FEATURES OF THE CORTICAL ACTIVITY OF MEN HAVING A HIGH OR LOW ALPHA-FREQUENCY BACKGROUND OF THE EEG WHILE PERFORMING ALTERNATE FINGER MOVEMENTS

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Summary: The purpose of this paper is to identify the cerebral electrical activity features in men with a high or low α-frequency background while performing the alternate finger movements. A test group consisting of 104 healthy men from the ages of 19 to 21 was divided into two groups according to the magnitude of their individual α- frequency (IAF) median – groups with high (n = 53, IAF ≥ 10,04 Hz) and low (n = 51, IAF ≤ 10,03 Hz) levels of IAF. Changes in power and the coherence of the EEG oscillations during the alternate finger movements as well as intergroup differences were evaluated. Men with high a IAF are distinguished by higher rates of speed and accuracy in terms of their sensory-motor response. The role of inhibitory neural processes increases in the case of men whose frequencies are low. The implementation of alternating finger movements in male groups is accompanied by a decrease in the coherence of θ-, α1-, α3- EEG oscillations in the cortex in general, β- and γ-activity - in the rear temporal and occipital areas. In the frontal and central lobes of α2-, β- and γ- ranges an increase in EEG coherence fluctuations was observed. The power of θ-, α- and β1- waves, especially in the posterior cortex areas, decreases. A larger degree of low-frequency fluctuations in EEG power can be observed in the frontal area. Thus, more economical brain processes providing the processing of any sensory or motor information in men with a high IAF determine higher levels of the speed and accuracy of their sensorimotor responses. Men with a low IAF have lower ductility but a higher voltage of brain processes correlated with a decrease in the sensorimotor response of speed capabilities increasing the role of inhibitory effects.

Key words: power, coherency, electroencephalogram, individual alpha-frequency, alternate movements by fingers

Introduction

Human functional capabilities largely depend upon the genetic qualities of person's nervous system. A direct reflection of the human nervous system individual characteristics is human brain activities where the electroencephalogram (EEG) is its integrative characteristics. It shows the activities of many neuronal groups primarily resulting in the manifestation of the background electrical activity (Begleite et al., 2006; Van Beijsterveldt et al., 2002). It is believed that the spontaneous cortical electrical activity is determined by genetically grounded characteristics of the brain structural and functional organization. It is also clear that features of the structural and functional organization of the brain underline individual differences and functional abilities. It turned out that the most informative frequency among various parameters of the background of the EEG belongs to the maximum peak of EEG α-rhythm (Anokhin et al., 2006; Hooper 2005). Various α-sub-bands are differed by the specific brain generators, functional significance, and varying degrees related to the major systems of the brain activation (Klimesch et al., 2007). A low or high range of the α-rhythm superiority in the background encephalogram of the person can cause his/ her psychomotor and cognitive abilities (Doppelmayr et al., 2005; Hyde 2005).

Simultaneously, it has been found a lack of information about detected features of the central programming in men with the different individual α-frequency while performing manual movements. Existing data, despite their importance, are inconsistent and insufficient yet.

In view of this, the main goal of our research is to elucidate issues answering the question how the function of the cerebral cortex is changed in men with a different output individual α-frequency under the influence of alternative movements in response to special signals. This issue is urgent and has not only the theoretical importance but also obvious practical application as it concerns fundamental matters affecting the neuro-physiological purposeful human hand movements. The alternative movements of fingers used in our study as a motor load are the most commonly using manual movements by a person and playing a significant role in the person's day-to-day life,

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training, operator performance and production activities. The elucidations of the EEG prognostic criteria and their successful implementation have become increasingly important in case of the electronic engineering significance in people's public life, particularly, in the practice of the distance manual control and its evolution.

The aim

The purpose of this paper is to identify the cerebral electrical activity features in men with a high or low α-frequency background while performing the alternate finger movements.

Materials and methods

Participants

The participants in our study were 124 male volunteers from the ages of 19 to 21, each of whom has 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 healthy and had normal hearing with regard to the judgment and advisory conclusions of their medical professionals.

Procedure

Psychophysiological examination

As part of the psychophysiological testing for each subject was determined profile of manual and auditory asymmetry. It 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).

