

Brain processes during the perception of sensory signals in men with high and low output α -frequencies

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KEY WORDS

Electrical activity
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ABSTRACT

Background: Human functional capabilities largely depend upon genetic qualities of person's nervous system. The registration of the spontaneous electroencephalogram (EEG) is among the physiological techniques allowing making a direct estimation of specific features of the nervous system, in particular, the human brain activity. **Purpose:** The study is devoted to the investigation of brain processes in men with high and low levels of individual α -frequency determined in a quiescent state during the perception of sensory signals. **Methods:** A test group consisting of 104 right-hand 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 ($n = 53$, $IA \geq 10,04$ Hz) and low ($n = 51$, $IAF \leq 10,03$ Hz) levels of IAF. The power and coherence of the electrical activity of the cerebral cortex as well as inter group differences were evaluated in a quiescent state and during the perception of sensory signals by Subjects. **Results:** A localized power increase of the EEG α 1-waves are registered in frontal areas, β 1, β 2- oscillations - in the anterior cortex, γ - activity - around the scalp and its decrease is present in the posterior temporal, parietal and occipital cortex leads, especially in the α - and β - frequency spectrum during the perception of sensory signals in men with a high IAF. The generalized depression of the θ -, α - and β - activity of the cortex is fixed in individuals with a low IAF while the expression of γ - waves is more local. The generalized increase of data in EEG coherence fluctuations throughout the frequency spectrum of the EEG in the cortex is set in all Subjects. The dextrocerebral preponderance is observable in posterior structures of the Subjects' right hemisphere. A localized decrease of the coherence concerning θ -, α 1-, α 3-, β - and γ - oscillations are traced in the frontal and anterior temporal areas of the left hemisphere. **Conclusion:** We are of the opinion that the establishment of such common factors in the studied groups is an important step towards the release of the clear prognostic criteria for the functionality of men in the sensory area according to the congenital features of brain function.

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Introduction

Any cerebral competence or sensory system capability of any person is critical for more and more jobs appearing in the modern world. A direct reflection of the individual characteristics of the brain is based on its background electrical activity. The nature of the spontaneous human electrical activity of the cortex is believed as genetically determined and grounded by features of the structural and functional organization of the brain.¹⁻³ An individual variability of the amplitude-frequency characteristics of the α (alpha) rhythm of the electroencephalogram (EEG), including the maximum α -rhythm frequency peak is the most informative for determining the state of the main physiological functions of a person among the various rhythms of the EEG background.¹⁻⁵ Different frequency bands of the α -rhythm generator have different brain generators and functional significance.⁶

Therefore, we suggest a hypothesis that the prevalence of high or low frequency ranges of the α -activity in the EEG background of man led to specific features of the brain processes in the perception of sensory signals.

Scientific community pays much attention to the analysis of electro physiological correlates of cortical processes during the sensory signals.¹⁻⁷ Previous studies indicate that¹⁻⁹ cortical potentials depend on the complexity of stimuli, sex, subjects' age, their individual experience in response to the auditory stimuli (tones, speech, etc.). However, it should be noted that the above features of the brain indicated by authors, despite their importance, are still insufficient for a comprehensive understanding of the individual characteristics of the human brain processes during the perception of sensory signals by subjects.

It provides an objective basis for more detailed studies of this phenomenon and for its individual typological characteristics.

The purpose of the study is to figure out how the perception of sensory signals alters a brain functioning in subjects with a high or low initial individual α -frequency.

Methods

The participants in our study were 124 male 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 Subjects were healthy and had normal hearing with regard to the judgment and advisory conclusions of their medical professionals.

Psychophysiological examination. As part of the psychophysiological testing for each subject was subjected to profiling of manual and auditory asymmetry. It is determined by the nature of responses in the survey, execution of the motor and psych-acoustic tests and counting the individual ratio of the manual and auditory asymmetries (K skew) (form. 1).¹⁰

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

where \sum_{right} – the amount of tasks where a right hand (right ear) is dominating during their execution, \sum_{left} – the amount of tasks under which the left hand (left ear) is dominant.

