with control peculiarities of manipulative movements (MM). A test group consisting of 113 healthy right-handed women from the ages of 19 to 21 was divided into two groups according to the average magnitude of their individual modal α -frequency – groups with high and low values of individual modal α -frequency (I α F). The ideal time of a simple sensorimotor reaction and choice-point behavior as well as speed capabilities of nervous processes during the finger tapping test, and measures of the power spectrum of EEG spectral components individually determined for each testee in quiescent intervals and while performing alternating movements by the fingers of the right hand were evaluated. Alternate female finger movements were accompanied by a decrease in the EEG α 2- and α 3-activities in the posterior cortical areas, and β 1- and γ -activities in the frontal, temporal and central areas of the cortex compared with the same in the immobile state; they were also characterized by the generalized growth of θ -oscillations and local (in the frontal leads) – α 1- and β 2-activities. Thus, in both groups of women surveyed the increase in activity of those cortical structures that ensure its implementation – sensory perception, motor start and motor programming commands and sense-motor coordination, was found. When MM are performed by women with a higher output α -frequency, they were characterized by more local changes in the electrical activity of the cerebral cortex. People with a lower modal α -frequency were characterized by somewhat less specific and differentiated features of the cortex activation. Alternating movements of fingers performed by women with low I α F were associated with higher EEG θ -, α 1-, α 2-activities, generally in the cortex, and α 3-, β - and γ -oscillations – in the posterior areas than in those with high I α F. Instead of this, a relatively lower power spectral EEG was recorded in the frontal leads of the range consisting of α 3-, β - and γ -oscillations. Intergroup differences found by us may indicate a higher status regarding a specific cortical tone, its readiness for activity and control of information processes in people with high I α F in comparison with those who had low I α F. It is natural that different levels of features of such activation systems achieve specific outcomes in testees with a different starting I α F. Women with a higher I α F had better speed characteristics of nervous processes.

Keywords: electroencephalogram; individual mode of the α -rhythm; female testees; finger movements

Біоелектрична активність мозку під час виконання маніпулятивної моторики у жінок із різною модальною альфа-частотою

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Обстежено 113 правопрофільних жінок віком 19–21 років, яких поділили на дві групи: з високими та низькими значеннями модальної альфа-частоти, визначеної індивідуально у стані спокою. Оцінювали час простої сенсомоторної реакції та реакції вибору, швидкісні можливості нервових процесів під час тепінг-тестування, показники спектральної потужності частотних компонентів електроенцефалограми обстежуваних у стані спокою, під час почергових рухів пальців правої руки. Жінки з високою модальною α -частотою мали кращі швидкісні характеристики нервових процесів. Почергові рухи пальців у жінок супроводжувалися зниженням потужності α 2- і α 3-активності задніх кортикальних ділянок, β 1- і γ -активності – лобових, скроневих і центральних ділянок порівняно зі спокоєм; характеризувалися генералізованим зростанням θ -коливань і локальним (у лобових відведеннях) – α 1- і β 2-активності. Для осіб із низькою модальною α частотою притаманні менш специфічні та диференційовані особливості активації кори. У жінок із низькою α частотою виконання почергових рухів пальцями пов'язане з вищою потужністю θ -, α 1-,

α_2 -активності загалом у корі, α_3 -, β - і γ -коливань – у задніх ділянках, ніж в осіб із високою α -частотою. Натомість у лобових відведеннях у діапазоні α_3 -, β - і γ -коливань реєстрували порівняно нижчу спектральну потужність електроенцефалограми.

Ключові слова: електроенцефалограма; індивідуальна мода альфа-частоти; тестовані жіночої статі; рухи пальців

Introduction

Movements by the upper extremities, particularly but not exclusively, by human fingers, form the basis of the manual movements in any labor activities. This or that person's individual functional capacities of the motor system acquire a critical score for successful learning of a wide range of trades in present-day society. For this purpose, the academic community places greater emphasis on issues dealing with the personality traits of the cerebral processes guaranteeing the motorial programming of manipulation movements (MM). Various aspects of the abovementioned problem were studied in the area of neurophysiology concerning motor activities (Sheth and Shimojo, 2002; Ioffe, 2003; Rhodes et al., 2004; Hatfield et al., 2005; Wise and Willingham, 2009; Grigal and Kurganskiy, 2010; Pavlovych et al., 2012; Cavallo et al., 2014). MM are obviously associated with significant alterations of the brain's activities ensuring the formation of the appropriate motor programs and orders. However, specific information concerning these processes in the cerebral cortex is still very limited. It is not improbable that certain performance measures of the cerebration correlated with MM – their amplitude, speed and accuracy, exist.

