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EEG Activity during Realization of Manual Movements by Individuals with Different Characteristics of the Alpha Rhythm

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We examined 105 19- to 21-year-old men with a high or low individual modal alpha-frequency in their background EEGs. Latencies of the sensorimotor simple and complex (choice) reactions, rate capabilities of the nervous processes in the tapping test, and spectral power and coherence of the frequency EEG components were estimated. Estimations were obtained for each examined person in the resting state and during finger movements with a force loading (bending of the fingers in the fist and their spreading). Men with relatively high background modal frequencies of the alpha rhythm were characterized by a higher level of the attention selectivity and more local modifications of EEG activity related to realization of manual movements. Somewhat less-differentiated patterns of cortical activation were typical of persons with lower modal alpha-frequencies; this may correlate with a lower plasticity of the cerebral processes under conditions of the control of manual motor activity with force loading and maintenance of the pre-set movement rate. Men with higher modal alpha-frequencies demonstrated better rate indices in the performance of sensorimotor reactions.

Keywords: modal alpha-rhythm frequency, manual movements, force loading, electroencephalogram, spectral power, coherence, psychodynamic properties.

INTRODUCTION

In today's world, there are more and more professions for which functional capabilities of the motor system of an individual are critical. Movements of the upper limbs of humans (manual movements, MMs) in the presence of a certain force loading form the basis of manipulatory motor events in labor activity. It is quite natural that more and more attention is focused on the problem of individual peculiarities of the cerebral processes providing central programming and control of such MMs. Various aspects of the above problem were examined in a number of studies (e.g., [1–5]). The MMs are obviously related to significant modifications of the activity of cerebral structures providing formation of the respective motor programs and commands. Specific information on these processes in the cerebral cortex remains, however, rather limited. At the same time, it is logical to believe that there are certain indices of functioning of the brain, which correlate with the manual motor activity in the presence of force loadings.

For the respective set of problems, the data obtained using electroencephalography are of special value. It was found that EEG phenomena and FMRT patterns recorded during realization of MMs are characterized by high interindividual variability [6–8]. Individual values of the amplitude/frequency parameters of the EEG alpha rhythm, in particular of the modal frequency of the above rhythm, demonstrated considerable informational value in estimations of the state of main psychophysiological functions in humans [8–14]. According to the obtained data [8, 15], an optimum coordination of the processes of organization of a movement and the ability of an individual for self-control positively correlate with the spectral power of the individual alpha range in the EEG composition. At the same time, tension of the mimic muscles (which are not involved in the realization of voluntary MMs) negatively correlates with the above EEG index. Domination of the relatively high- or low-frequency alpha rhythm in the background EEG was interpreted as a valuable prognostic criterion of the

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efficiency of different types of professional activity and intellectual capabilities [8, 9, 16–20]. Such conclusions are based on the fact that the modal frequency of the EEG alpha rhythm is believed to be a feature rigidly determined genetically [10, 11, 14, 21–23]. This parameter reflects important innate features of the organization of thalamic and cortical neuronal networks, up to the specificity of ion processes in the respective cells [24, 25].

Despite the exclusive importance of the results obtained by different researchers, it should be emphasized that such information remains obviously insufficient for detailed understanding of individual peculiarities of neural control of the MMs (first of all, of the targeted movements) in humans. Information on how such innate aspect of brain functioning, as the alpha-rhythm modal frequency, is related to the control of the activity of distal hand muscles in the course of MMs (in particular, realized with force loading) is crucially limited.

We tried to identify certain peculiarities of the cerebral processes related to the control of MMs in men with a comparatively high or a low modal alpha-rhythm frequency in the background EEG. We took into account the prognostic value of the respective information, in particular from the aspect of the rate capabilities of the nervous processes.

METHODS

One hundred and twenty-four healthy 19- to 21-year-old men were involved in the tests. Preliminarily, we estimated the profile of their manual and auditory asymmetries according to the pattern of responses in the course of interrogation and performance of the motor and psychoauditory tests [26]. In the following study, only persons with clearly manifested dextral manual and auditory asymmetries (coefficient of asymmetry greater than +50%) were involved. This total group included 105 individuals.

Rate capabilities of the nervous processes of the tested subjects were estimated according to the latencies of the simple and complex sensorimotor reactions and results of tapping testing (computer system Diagnost-1). After completion of the testing, the subjects had a 30-min-long rest for smoothing of the influences of the earlier performed tests on the results of subsequent EEG testing.