Further studies involved dextral subjects whose coefficients of manual and auditory asymmetries were positive and were above 50%. The total number of men were 104. All examinations were performed in the morning. The profile of the asymmetry and psycho dynamic properties of neural processes was evaluated 30 minutes before the EEG recording registration. It was impossible to influence the experiment, particularly, the EEG results.

EEG testing procedures. The subjects 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 during perception of sensory signals

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 electronic version of the drum battle (the software of Finale 2006) was used as the sensory signals. 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 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.⁶ 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 Subjects in according to the value of the median:

- subgroup with a high IAF ($n = 53$, $IAF \geq 10.04$ 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 algorithm⁶ was used and the truth of which was that the upper limit of $\alpha 3$ -subband was set to the right side of the IAF 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.

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 Subjects' 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 Subjects' subgroups, the Student's t -test (indicator t) was used between steps of testing both for independent equal samples and for dependent samples. Significant differences between Subjects' subgroups and among steps of testing were statistically considered at $p \leq 0.05$ and $p \leq 0.001$.

Results

Changes in power and coherence during the acoustic stimulation in the Subjects' groups. A localized power increase of the EEG $\alpha 1$ -waves is registered in frontal areas ($p \leq 0.05$), $\beta 1$ -, $\beta 2$ -oscillations - in the anterior cortex ($p \leq 0.05$, $p \leq 0.001$), γ - activity - throughout the scalp ($p \leq 0.001$) (Fig. 1) in men with a high IAF during the acoustic stimulation. The EEG power reduction is registered in the posterior temporal, parietal and occipital cortex leads ($p \leq 0.05$, $p \leq 0.001$) as well as in $\alpha 2$ - and $\alpha 3$ - sub bands and occipital areas ($p \leq 0.05$), and in the β - frequency spectrum. Individuals with a low IAF have a fixed and generalized depression of the θ -, α - and β - activity of the cortex ($p \leq 0.001$) in the cortex itself, and more local expression of γ - waves in the left frontal and anterior temporal areas ($p \leq 0.001$) (Fig. 1).

A generalized increase of the coherence magnitude of the EEG fluctuations occurs in the frequency spectrum of the EEG in the cortex ($p \leq 0.05$, $p \leq 0.001$) of all subjects' groups compared with these groups in a quiescent state (Fig. 2). The significance of changes was larger in the right hemisphere, particularly, in its posterior structures. A localized coherence decrease of $\alpha 3$ -, β - and γ -activity in men with a high IAF, as well as θ -, $\alpha 1$ -, $\alpha 3$ -, β - and γ -oscillations - in men with a low IAF are traced in the frontal and anterior temporal areas of the left hemisphere.

Intergroup differences. Men with a low IAF in a quiescent state are characterized by higher power θ - ($p \leq 0.05$), and by $\alpha 1$ - and $\alpha 2$ -oscillations ($p \leq 0.001$) of the EEG generally in the cortex, as well as by lower power - in the range of $\alpha 3$ -, β -, γ -frequencies in the frontal, central and temporal leads compared to the male subgroup with a high IAF (Fig. 3). Men with a low IAF had relatively higher coherence of the electrical activity in the whole frequency spectrum ($p \leq 0.05$). This feature takes on greater significance in the $\alpha 2$ - and $\alpha 3$ - bands in the frontal, temporal and central areas ($p \leq 0.05$, $p \leq 0.001$).