Scientists (Kristeva et al., 2005; Bazanova and Aftanas, 2007; Grandy et al., 2013; Morenko et al., 2014) found out that individual values of the amplitude-frequency characteristics of any α -rhythm, including the modal frequency of such a rhythm, demonstrate a significant informational content in determining the state of the main physiological functions of a person. According to the data of Kristeva et al. (2005), Bazanova and Aftanas (2007), the ideal coordination of processes organizing movements and capacity for censorship are positively correlated to the power of the individual EEG α -range and negatively to the tension of the muscles of the facial expression (forehead) being inactive during the MM autocinesia. These statements are study specific of the authors (Kaplan and Borisov, 2003; Angelakis et al., 2004; Anokhin et al., 2006; Begleiter and Porjesz, 2006; Klimesch et al., 2007) who consider the modal EEG α -frequency as rigidly determinate by a genetic trait inasmuch it reflects the essential innate peculiarities of the structural organization of any thalamic and cortical neurons (Page et al., 2006; Ng and Raveendran, 2007; Spergel, 2007).

Estimating the crucial importance of results obtained by different scientists, it is worth mentioning that such information is clearly inadequate for a thorough understanding of personality traits of the neurophysiological maintenance of the goal directed movements of any individual. Records are critically limited as to the way in which such an innate aspect of the mental functioning as a modal frequency of EEG α -rhythm deals with the activities regulating distal hand muscles during the execution of MM. The prognostic value of an individual's cerebral activities dealing with MM is marginally studied today. At the same time, the question of the interconnection of certain EEG rhythms characteristics, above all α -rhythm, with control peculiarities of distal movements of the upper limbs is an essential component of

the important general biological problems of coordinated activity of the brain's motor systems and of the activity of the executive apparatus during the implementation of motor functions.

With the aim of shedding light on such issues, we conducted a study of changes in the power spectrum of the EEG frequency components during the time of execution of alternating movements by fingers in men having some different modal alpha-frequencies (Morenko et al., 2014). According to the results obtained, all the men had the power reduction of θ -, α - and β_1 -waves, especially in the posterior cortical areas as well as some power growth of the EEG (θ - and α_1 -) low-frequency vibrations in the frontal area. However, men with a low mode of α -frequency had a lower power of the EEG α_1 -, β - and γ -activities in the frontal areas whilst the higher power of the EEG frequency components and generalization of such changes were found to be greater in the parietal, occipital, central and temporal lobes than in men with a higher modal α -frequency. Peculiarities of the cortical electrical activity determined in the flow of the regulation of the manipulation movements in men with a high mode of α -frequency were associated with relatively higher rates of the speed and accuracy of the sensorimotor responses. Taking into consideration the obtained results concerning men and the general scientific relevance of the gender flow phenomena of the cerebral activities particularly but not exclusively during MM, it is appropriate to carry out the relevant studies with the involvement of women as testees.

The goal of our research is to find out the specifics of the EEG power spectrum during the execution of alternating movements by fingers of women with higher and lower modal frequencies of the EEG α -rhythm, taking into account the prognostic value of the relevant data in the area of the speed capabilities of nervous processes.

Materials and Methods

The object of the study. The participants in our study were 136 female volunteers from the ages of 19 to 21, each of whom had given written consent. Biomedical ethics rules in accordance with the Helsinki Declaration of the World Medical Association on the Ethical Principles of Scientific and Medical Research involving Human Subjects were adhered to during the experiment. All the testees were judged by medical professionals to be healthy and have normal hearing. The survey of the women was conducted during the secretory phase of the menstrual cycle.

Psychophysiological examination. As part of the psychophysiological testing the profile of manual and auditory asymmetry was determined for each subject. It was determined by the nature of responses in the survey, execution of the motor and psychoacoustic tests and counting the individual ratio of the manual and auditory asymmetries (K skew) (form. 1) (Zhavoronkova, 2009):

$$K_{\text{skew}} = \frac{\sum_{\text{right}} - \sum_{\text{left}}}{\sum_{\text{right}} + \sum_{\text{left}}} \times 100\%$$

where Σ_{right} – the number of tasks where the right hand (right ear) is dominating during their execution, Σ_{left} – the number of tasks under which the left hand (left ear) is dominant.