For each examined subject, the procedure of EEG recording included two subsequent intervals, that in the state of the functional rest and that with realization of bending the fingers in the fist and their spreading (grasping-type movements) with the presence of force loading. During flexions and extensions of the fingers, the subject should hold loadings of about 10 N (1.0 kg force) by semiflexed fingers. Low-frequency auditory stimulation was used as a rhythmic signal for bending and spreading of the fingers. Rhythmic acoustic signals mimicked a drumbeat (frequency 2 sec^{-1}, software Finale 2006, total number of stimuli in the test 80). The above rather low frequency of auditory signals is related to the fact that such frequency corresponds to the frequency range of the MMs with force loading determined by biomechanical capabilities for realization of the movements of the distal hand links. Acoustic signals were applied binaurally using four loudspeaker columns positioned at a 1.2 m distance from the tested subject [27]. The duration of each signal was 120 msec, and its frequency range corresponded to 220–235 Hz; the loudness on the column output did not exceed 50 dB above the hearing threshold (measured by a DE-3301 sound meter).

EEG was recorded using standard methodic approaches (a computerized complex Neirocom, the Scientific/Technical Center KhAI-Medika, Kharkiv, Ukraine, state certificate No. 6038/2007, January 26, 2007). Monopolar recording was used; active electrodes were located according to the 10–20 international system on 19 points on the scalp. Frontal (Fp1, Fp2, F3, F4, F7, and F8), central (C3 and C4), temporal (T3, T4, T5, and T6), parietal (P3 and P4), occipital (O1 and O2), and sagittal (Fz, Cz, and Pz) leads were used. Leads with odd indices corresponded to the left hemisphere, while those with even indices corresponded to the right hemisphere. Joined contacts on the earlobes served as the reference electrode. Additional reference electrodes between the rostral frontal and lateral frontal leads (Ref) and between the right and left rostral frontal leads (N, nasion) were used to improve the quality of records. The frequency characteristics of the EEG set allowed us to provide satisfactory quality of recording of the theta to gamma (inclusive) EEG rhythms.

The EEG data were primarily analyzed using Neirokom software. The modal frequency for the spectral power segment of the EEG alpha range was measured for each lead during EEG recording in the resting state with the eyes closed. These values were averaged for all leads; the respective

mean value was considered the individual modal alpha frequency of the subject (IαF, Hz) [17]. The examined sampling was conventionally divided into two groups (see below). The subjects with IαF values smaller than the mean value for general sampling were combined in a low-IαF group, while subjects with the IαF values exceeding the average intersampling value formed a group with relatively high IαFs. Additionally, we estimated the level of stability of the IαF value in the resting state according to results of measuring of this parameter during five subsequent days.

Borders of the frequency EEG subranges were estimated individually [17, 18]. The upper border of the alpha3 subrange was localized rightward from the IαF with a 2.0 Hz interval; simultaneously, this value corresponded to the lower border of the beta1 frequency band. The lower border of the alpha2 subrhythm was localized leftward from the alpha rhythm mode with a 2 Hz interval. The lower border of the alpha1 subrange was at the distance of 4 Hz, and that of the theta rhythm was at the distance of 6 Hz. The upper border of the beta1 subrange was determined as 25 Hz (according to the generally accepted classification), and borders of the beta2 and gamma bands were 26–35 and 36–45 Hz, respectively.

The spectral powers of EEG oscillations of the above-mentioned rhythms and subrhythms, as well as the coherence of oscillations in inter- and intrahemisphere lead pairs, were calculated using the respective standard software. We took into account coherence coefficients greater than 0.5.