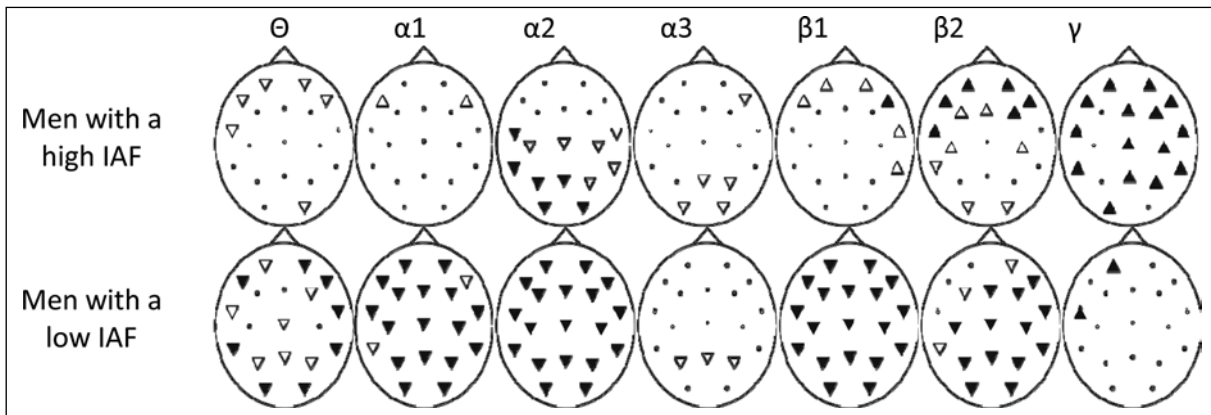


Fig. 1: Changes in EEG power fluctuations in the perception of sensory signals by male subgroups.
Note: 1) \blacktriangle \blacktriangledown \blacktriangledown increase (decrease) of power compared to power in a quiescent state, $p \leq 0.05$ (white triangle), $p \leq 0.001$ (black triangle).

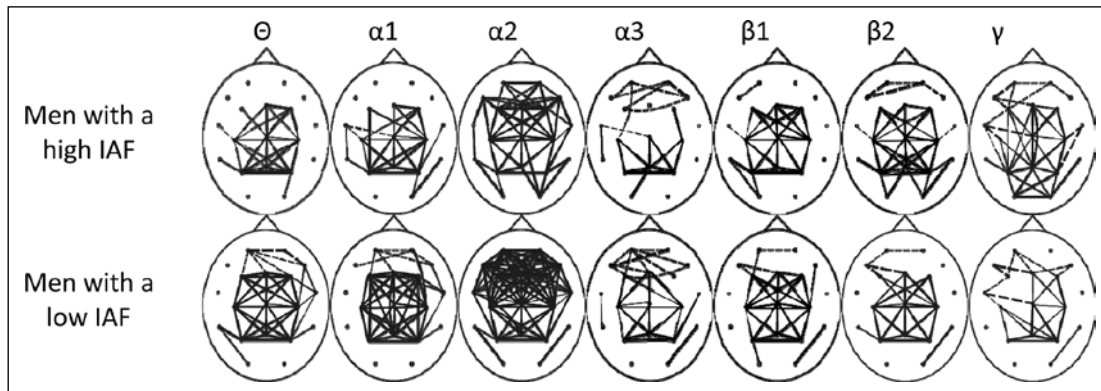


Fig. 2: Changes of EEG coherence oscillations in the perception of sensory signals by subgroups of men.
Note: 1) \Rightarrow (\Leftarrow) Increase (decrease) of the coherence compared with the coherence in a quiescent state, $p \leq 0.05$ (a thin line), $p \leq 0.001$ (a thick line).