Further studies involved dextral testees whose coefficients of manual and auditory asymmetries were positive and were above 50%. The total number of women was 113.

The level of speed properties of the testees' nervous processes was surveyed with a simple sensorimotor reaction taking into consideration time period and sensorimotor responses in the choice of one of three objects as signals (triangles, circles, squares). See the program "Diagnostician-1", Ukraine. All testees had to respond to the certain stimuli as quickly as possible by pressing a button with the right hand.

All examinations were performed in the morning. The profile of the asymmetry and time of simple and complicated sensory-motor reactions was evaluated 30 minutes before the EEG recording registration. It made it impossible to influence the experiment, particularly, on EEG results.

EEG testing procedures. The testees were in a quiescent state with their eyes closed and in a reclining position with their limbs relaxed and not crossed during the EEG testing. The experiment was carried out in a room which was sound-proof and light-proof. The whole experimental procedure consistently included the following steps for each testee:

Step 1. The EEG recording in the functional balance (background);

Step 2. The EEG recording while performing the alternate movements by fingers of the right hand.

Each step lasted 40 s. To exclude edge effects, the EEG recording registration was started 15 s after the beginning and had been stopped 5 s after its completion.

The testees performed finger movements one by one in the following order: forefinger – fourth finger – third finger – little finger. The sequence of movements was reported to the testees just before the test to minimise stereotyping of the task.

Movements of each finger involved its bending and unbending. Each finger flexion or extension was performed by the testees in response to the sound. The electronic version of a drum battle (the software of Finale 2006) was used for this purpose. Binaural stimuli were produced by four speakers placed in different corners of the room at the distance of 1.2 m from the testee's right or left ear. The stimulus duration was 130 ms; the playback sound volume did not exceed 55–60 dB at the outlet from the speakers under the measurements carried out by the sound level meter of the 'DE-3301' type (certificate of attestation # 025-2009, valid until 21.12.2014). Additionally, the sound loudness was individually regulated to ensure that each testee achieved the necessary level. The rate of the sound stimuli delivery was 2 c^{-1} . The choice of the relatively low acoustic stimulation was based on the fact that such frequency corresponds to the frequency range of the MM execution. Such a range is essentially determined by biomechanical movements implemented by the distal parts of the hand.

Registration and primary analysis of EEG data.

Active electrodes were placed in accordance with the international system 10/20 at nineteen points on the scalp of the head during the electroencephalogram (EEG "Neurocom", and the Certificate of State Registration # 6038/2007, valid until 18.04.2014) recording. The performance of the EEG recording was monopolar, with the

use of ear electrodes as a reference. The Fourier analysis era was 4 s with a 50% overlap. Duration of sample was 40 s. ICA-procedure analysis was used for the rejection of EEG anomalies.

The spectral power (μV^2) of the brain electrical activity in the θ -, α -, β - and γ -frequency intervals were also evaluated. Taking into consideration the functional heterogeneity of different sub-bands of the EEG α - and β -rhythms, the changes in the spectral power of each of them were considered.

The mode of the EEG α -rhythm spectral power was determined for each testee at each EEG lead and when they (testees) were motionless and had their eyes closed. Its value was averaged for all the leads; the value obtained was considered as an individual α -frequency for each testee ($I\alpha F$, Hz) (Klimesch et al., 2007; Angelakis et al., 2004). Any average value of the index was calculated for all the men and women.

Conditional distribution of the sample was taken into account. The testees, having the value of $I\alpha F$ less than average, belonged to the group of testees with a low $I\alpha F$. The testees, having value of $I\alpha F$ higher than average, joined the group of testees with a high $I\alpha F$, and additionally, the level of the value sustainability of the EEG individual α -frequency was identified for ten testees in quiescent intervals and according to the indicators of human memory registered in different days.

The EEG frequency interval limits were determined individually, relying on the value of the testee's $I\alpha F$. The following algorithm (Angelakis et al., 2004; Klimesch et al., 2007) was used and the truth of which was that the upper limit of $\alpha 3$ -subband was set to the right side of the $I\alpha F$ in increments of 2 Hz. It corresponded to the lower limit of the $\beta 1$ -band. The upper limit of the $\beta 1$ -sub-band was defined according to the standard concepts as 25 Hz. The lower limit of the $\alpha 2$ -band was determined in steps of 2 Hz to the left of the peak, and the $\alpha 1$ -band in 4 Hz steps, as well as θ -frequencies – in 6 Hz. Limits of $\beta 2$ - and γ -bands were recognized as standard, properly, 26–35 Hz and 36–45 Hz.