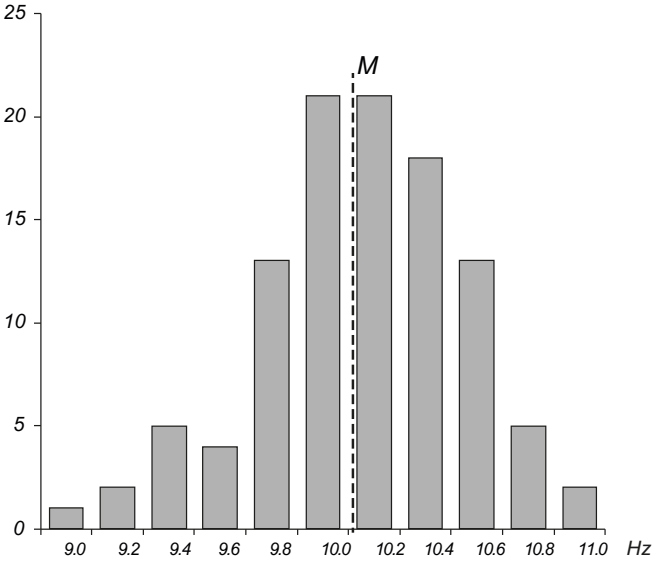
The normality of distributions of the numerical data in the samplings was checked using the Shapiro–Wilk *W* test (Statistica 6.0, Stat-Soft, 2001). The distributions of our data usually corresponded to the normality requirement; thus, we calculated mean, s.d., and s.e.m. values. The significance of intergroup differences was estimated using parametric tests, in particular, the Student's *t*-test for dependent samplings (test-to-test comparisons) and for independent equal samplings (intergroup comparisons). Statistical calculations and plotting of the graphs and diagrams were performed using M. Excel Windows Vista.

RESULTS AND DISCUSSION

Estimation of the individual modal frequency of the EEG alpha range. The mean value of the alpha-range modal frequency in the examined sampling of men was 10.04 ± 0.03 Hz. The maximum of the histogram of individual values of this parameter was smoothed, while there were no clear manifestations of bimodality of this distribution (Fig. 1). This is why we should divide the examined sampling into two groups only conventionally, with respect to the mean value of the modal frequency of the alpha range for the entire sampling. This allowed us to form two groups (nearly equal to each other by the numbers of individuals) with relatively high values of the IαF (n = 53; IαF ≥ 10.04 Hz) and with low values of this index (n = 52, IαF < < 10.04 Hz).

Values of the s.e.m. for the IαFs measured in five subsequent recordings of background EEGs obtained from 10 examined subjects during 5 days varied within a 0.003 to 0.024 interval. Thus, values of the IαF in the examined subjects were characterized by rather high stability.

Peculiarities of the psychodymanic characteristics of subjects with high and low values of the IαF. Individuals with a high IαF demonstrated, as a rule, shorter latencies of both simple sensorimotor reactions and complex (choice) reactions. They were also characterized by higher maximum rates of the



F i g. 1. Histogram of individual values of the modal alpha-rhythm frequency in the general examined sampling (n = 105). The mean value of the above parameter for the entire sampling is shown.

Table 1. Results of the Psychophysiological Tests Characterizing Psychodynamic Properties of Neural Processes in the Examined Subjects

Indices	Groups of subjects with the modal frequency of the alpha rhythm	
	high	low
Latency of the simple sensorimotor reaction, msec	232.35 ± 5.15	299.21 ± 6.40**
Latency of the choice sensorimotor reaction, msec	334.82 ± 7.19	399.9 ± 15.29**
Number of the tapping movements within a 30-sec-long interval	38.3 ± 1.9	32.14 ± 1.37*

Footnotes: Means ± s.e.m. are shown. One and two asterisks show cases of significant intergroup differences with P < 0.05 and < 0.01, respectively.