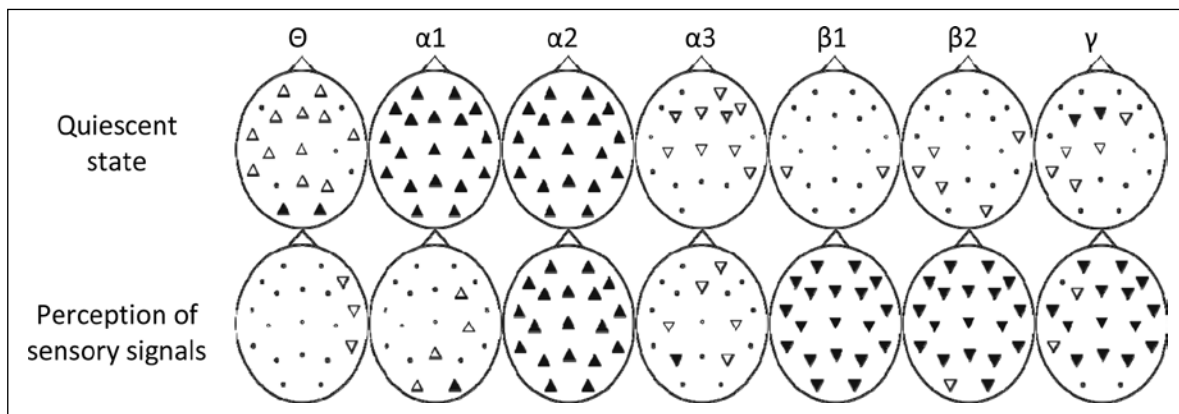


Fig. 3: Intergroup differences in power of EEG fluctuations in a quiescent state and during the acoustic stimulation.
Note: 1) \blacktriangle \blacktriangledown \blacktriangledown higher (lower) power in men with a low IAF in comparison with men with a high IAF, $p \leq 0.05$ (white triangle), $p \leq 0.001$ (black triangle).

The EEG power preponderance of α 1-activity is more observable in men with a low IAF in the Subjects' back right frontal, right central, parietal and occipital areas ($p \leq 0.05$) and α 2-waves - generally in their cortex ($p \leq 0.001$) during the acoustic stimulation than in men with a high α -frequency. However, relatively lower power of θ -, α 3-frequency ($p \leq 0.05$) was found

in patients with a low IAF. This feature is more significant in the range of β - and γ -activity and registered throughout the scalp ($p \leq 0.001$) (Fig. 3). Higher coherence of θ -, α 1- and α 2-EEG activity is observable in men with a low IAF in their frontal, temporal and central areas ($p \leq 0.05$, $p \leq 0.001$), α 3-, β 2- and γ -oscillations - in their temporal, parietal and central areas

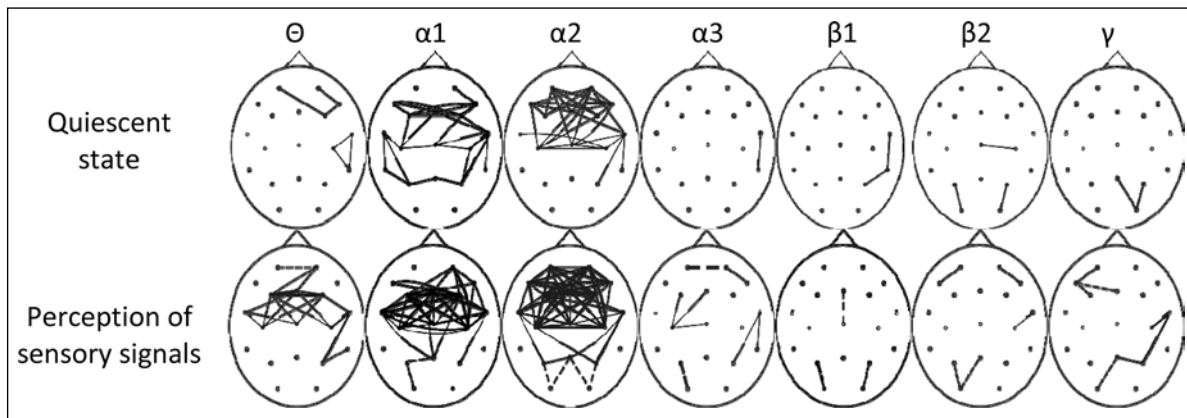


Fig. 4: Inter group differences in coherence of EEG fluctuations in a quiescent state and during the acoustic stimulation.
Note: 1) --- (---) higher (lower) coherence in men with a low IAF in comparison with men having a high IAF, $p \leq 0.05$ (a thin line), $p \leq 0.001$ (a thick line).