Formula 1

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

where Σ_{right} – the amount of tasks where a right hand (right ear) is dominating during their execution, Σ_{left} – the amount 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 men was of 104 people.

The level of psychodynamic properties of testees' nervous processes were 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 with pressing the button by the right hand. Men evaluated and measured time intervals in minutes.

All examinations were performed in the morning. The profile of the asymmetry and psychodynamic properties of neural processes was evaluated 30 minutes before the EEG recording registration. It made impossible to influence on 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 the edge effects, the EEG recording registration was started at 15 s after the beginning and had been stopped at 5 s by its completion.

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

Movements of each finger were in its bending and unbending. Each finger flexion or extension was performed by the testees in response to the sound. The electronic version of the 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 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 for each testee to achieve the necessary level. The rate of the sound stimuli delivery was 2 Hz.

Registration and primary analysis of EEG data

Active electrodes were placed in accordance with the international system 10/20 in 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.

Both the power (μV^2) and the coherence 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 power and coherence of each of them were considered, and coefficients of coherence (Coh) above 0.5 were analyzed as well.

The maximum frequency peak of the α-rhythm was determined for each testee in each EEG lead at a functional balance (Klimesch et al., 2007). Its value was averaged for all leads and the obtained values were considered as the testee's individual α-frequency (the individual alpha-frequency of EEG, IAF, and Hz). The IAF median was also determined and calculated for the group of men. It was 10.04 Hz. Thus, there were formed subgroups of testees in according to the value of the median:

- subgroup with a high IAF ($n = 53$, IAF ≥ 10.04 Hz);
- subgroup with a low IAF ($n = 51$, IAF < 10.04 Hz).

The EEG frequency interval limits were determined individually, relying on the value of the testee's IAF. The following algorithm (Klimesch et al., 2007) was used and the truth of which was that the upper limit of α3-subband was set to the right side of the IAF in increments of 2 Hz. It corresponded to the lower limit of the β1-band. The upper limit of the β1-sub-band was defined according to the standard concepts as 25 Hz. The lower limit of the α2-band was determined in steps of 2 Hz to the left of the peak, and the α1- band in 4-Hz steps, as well as θ-frequencies – in 6 Hz. Limits of β2- and γ-bands were recognized as standard, properly, 26 – 35 Hz and 36-45 Hz.

The resulting individual values of the power and coherence of EEG oscillations within the selected groups of men were averaged for each lead.

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). Based on test results, it was found that all of our studied samples had a normal data distribution. To estimate the significance of differences existing in testees' subgroups, the Student's t-test (index t) was used between steps of testing both for independent equal samples and for dependent samples. Significant differences between testees' subgroups and among steps of testing were statistically considered at $p \leq 0.05$ and $p \leq 0.001$.

Results

Psychodynamic properties of neural processes in the testees' groups with different levels of IAF

The testees with a high IAF spend less time both for a simple sensorimotor coordination and any choice reaction ($p \leq 0.001$) (table 1) . The analysis and evaluation of metering minute time intervals indicate that the testees having a high IAF are characterized by more accurate estimation of time (table 2) than others. Moreover, men with a low IAF have relatively higher overestimation as well as incompletely measured timeslots. Simple with Choice Sensorimotor Reaction Latency and Estimation and Constant Time-Step Advancement in Minutes in Testees' Subgroups is shown in table 1, table 2.

Table 1. Simple with Choice Sensorimotor Reaction Latency in the Surveyed Subgroups (sec)

	Subgroups	Mean±SD
Simple reaction time	Men with a high IAF	232.35±5.15
	Men with a low IAF	299.21±6.40^^
Choice reaction time	Men with a high IAF	334.82±7.19
	Men with a low IAF	399.9±15.29^^

own study

Note to Tables 1 and 2:

^ ^^ – differences between subgroups of men, $p \leq 0.05$ and $p \leq 0.001$.