Statistical analyses. A statistical data analysis was performed by using the package Statistica 6.0 (Stat-Soft, 2001). Any normalcy of the data distribution in testees' subgroups was evaluated by means of the Shapiro-Wilks test (indicator SW). Since the distributions of our data were usually normal, we calculated the average values (M), standard deviation (σ) and error of average value ($\pm m$). $M \pm m$ is specified in the text and tables. To estimate the significance of differences existing in testees' subgroups, the Student's t -test was used between steps of testing both for independent equal samples and for dependent samples. Differences between testees' subgroups and among steps of testing were statistically considered significant at $P < 0.05$ and $P < 0.01$.

Results

The individual modal frequency evaluation of the α -EEG activity and individual limits of the frequency content of the EEG sub-range in the findings for female testees. The average value of the modal frequency of any α -activity in samples of female testees was 10.25 ± 0.03 Hz. Considering the leveled

nature of the individual α -frequency value histogram (Fig.1) in the female testees, the conditional distribution of samples was made under the average mean of the modal frequency of α -

activity. Two groups were formed, in particular, groups having a high value of $I\alpha F$ ($n = 59$, $I\alpha F \geq 10.25$ Hz) and groups with a low value of $I\alpha F$ ($n = 54$, $I\alpha F < 10.25$ Hz).

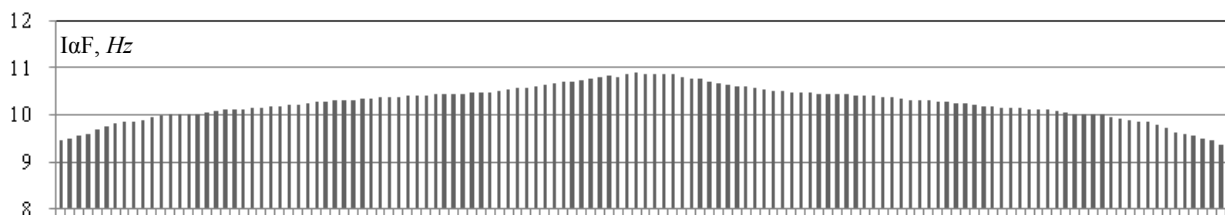


Fig. 1. Histogram of values of α -frequency mode in female testees:
vertical columns – individual values of the EEG α -frequency mode in samples involving female testees

Features of the output speed characteristics of the nervous processes in women with high and low $I\alpha F$. Women with a high $I\alpha F$ showed a shorter time for simple and complex reactions (Table).

Changes in spectral power while performing alternate finger movements in the testees' groups. Some decrease in the spectral power of the EEG especially in the posterior cortical areas, in $\alpha 2$ - ($P < 0.05$) and $\alpha 3$ -subranges ($P < 0.05 - < 0.01$) in comparison with the state of immobility (Fig. 2) was recorded in both female groups.

Table
Results of psycho-physiological tests characterizing time of simple and complex sensor and motor reactions in women

Value	Women	
	with high $I\alpha F$	with low $I\alpha F$
Simple Reaction Time, <i>ms</i>	253.4 ± 6.5	$322.5 \pm 6.6^{**}$
Selection Reaction Time, <i>ms</i>	378.3 ± 8.7	$435.7 \pm 9.4^{**}$

Note: ** – indicators of significant differences between the groups of the testees with a high and low $I\alpha F$, $P < 0.01$.