($p \leq 0.05$) than in those with a high α -frequency (Figure. 4). However, relatively lower coherence is in parietal and occipital areas of the EEG α -, β - and γ -band ($p \leq 0.05$), in front of the frontal leads - in θ -, $\alpha 3$ - and γ -frequencies ($p \leq 0.05$).

Discussion

Subjects with a high IAF are characterized by some lower EEG power of θ -, $\alpha 1$ -, $\alpha 2$ -waves and higher - $\alpha 3$ -, β - and γ -waves being in a quiescent state than those with a low IAF. According to the literary sources¹¹⁻¹³ the decrease of power of θ - and low α -activity is associated with the state of readiness and maintenance of attention whilst the expression of $\alpha 3$ -, β - and γ -oscillations – with the organization of specific forms of attention required to ensure higher cognitive functions. Thus defined differences in the level of the EEG power frequency band among the groups of Subjects may indicate the status of relatively higher activation tone of the cortex and its readiness to any activity and control of information processes in individuals with a high IAF.

These intergroup differences in power of the electrical activity of the cortex complement relatively higher levels of the coherence, especially in frontal, temporal and central areas of the cortex in men with a low IAF.

It may create conditions for compensatory relief in case of the excitation spread between the individual “nodes of the structural and functional system of the perception” against the background of the lower crust in the functional state of the examined groups.¹⁴ The functional meaning of this type of the spatial synchronization in the cortex is associated with higher levels of stress in brain processes¹⁵⁻¹⁶ modulating by the increasing tonic influence of such brain structures as the limbic system (in the low-frequency range) and the reticular formation (in the band of the high EEG frequency).

The spectral analysis of the EEG power fluctuations during the acoustic stimulation in groups of Subjects detects a unidirectional blocking of θ -, α - and β -EEG activity in the cortex, resulting in active processes of the sensory processing and the increase attention to the external afference ($p \leq 0.05$ $p \leq 0.001$).¹⁷ The localization of the activation changes mostly in the parietal and occipital areas in men with a high IAF is a reflection of the sensory-spatial analysis of stimulus identification¹⁵⁻¹⁸. More

diffuse and significant depression of EEG oscillations in the cortex of Subjects with a low IAF is the evidence of greater role of the nonspecific activating effects. According to P. A. Revest et al.¹⁴, wide areas of the cortex included into the reaction may be an extensive reticulo - cortical activation type of the CNS.

The analysis of the coherent relations of the EEG oscillations in the EEG frequency spectrum highlights a generalized increase in all Subjects' cortex. The significance of changes in the posterior temporal, parietal and occipital areas is greater in the right hemisphere, which probably reflects the holistic nature of the analysis of the Subjects' sensory stimulation. According to literature an increase in a spatial synchronization of EEG oscillations established under these conditions in the cortex creates favorable conditions for the spread of the excitation in the cortex during the processing of sensory information.¹¹⁻¹⁴

The localized increase of power and reduction of coherence was registered in the frontal and anterior temporal areas, especially the left hemisphere along with the process of depression and spatial synchronization of EEG oscillations in subjects. The increased localized capacity of $\alpha 1$ -activity recorded in both men and women's frontal areas is an indicator of the control allowing you to use braking (“braking filter”) and to focus cortical processes on the current problems and to prevent some significant influence of irrelevant factors⁶. According to A. Wrobel²⁰ one associates the $\beta 1$ -activity growth in men with the increased sensory spatial attention and its focus-setting. The expression of $\beta 2$ -rhythm in the frontal and temporal areas of the cortex in patients with high IAF can be interpreted as electrophysiological correlate of some increase in the “differential attention”,²¹ a process facilitating closer interaction among widely distributed neural networks involved in processing information.