Table 2. Estimation and Constant Time-Step Advancement in Minutes in Testees' Subgroups

	Subgroups	Mean, %
Overestimation of measured timeslots	Men with a high IAF	14.60
	Men with a low IAF	24.00
Accurate estimation of measured timeslots	Men with a high IAF	65.40
	Men with a low IAF	56.00
Underestimation of measured timeslots	Men with a high IAF	20.00
	Men with a low IAF	20.00

own study

Changes in the electrical activity of the cortex while performing the alternate movements by fingers of men with a high or a low output IAF

The increasing power of θ-, α1-and β2-waves of the EEG in the frontal area as well as γ-activity - generally in the cortex ($p \leq 0.05$, $p \leq 0.001$) was observed *in men having a high IAF* and performing the alternate movements by fingers rather than in quiescent state. Moreover, the recorded relative depression of EEG oscillations was seen in the parietal-occipital and posterior temporal areas, particularly, in the left hemisphere, and in the θ-and α1-sub-bands, or in the α2-, α3-and β1-bands ($p \leq 0.05$, $p \leq 0.001$) – generally in the cortex. These power changes in the electrical activity of the cortex are accompanied by the desynchronization of θ-, α1, α3-waves of the EEG oscillations in the cortex ($p \leq 0.05$), as well as β-and γ-waves – in the back temporal, parietal and occipital lobes ($p \leq 0.05$, $p \leq 0.001$). Furthermore, a comparatively increase value of the α2-subband coherence was registered in the frontal and central, right anterior temporal and left parietal areas ($p \leq 0.05$, $p \leq 0.001$), and β1-activity – in the central area ($p \leq 0.05$), β2 waves - in the frontal and central-parietal areas ($p \leq 0.05$, $p \leq 0.001$), and γ-rhythm - in front of the frontal area of the cortex ($p \leq 0.05$). Changes in power and coherence of EEG oscillations in the cortex of men with a high IAF during the alternate finger movements are in Fig. 1.

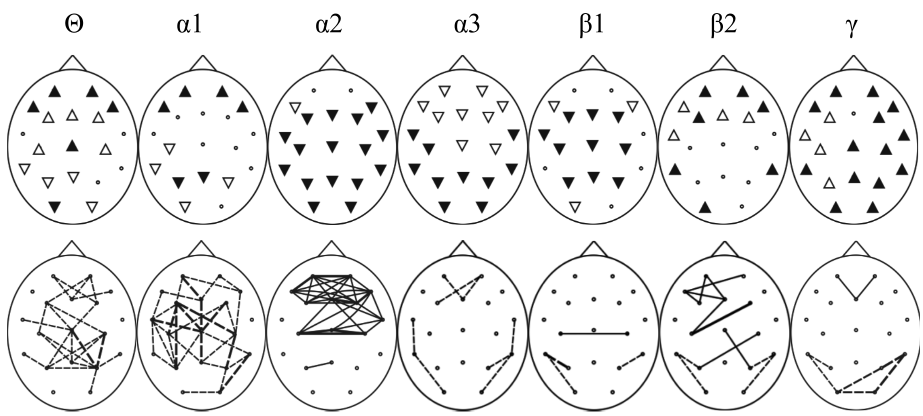

Figure 1. Changes in power and coherence of EEG oscillations in men having a high level of IAF during the alternate finger movements

own study

Notes to Fig.1-2:

1) △▽▲▼ increase (decrease) of power, $p \leq 0.05$, $p \leq 0.001$,

2) ═ (- - -) increase (decrease) of coherence, $p \leq 0.05$, $p \leq 0.001$.

The alternate finger movements performed by men having the low IAF are accompanied by a comparable growth of power in θ-, α1-, α3-waves of the EEG oscillations in the frontal area, β2-and γ-waves – generally, in the cortex ($p \le 0.05$, $p \le 0.001$) compared with rest. However, a relative decline was fixed in the temporal and posterior parietal-occipital parts of θ-, α1-and α3-bands, generally, in the cortex - the α2-and β1-subbands ($p \le 0.05$, $p \le 0.001$). Under these conditions, some decrease was seen in the coherence values of θ-and α1-waves of EEG oscillations in the cortex ($p \le 0.05$, $p \le 0.001$), α2-, α3-and β1-and γ-waves - in the temporal and parietal area ($p \le 0.05$), predominantly, in the right hemisphere, compared to the background. Instead of it, the relative intensification was observed in the coherence of α2-, α3-, β-and γ-frequencies of the EEG activity in the anterior, central and temporal areas of the cortex ($p \le 0.05$, $p \le 0.001$). Changes in power and coherence of EEG oscillations in the cortex in men with a low IAF during the performance of alternate finger movements is shown in Fig. 2.