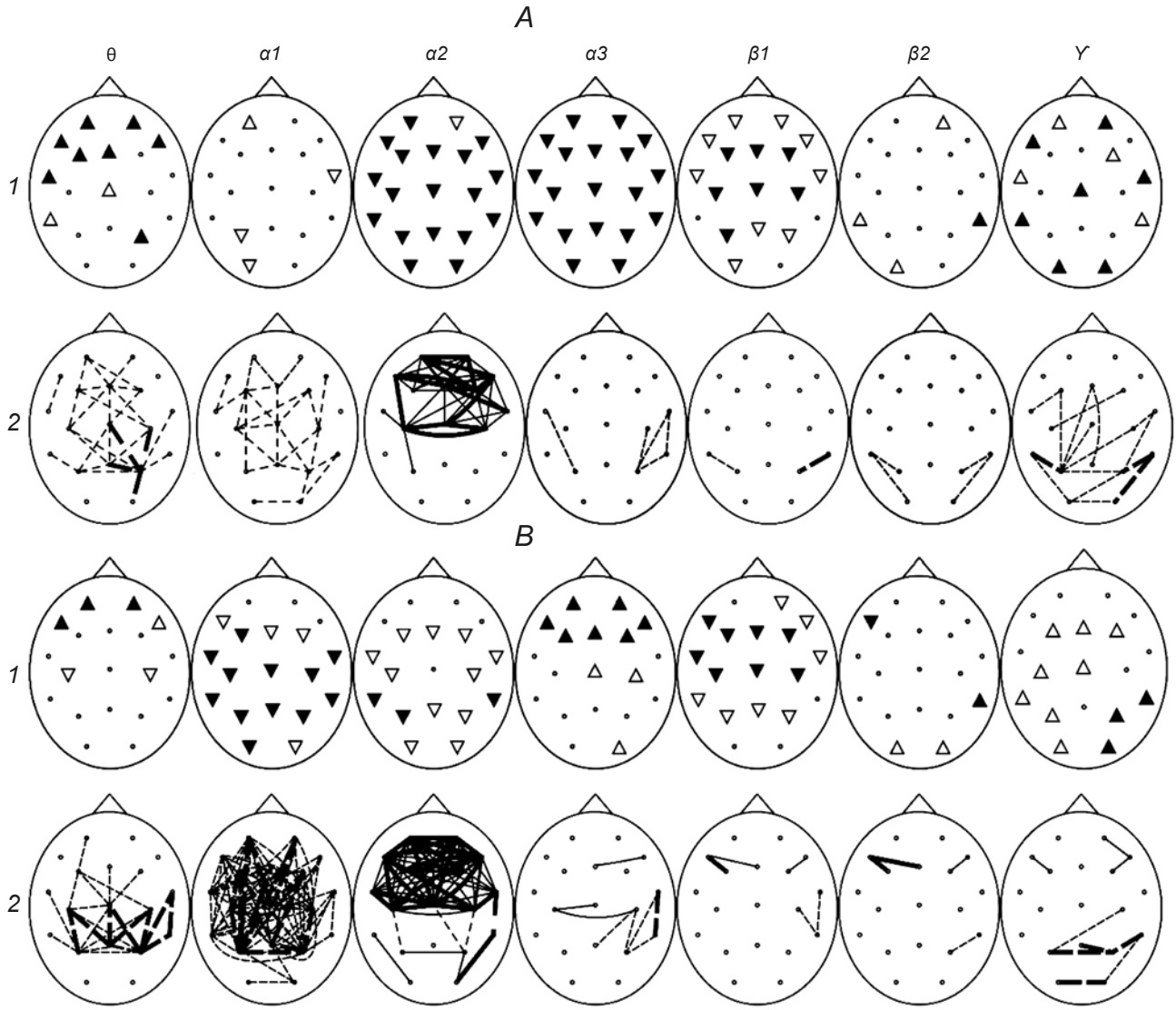


Fig. 2. Topography of changes in the spectral power (1) and coherence (2) of the frequency EEG components in the groups of subjects with a high (A) and low (B) modal alpha-rhythm frequency in the course of movements of the fingers with force loading (compared with the respective indices in the resting state). In panels 1, triangles with the upward-directed tip show cases of increases in the power, while those with the downward-directed tip show decreases of this parameter; open and filled symbols correspond to significant differences with $P < 0.05$ and < 0.01, respectively. In panels 2, solid and dotted lines indicate cases of increase and decrease of the coherence; thin and thick lines correspond to significant differences with $P < 0.05$ and < 0.01, respectively.

hand movements in the tapping test (Table 1). These facts show that individuals with high IαF possess, in general, higher rate capabilities of the neural processes related to the control of the above motor phenomena.

EEG recorded during realization of the MMs with force loading in subjects with high and low individual IαFs. Within segments of the MM performance, men with relatively high IαFs demonstrated, as a rule, smaller values of the coherence coefficients for theta, alpha1, alpha3, beta, and gamma oscillations ($P \leq 0.05$ or ≤ 0.01), than those observed in the resting stat (Fig 2).