The increased power of γ -activity is set in the cortex ($p \leq 0.001$) of all subjects. It is more significant and diffuse for the group of subjects with a high IAF. According to E. Basar et al.²², it is an indicator of the activation of many neural networks enhancing the interaction between spatially distanced populations of cortical neurons. Thus, the conditions for the binding of different sensory, cognitive and executive processes are created and higher state of readiness and attention (expectations) of sensory information is provided.²² This pattern of γ -waves is associated with the thalamic system of the brain where neurons

with specific properties are able to generate γ -oscillations and transmit their signals to the cortical neurons.²³ The occurrence of the diffuse γ -activity is associated with some need to maintain a high level of the attention during the activity.²³ According to these data, higher levels of voluntary attention, found during the acoustic stimulation in the group with a high IAF are correlated with diffuse character of the activity. A power increase of γ -rhythm was more localized in the frontal and temporal areas in Individuals with a low IAF. Neuron-detectors of the auditory cortex are sources of a localized γ -rhythm, according to F. Pulvermüller et al.¹¹ This γ -rhythm consisting of a sensor response is likely to be the criterion improving the efficiency of synaptic contacts in the network involving the neuron-detectors encoding sensory information.¹³ It is possible that an increased activity of neuron-detectors in the auditory cortex is a compensatory mechanism necessary for successful processing of sensory information on the background of extensive type of the cortical response to the sensory stimuli and lower levels of the selective attention in patients with a low IAF. Apart from this the estimation of biomolecules in patient's body fluids such as blood, or CSF may also act as an effective diagnostic tool for various brain related disorders such as ALS or Parkinson.²⁴⁻²⁷

According to data obtained by M. I. Posner et al.²⁸ in the process of the visual attention study, a local desynchronization of the frontal cortex reflects the ease of its effects on other cortical areas during their direct activity. So, the coherence reduction of the electrical activity established by us in the frontotemporal area, especially in the left hemisphere of Subjects may be a reflection of some decrease of its effects on other cortical areas. It can additionally enhance the functional interaction in the posterior parts, especially in the right hemisphere, providing faster and easier implementation of task using a holistic analysis.

Intergroup differences in the perception of sensory stimuli generally reflect the characteristics of brain processes found in the Subjects in a quiescent state. However, men with a low IAF are characterized by some lower EEG power in the low and high band frequencies and may indicate a higher level of a non-specific activation of the cortex.

Conclusions

Being in a quiescent state, men with a high IAF are characterized by some lower power of θ -, α_1 -, α_2 - and β_1 -activity and by higher - in the range of α_3 -, β_2 - and γ -frequency oscillations as well as by lower values of the EEG coherence in the frontal, temporal and central parts of the cortex than individuals with a low IAF. It may indicate the status of relatively higher activation tone of the cortex and its preparedness to activities and control of information processes in individuals with a high IAF. However, the spread of excitation in the cortex obviously modulated by limbic-reticular complex is compensatory facilitated in men with low IAF.

The analysis of received results has revealed distinctive features of brain processes during the perception of sensory signals in men with a high and low output IAF. The growth of localized capacity of α_1 -wave of the EEG in frontal areas, β_1 -, β_2 -oscillations - in the anterior cortex, γ -activity - all over the scalp and its reduction in the posterior temporal, parietal and occipital cortex leads primarily in the α - and β -frequency spectrum are present in men with a high IAF. A generalized expression

of γ -waves are more localized in individuals with a low IAF depression of θ -, α - and β -activity of the cortex. A generalized increase in EEG coherence fluctuations throughout the frequency spectrum of the EEG in the cortex is in all Subjects. Dextrocerebral preponderance was revealed in posterior structures of the right hemisphere. A reduced localized coherence of θ -, α_1 -, α_3 -, β - and γ -oscillations is present in the frontal and anterior temporal areas of the left hemisphere. Such changes in power and coherence of the electrical activity of the cortex may indicate a higher level of the voluntary attention in men with a high IAF. It allows facilitating the information processing in cortical projections of a sensory signal. The cortical response was extensive in nature (generalized excitation processes) in Subjects with a low IAF and a lower level of the selective attention is observed as well as more modulated by nonspecific structures of the brain stem.

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