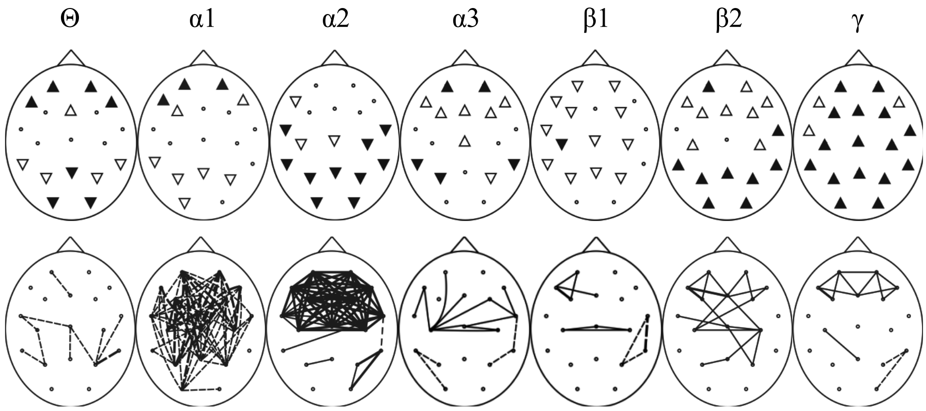

Figure 2. Changes in power and coherence of EEG oscillations in men having a low levels of IAF during the alternate finger movements
own study

Differences in power and coherence of EEG oscillations between subgroups of men

Men with a low IAF belonging to this subgroup are characterized by a higher power of θ-, α-and β1-waves ($p \le 0.05$, $p \le 0.001$) in their cortex than men having a high IAF. Meanwhile, a relatively lower power is observed in α1-, β-and γ-bands ($p \le 0.05$, $p \le 0.001$), especially in the frontal area. Men with a low IAF have relatively higher EEG coherence oscillations in the cortex ($p \le 0.05$). The significance of these differences is increased in the frontal area of the cortex ($p \le 0.05$, $p \le 0.001$). Differences in power and coherence of the EEG oscillations between subgroups of men are presented in Fig. 3.

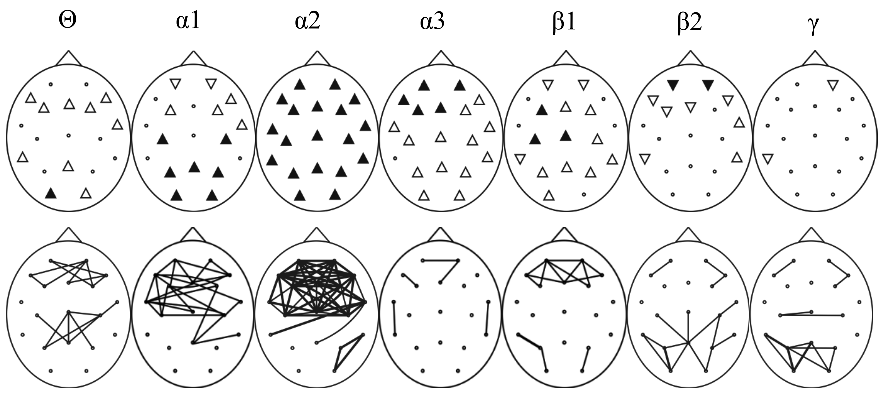

Figure 3. Differences in the EEG frequency power between male subgroups during alternate finger movements
own study

Notes to Fig.3:

1) △▽▲▼ higher (lower) rates in men with a low IAF level, $p \le 0.05$, $p \le 0.001$,

2) ══ (╌╌) rates in men with a low IAF level, $p \le 0.05$, $p \le 0.001$.

Discussion and conclusions

Psychodynamic properties of nervous processes in men with a high or low background IAF

Any analysis of the brain activity during the alternate movements performed with fingers requires a delineation and consideration of psychodynamic properties of the nervous system in men with different levels of the IAF.