It can be assumed that such changes were related to a decrease in the intensity of nonspecific activating influences coming from the reticular formation to the cortex and septum; the latter structure is probably responsible, to a considerable extent, for generation of low-frequency EEG oscillations [28]. At the same time, functioning of the cortical structures most directly involved in the control and realization of motor activity is maintained at a sufficiently high level. This was indicated by increases in the coherence of alpha2 oscillations in the frontal, anterior temporal, and central cortical zones and by some decrease in the power of alpha oscillations in the left temporal/occipital zone (within the alpha1 subrange, $P < < 0.05$). Such shifts typical of the alpha2 and alpha3 EEG subranges ($P < 0.01$) were spread over the entire scalp (Fig. 2). According to our considerations and those of other authors [29, 30], such events can reflect the enhancement of activity in the cortical zones involved in the processes of sensory analysis, motor programming, and integration of sensorimotor information. Within the theta and alpha1 ranges, the coherence within frontal zones increased ($P< 0.05$ or 0.01); this can be related to intensification of recurrent frontocortical–thalamic influecnes [18] and, respectively, to an increase in the level of selective voluntary attention [31]. Such modifications can also be a correlate of actualization of operative memory [4, 29]; this allows the subject to fix information related to sensory stimuli within an attention focus and to control the movements. Simultaneously, high-frequency EEG components (beta2 and gamma activity) were intensified ($P < 0.05$ or 0.01). Such shifts observed under the above-mentioned conditions may reflect facilitation of interaction among extensive neuronal networks involved in sensorimotor integration [32].

Men with relatively low IαFs mostly demonstrated increases in the coherence coefficients for alpha2 activity in the frontal, anterior temporal, and central areas and increased coherence of alpha3, beta, and gamma oscillations in frontal cortical zones ($P< 0.05$ or 0.01). Intensified coherence relations in high-frequency EEG spectrum segments observed under the above conditions can be indicative of intensification of a nonspecific activity in the cortex. Simultaneously, similarly to what was observed in men with high IαFs, the coherence of theta and alpha1 oscillations decreased across the entire cortex, while the coherence of alpha3, beta, and gamma oscillations decreased within the posterior cortical areas (first of all, in the right hemisphere; $P< 0.05$ or 0.01). Bilateral increases in the coherence of high-frequency EEG components in the frontal and central zones and simultaneous decreases in its values in the posterior temporal and occipital cortical regions attracted special attention. If we take into account the data on EEG modifications during the performance of some cognitive tasks (perception of double images), such phenomenology can by hypothetically correlated with reciprocal switchings off of the attention focus from processing of sensory stimuli to programming of the movements; the latter process is realized mostly in the frontal and central cortical areas.

Decreases in the power of alpha1, alpha2, and beta1 waves in most cortical regions and increases in this parameter within the theta and alpha3 ranges (in frontal zones), beta2 waves (in the posterior temporal and occipital sites), and gamma oscillations (generalized shifts were observed across the entire cortex), as compared with the respective indices in the resting state ($P< 0.05$ or 0.01), were typical of this group (Fig. 2). Special attention should probably be paid to increases in the power of alpha3 waves in frontal leads ($P< 0.05$) typical of men with relatively low IαFs. Such feature may reflect additional inhibition of cortical mechanisms of the sensory input [17, 31]. Such phenomenon can be an EEG correlate of the process of comparison of the afferent information flow describing new parameters of the muscle function with descending influences coming from the frontal cortex; the latter carry information on the preceding motor programs. Such inhibitory descending influences in the course of realization of “novel” (non-routine) movements interfere with realization of a new coordination

[34]. These influences are related to the relatively lower plasticity of the respective neuronal networks [31] and may be considered a definite compensatory phenomenon against the background of a low level of attention selectivity [17].