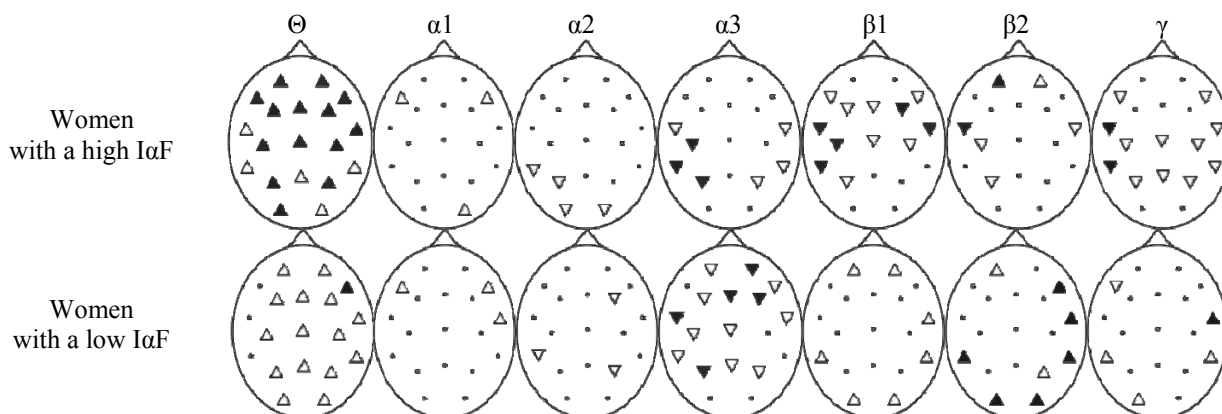


Fig. 2. Topo maps of changes in EEG spectral power fluctuations while performing alternate finger movements by female subgroups: Δ , \blacktriangle , ∇ , \blacktriangledown – increase (decrease) of power compared to power in a quiescent state, $P < 0.05$ (white triangle), $P < 0.01$ (black triangle)

Furthermore, women with higher $I\alpha F$ had the reduced spectral power of the $\beta 1$ - and γ -activities in the frontal, temporal and central areas of the cortex ($P < 0.05 - < 0.01$) compared to the state of immobility. Against the background of such changes in both female groups, there was found a generalized growth of spectral power of the EEG θ -oscillations ($P < 0.05 - < 0.01$). Such changes of the PS of the θ -activity were less significant ($P < 0.05$) in women with lower $I\alpha F$. The increase in spectral power of the $\alpha 1$ - and $\beta 2$ -activities ($P < 0.05$) was registered in the frontal areas (Fig. 2). Women with lower $I\alpha F$ had more generalized growth of β - and γ -activities and their power in the cortex ($P < 0.05 - < 0.01$).

Intergroup Differences. Women with lower $I\alpha F$ performing alternating movements with their right hand fingers had a higher θ -, $\alpha 1$ -, $\alpha 2$ - PS ($P < 0.01$) generally in the cortex, and $\alpha 3$ -, β - and γ -activities ($P < 0.05$) – in the posterior areas than women with higher $I\alpha F$. Instead of it, relatively low

EEG spectral power (Fig. 3) was registered in the frontal leads of the $\alpha 3$ -, β - and γ -oscillations ($P < 0.05 - < 0.01$).

Discussion

The aim of our study was to determine the characteristics of the EEG spectral power during the performance of successive movements by fingers of women with higher and lower modal frequencies of the EEG α -rhythm while taking into account the prognostic value of the relevant information in the speed of nervous processes.

Features of the output speed characteristics of the nervous processes in women indicate the higher speed capabilities of nervous processes in women with higher $I\alpha F$ compared with those with lower $I\alpha F$.

The implementation of the alternating movements by the right (dominant) hand was accompanied by a decrease of the

EEG spectral power in both groups of women, especially in the posterior cortical areas, in $\alpha 2$ - and $\alpha 3$ -subranges compared to the state of immobility. In our opinion and according to Buzsáki et al. (2006) Tebenova (2009), these effects may reflect the increase of activity in the cortical areas involved in the processes of sensory analysis, sensory-spatial attention, and the motor programming. At the same time, women with higher I α F had a reduction of the spectral power of the $\beta 1$ - and γ -activity in the frontal, temporal and central areas of the

cortex compared to the state of immobility. According to some authors, high-frequency electrical activity is modulated by the brain stem structures of the cortex, particularly the reticular formation (Revest et al., 1994; Boldyreva et al., 2000; Razumnikova et al., 2009). The latter creates a non-specific activation impact on the cortical processes and causes some high expression of EEG components. So, obviously, the pattern established by us is a manifestation of a certain decrease in the non-specific activation processes in this group of testees.