Testees with a high IAF are characterized by a higher speed performance of the neuro-motor apparatus in terms of both simple sensorimotor and choice reactions requiring the involvement of associative processes, re-encoding of information, and complex inter-system interactions. Men of this subgroup are also characterized by a more accurate estimation of time, which may indicate an increase in balance of nervous processes of the excitation and inhibition (Bushov et al., 2003). Long-term observations of researcher that was made by Portnova et al. (Portnova et al., 2010) show a direct correlation between the perception of time and the activities: the more accurate perception of time, the more successful activities are. Men with a low IAF have relatively higher rates of the overestimation and incompletely measured minute intervals. Thus, it may indicate a predominance of neural inhibitory processes. Aforesaid psychodynamic features of nervous system caused by the prevalence of low or high α-frequency rhythm in the background EEG made an impact on the electrical activity of the cortex while performing the alternate finger movements.

Features of the cortical activity while performing the alternate movements of fingers in subjects having a different IAF

The phenomenon of the spatial desynchronization occurred in the θ-, α1-, α3- frequencies of the EEG bands in the whole cortex, and in the β-and γ-frequencies – in the back temporal and occipital areas is an important aspect of brain processes during the alternate finger movements performed by men having a high IAF. These changes may reflect a decrease in the functional state of the cortex (Klimash et al., 2010). We think this reduction may be caused by conditional nonspecific activating influences of the reticular formation both on the cortex, and the septum which generates low-frequency EEG oscillations (Klimash et al., 2010). However, those brain structures directly guaranteeing the implementation of activities are supported at high levels of activity. The increased coherence of EEG α2-, β-and γ-waves in the frontal and central lobes, a depressed electrical activity of the cortex in the range of θ-, α-and β1-oscillations, especially in the posterior cortex became the evidence of it. In our opinion and according to the literature (Buzsáki 2006; Tebenova 2009), these phenomena may reflect an increase in the interaction of cortical areas involved in the processes of sensory analysis, motor programming and integration of sensory and motor information. An increase diffusivity of changes in the range of α2-, α3-and β1-waves of the EEG may indicate a weighty enhance of the sensory-spatial attention. The phenomenon of the dual semispherical spatial-frequency synchronization of any activity in the frontal and central lobes of its simultaneous desynchronization primarily in temporal and posterior occipital areas of the cortex attracts attention. It should be noted that the effects of simultaneous alpha synchronization and desynchronization in the anterior posterior cortical areas are observed while carrying out some cognitive tasks (Pfurtscheller et al., 1999). Based on these data the spatial processes of the β-and γ-synchronization found in men with a high IAF and α3-, β-and γ-synchronization found in men having the low IAF may indicate the role of the integrative processes and mental tensions during the formation of motor commands. Simultaneously, the asymmetric desynchronization in posterior temporal and occipital areas apparently reflects to the reciprocal changes in the focus of the attention – from processing of sensory stimuli to the process of programming movements in the frontal and central areas. The frontal expression of θ-, α1-waves is a consequence of the increased frontal thalamic feedback effects (Klimesh et al., 2007) it is likely to increase the selectivity of any voluntary attention and updating the memory trace. A diffuse increase of power in β2-and γ-oscillations occurred in the cortex can display the interface of widely distributed neural networks involved in sensorimotor integration (Pulvermuller et al., 1997).

Changes of the EEG power and coherence found in men with a high IAF are generally observed in men with a low IAF too. However, the phenomenon of the spatial synchronization in α2-, α3-, β-and γ-sub-bands are more important. Thus, the conditions for a compensatory relief of the excitation and its spread among different nodes of structural and functional systems of the perception (Zhavoronkova 2009) are created under these conditions. Such changes may be indicative as to a greater stress in brain processes modeled under the nonspecific effects of the reticular formation (Knipst et al., 1982). The observed power increase in α3-waves of the frontal zone may reflect on additional braking mechanisms of sensory input and activity of thalamocortical neural feedback loops (Klimesh et al., 2007). According to Ioffe (Ioffe 2003), the program including two components: a picture of the new coordination and a drawing of specialized downstream impacts was formed in the performance of unusual movements in the motor cortex. Under these conditions, a local synchronization of α3-activity found by us may be the EEG correlation in the mapping process to compare any afferent information flow and new parameters of the muscles with descending impulses from the frontal cortex of the previous motor program. Such descending inhibitory influences on the course of unusual movements interfere in the implementation of new coordination