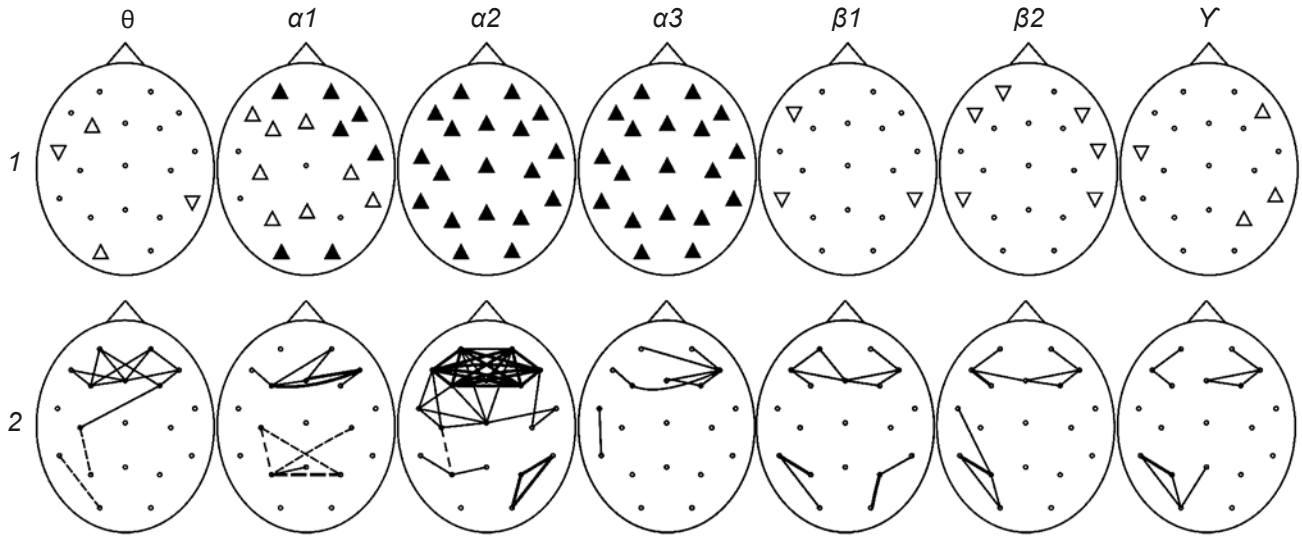
Intergroup differences of the EEG parameters. Tested subjects with lower IαFs, when performed MMs with force loading, demonstrated a higher power of alpha oscillations and gamma activity in the cortex ($P < 0.01$ and $P < 0.05$, respectively) and, simultaneously, a lower power of beta oscillations ($P< 0.05$), especially in the temporal regions (Fig. 3).

Individuals with low IαFs were characterized by a stronger coherence of most frequency EEG components in the cortex ($P< 0.05$ or 0.01). Simultaneously, oscillations of the theta, alpha1, and alpha2 ranges in posterior cortical areas demonstrated smaller coefficients of coherence ($P < 0.05$; Fig. 3).

It should be emphasized that men with high IαFs were, in general, characterized by more local patterns and greater asymmetry of the described cortical reactions, while men with lower alpha modal frequencies showed more generalized patterns of the phenomena related to cortical activation.

Thus, results of our study allow us to describe certain special features of cerebral processes observed during realization of the "force-overcoming" MMs synchronized with sensory signals, which are typical of individuals with different parameters of the alpha rhythm (in particular, with different modal frequencies of this rhythm). In both groups of the examined men, we observed certain decreases in the nonspecific tone of the cortex. Simultaneously, functioning of the cortical structures most directly involved in the control and realization of this type of motor activity (sensory perception, motor programming and switching on of the motor commands, and sensorimotor coordination) is maintained at a sufficiently high level. In the course of MMs with force loading, men with a higher background alpha frequency showed a somewhat higher level of attention selectivity and more local modifications of cortical electrical activity. Subjects with a lower alpha frequency demonstrated somewhat less differentiated patterns of cortical activation. This can be related to lower plasticity of the cerebral processes in a situation where it is necessary to counteract force loading and to track the pre-set movement rate.

The levels of capabilities of the cerebral activation system with respect to the reaching of a concrete result are noticeably different in subjects with different values of the IαF. Men with higher values of this parameter probably have better rate characteristics of the nerve processes. It should,



F i g. 3. Topography of intergroup differences of changes in the spectral power and coherence of the frequency EEG components in the course of movements of the fingers with force loading. Triangles with the upward- and downward-directed tips show cases of the greater and lower average spectral power in tested subjects with a low modal frequency of the alpha rhythm. Solid and dotted lines show cases of greater and smaller coherence coefficients in the above group compared with the respective parameters in the group with higher modal alpha frequencies. Other designations are similar to those in Fig. 2.

however, be taken into account that such regularities are only of a statistical nature.

Results of our studies demonstrated that the modal frequency of the alpha range measured in the resting state can have certain prognostic value with respect to cerebral processes related to the performance of MMs with application of force loading and also with respect to individual rate capabilities of the neural processes.

This study met the international ethical principles expressed in the Helsinki Declaration (1964 and subsequent editions), which was confirmed by the Ethics Committees of the Lesya Ukrainka East European National University (Luts'k, Ukraine). All participants were volunteers; they were informed in detail on the testing procedure, and written informed consent was obtained from all of them.

The author of this publication, A. G. Morenko, confirms the absence of any conflict related to the commercial or financial problems and to the relations with organizations or persons, which could in any way be associated with the investigation.

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