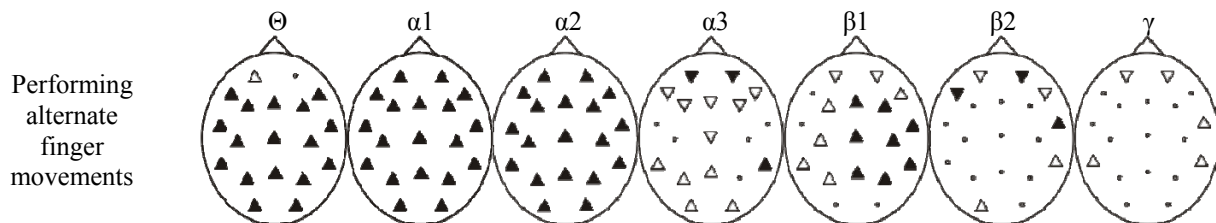


Fig. 3. Intergroup differences in spectral power of EEG fluctuations during performance of alternate finger movements by female subgroups: Δ , \blacktriangle , ∇ , \blacktriangledown – higher (lower) power in women with a low I α F in comparison with women with a high I α F, $P < 0.05$ (white triangle), $P < 0.01$ (black triangle)

Against the background of these changes, a generalized growth of the PS of the EEG θ -oscillations was revealed in women from both groups. According to scientists (Boldyreva et al., 2000; Pavlovych et al., 2012), it can be interpreted as a correlate strengthening of the emotional and motivational backgrounds being modulated by the limbic system. It should be emphasized that women with lower I α F had spectral power changes in the θ -activity of less significance. According to data from the literature (Klimesch et al., 2007), the increment in the $\alpha 1$ - and $\beta 2$ -activity of the frontal areas in all the women may reflect, on the one hand, the updating processes of the memory which allow a person to keep the necessary focus of sensory and motor information and manipulate it, but on the other hand, the increase in the power of $\alpha 1$ -oscillations in the frontal area ($P < 0.05$), may be associated with the increased selective attention as a mechanism to facilitate functioning of the active cortical structures. A more generalized growth capacity of the β - and γ -activity was recorded in the cortexes of women with lower I α F, which may be a nonspecific correlate enhancing the cortical activity (Pulvermuller et al., 1997).

According to sources in the literature (Klimesch et al., 2007; Razumnikova et al., 2009), higher θ -capacity and lower α -activity is associated with some decrease in the state of the readiness and maintenance of some attention and the decrease of the $\alpha 3$ -, β - and γ -oscillations in the frontal areas – with the organization of specific forms of attention necessary for higher cognitive functions. Then, the differences found by us in EEG frequency components of power between the groups of testees may indicate the status regarding a lower specific cortical tone, its readiness for any activity and control of information processes in testees with lower I α F compared with those testees with higher I α F. At the same time, higher PS in the posterior cortical areas in the high frequency ranges of the EEG ($\alpha 3$ -, β - and γ -) may indicate a predominance of the non-specific activation patterns in the reaction of encephalic processes (Pulvermuller et al., 1997; Boldyreva et al., 2000; Morenko et al., 2014).

Conclusions

The theoretical generalization of research results makes it possible to outline the features of the brain processes that were observed during the execution of successive finger movements initiated by the sensory signals in people with different modal frequencies of α -rhythm. Alternate female finger movements were accompanied by a decrease in the EEG $\alpha 2$ - and $\alpha 3$ -activities in the posterior cortical areas, and $\beta 1$ - and γ -activities in the frontal, temporal and central areas of the cortex compared with the same in the immobile state; they were also characterized by the generalized growth of θ -oscillations and local (in the frontal leads) – $\alpha 1$ - and $\beta 2$ -activities. Thus, in both groups of women surveyed an increase in activity of those cortical structures that ensure its implementation – sensory perception, motor start and motor programming commands and a sense-motor coordination, was found. When MM were performed by women with higher output α -frequency, they were characterized by more local changes in the electrical activity of the cerebral cortex. People with lower modal α -frequency were characterized by somewhat less specific and differentiated features of the cortex activation. Alternating movements of fingers performed by women with lower I α F were associated with higher EEG θ -, $\alpha 1$ -, $\alpha 2$ -activities, generally in the cortex, and $\alpha 3$ -, β - and γ -oscillations – in the posterior areas than in those with higher I α F. Instead of this, a relatively lower power spectral EEG was recorded in the frontal leads of the range consisting of $\alpha 3$ -, β - and γ -oscillations. Intergroup differences found by us may indicate a higher status regarding a specific cortical tone, its readiness for activity and control of information processes in people with higher I α F in comparison with those who had lower I α F.

A different level of features of such activation systems is natural for achievement of specific outcomes in testees with a different starting I α F. Women with higher I α F had better speed characteristics of nervous processes.

The results of the study indicate that the value of a female α -frequency mode determined in the state of the immobility may have a prognostic value with regard to the reaction of cortical processes during performance of alternating movements by the fingers.

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