(Ioffe 2003), and according to Kostandov (Kostandov 2010), they indicate a lower ductility of the set. Apparently, such specific cortical dynamic processes indicate a greater subjective difficulty of the task to men in this group, most inhibitions of nervous processes and the need to involve additional mechanisms assisting in information processing for its implementation during activities. Obtained results are correlated with our data (Korsakova et al., 1995) as to the decrease of thalamic projections to the cortex reduces its specific activation and selectivity as well as plasticity and nervous processes.

Defined power and coherence changes in subgroups of men are generally justified by testing conditions, which put forward higher requirements for facilities of the surveyed to efficiently allocate attention between the sensory perception and motor response as well as rebuild a motor program as a result of the inclusion of work performed by different muscles of various fingers. Identified cortical activation processes may be also associated with overcoming of the motor command disorganization in case of a less stereotyped experimental task.

Differences in power and coherence of the EEG oscillations between subgroups of men during the alternate finger movements generally showed higher levels of expression and spatial synchronization of EEG oscillations in the cortex of men having a low IAF. These patterns may reflect the higher voltage level of brain processes (Knipst et al., 1982) modulated by tonic effects of nonspecific brain systems: the limbic system – in the low-frequency range and the reticular formation – in the high frequency band of the EEG (Pulvermuller et al., 1997; Buzsáki 2006). A lower α1-, β-and γ-power in the frontal area can be the indicator of a lower level of specific attention providing the control under information and abstract thought processes in men with a low IAF.

Thus, the performance of alternate movements of fingers in subgroups of men is accompanied by a certain decrease in the functional state of the cortex as the general trends caused by the conditional reduction of nonspecific reticular formation impacts both on the cortex and the septum, which generates low-frequency EEG oscillations. Simultaneously, cortical areas being directly involved in the processes of the sensory perception, sensory-spatial attention, motor programming and sensorimotor integration are supported at high levels of activity. The frontal EEG expression of low-frequency vibrations provided with a feedback of the frontal and thalamic influences probably increases the selectivity of the voluntary attention and updating the memory trace. The observed spatial synchronization of high-frequency EEG oscillations in the frontal and central lobes of the cortex and simultaneous desynchronization in posterior may be mechanisms of the reciprocal change of the focus on the process of programming and running of motor commands rather than on processing of sensory stimuli.

The detected cortical activities have specific features in men with high and low background IAFs and are closely related to psychodynamic properties of nervous processes. More economical brain processes providing the sensory and motor information processing in men with a high IAF determine the best performance of some speed and accuracy of their sensory-motor responses. Men with a low IAF have a lower ductility but a higher voltage of brain processes; need to involve additional mechanisms of information processing correlating with decreased sensorimotor speed capabilities in response, and increasing the role of inhibitory effects.

We are of the opinion that the establishment of such common factors in the studied subgroups is an important step towards the release of the clear prognostic criteria for the functionality of men in the fine motor area according to the EEG.

Conclusions

1. Men with high a IAF are distinguished by higher rates of speed and accuracy in terms of their sensory-motor response. The role of inhibitory neural processes increases in the case of men whose frequencies are low.
2. The implementation of alternating finger movements in male subgroups is accompanied by a decrease in the coherence of θ-, α1-, α3- EEG oscillations in the cortex in general , β- and γ- activity - in the rear temporal and occipital areas. In the frontal and central lobes of α2-, β- and γ- ranges an increase in EEG coherence fluctuations was observed.
3. The power of θ-, α- and β1- waves, especially in the posterior cortex areas, decreases during periods of alternating finger movements in male subgroups. A larger degree of low-frequency fluctuations in EEG power can be observed in the frontal area.
4. Men with a low IAF are characterized by higher power and coherence in their EEG oscillations over a wide frequency spectrum in the cortex area than men with high IAF . In the frontal area a relatively lower capacity of α1-, β- and γ- ranges is demonstrated in the case of men with low-frequency AIF.

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