Correlation of the Characteristics of EEG Potentials with the Indices of Attention in 12- to 13-Year-Old Children

N. V. Lutsyuk,[1] E. V. Éismont,[1] and V. B. Pavlenko[1]

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We studied correlations of the spectral characteristics of EEG with the indices characterizing the level of attention in 60 children (12 to 13 years old). Indices of voluntary attention were measured using a complex of psychological tests, including a Bourdon's test (correcture test), a two-stimulus go/no-go test, a computer test (a modification of the Bourdon's test for characterization of concentration and stability of attention), and Schulte's tables. Children manifesting a good working ability (corresponding to the results of the go/no-go test and correcture test) showed relatively high values of the ratio of spectral powers (SPs) of the beta 1 and theta rhythms. These ratios were greater in the right hemisphere; this is probably indicative of a greater contribution of neuronal mechanisms of this hemisphere to providing watchfulness and stability of attention. Children demonstrating increased impulsivity (according to the results of the go/no-go test) were characterized by low modal frequencies of the alpha rhythm in the occipital brain regions, while children with relatively high values of this frequency in various cerebral regions demonstrated high indices of attentiveness and rates of the cognitive processes. Children performing the test task with especially high accuracy were characterized by high ratios of SPs of the low-frequency beta rhythm *vs* theta rhythm (mostly in the central and parietal regions of both hemispheres). The approach we have applied can be used for measuring the objective indices characterizing the state of the attention sphere in children.

Keywords: EEG, spectral characteristics, attention, children.

INTRODUCTION

The necessity to study the cognitive sphere in medium-age schoolchildren is occasioned by the serious problems frequently specific for this age group. These are difficulties in school education, an insufficient level of development of voluntary attention, and various disorders of the latter [1, 2]. An objective characterization of the level of development of attention and its versatile diagnostics are necessary for timely identification of such disorders and their successful correction. Spectral analysis of EEG, which is at present extensively used, is considered one of the objective methods for studying the mechanisms of cognitive activity in humans; it can, in particular, be applied for diagnostics of some psychoneurological disorders and obtaining criteria of maturation of the brain [3-7]. Indices of the spectral power (SP) of the EEG frequency ranges can, to a certain extent, serve as markers of different functional states and individual peculiarities of the cerebral mechanisms [8, 9].

A number of studies of electrophysiological correlates of attention in children with attention deficit/hyperactivity syndrome (ADHS) have been performed [10, 11]. These studies showed lower ratios of the amplitudes of the beta 1 *vs* theta rhythm (mostly in the frontal regions), as compared with the respective indices in healthy children [12, 13]. In addition, studies of the evoked EEG activity also showed some differences between patterns of the evoked potentials (EPs) in children with ADHS and healthy subjects [12, 14]. In our earlier studies, we examined correlations between the characteristics of EPs recorded in different experimental paradigms and peculiarities of voluntary attention in healthy children [15-17]. Results of such studies (including those of our own works) showed that there are definite correlations between parameters of the EP components and indices of attention in healthy children. Nevertheless, information on correlations

[1] Vernadskii Tavricheskii National University, Simferopol', Crimean Autonomic Republic, Ukraine.
Correspondence should be addressed to
N. V. Lutsyuk (e-mail: biofeedback@bk.ru),
E. V. Éismont (e-mail: jane@crimea.edu), and
V. B. Pavlenko (e-mail:pavlenkovb@crimea.edu).

between amplitude/frequency parameters of EEG and different indices of voluntary attention in such children remains insufficient.

In this study, we examined correlations between spectral characteristics of the EEG rhythms and indices of voluntary attention in healthy children. Identification of such correlations is especially urgent, in particular, for further successful development of the technique of feedback by EEG characteristics (neurofeedback). Collection of the respective data will allow experimenters to estimate the efficacy of such an approach from the aspect of development of attention in healthy children and to select those characteristics of voluntary attention that are effectively influenced by one type of psychophysiological training or another.

METHODS

Sixty reasonably healthy 12- to 13-year-old children (30 boys and 30 girls) took part in the study.

EEG was recorded using a standard technique. An automated complex, including an electroencephalograph, an interface, and a computer, and the EEG Mapping 3 software (programmer E. N. Zinchenko) were used. EEG potentials were recorded monopolarly from frontal (F3, F4), central (C3, C4), parietal (P3, P4), temporal (T3, T4), and occipital (O1, O2) leads according to the 10-20 system.

Contacts fixed above the *proc. mastoidei* and connected with each other served as a reference electrode. Cut-off frequencies of the high- and low-frequency filters were 35.0 and 1.5 Hz, respectively, and 250 sec^{-1} digitization frequency was used. EEG signals were processed using fast Fourier transformation and smoothing according to the Blackman methods. The epoch of the analysis for fast Fourier transformation was 2.56 sec long.

The EEG samples recorded with eyes closed, with eyes open, and in the course of resolving an arithmetic problem (internal reverse counting). The average SP values were calculated within the following ranges: theta (4-8 Hz), alpha (8-13 Hz), the so-called sensorimotor rhythm [18] (12-15 Hz), beta 1 (16-20 Hz), and beta 2 (21-30 Hz). Because the EEG was recorded not only from the central region where the sensorimotor rhythm dominates, the latter type of activity (12-15 Hz) will be further called, according to Egner, a low-frequency beta rhythm [18]. The modal frequency of the alpha rhythm was determined as the mean of the frequencies demonstrating the maximum SP within the above frequency range in all the analyzed 2.56-sec-long samples. We also calculated the ratios of alpha SP *vs* theta SP, low-frequency beta SP *vs* theta SP, and beta 1 SP *vs* theta SP. The level of desynchronization, or the coefficient of reactivity (CR), was calculated as the ratio of the alpha SP with eyes closed and the respective index with eyes open.

Spectra of EEG were calculated separately for the three recording conditions, with eyes closed, eyes open, and at cognitive loading (arithmetic calculations). Each complex of samplings was, in total, 60 sec long.

Estimates of the attention indices were obtained using the following techniques. Indices of the rate of cognitive processes, inattention, and impulsivity were obtained using a two-stimulus go/no-go test, with pairs of acoustic tonal stimuli; the technique of this test was described in more detail earlier [16]. The following indices of attention were calculated: (i) efficacy of attention, i.e., the number of correct and sufficiently fast reactions to presentation of significant combinations (pairs) of stimuli (“low−low” or “high−high” tones), and (ii) impulsivity, i.e., the number of wrong reactions to presentation of insignificant combinations, with no necessity to perform sensorimotor reactions (pushing the button), at the arrivals of “low−high” and “high−low” pairs.

To determine concentration and stability of attention, we developed a computer program (a modification of the Bourdon test). Children were to type, using a keyboard, a succession of symbols according to the proposed sample. These samples looked like a combination of figures, from zero to nine, presented in a randomized order and separated from each other by comas. In total, 420 symbols were to be typed. After the test was completed, we calculated the following indices: (i) stability of attention, i.e., the ratio of the number of correctly typed combinations of symbols to the number of symbols required to be typed, and (ii) concentration of attention, the number of correctly typed symbols up to the arrival of the first error.

A “working efficiency” index was determined using Schulte’s tables. According to this test system [19], the lower the index obtained, the better the development of attention. To determine the “productivity of attention” and “accuracy of attention” indices, we used a letter version of the Bourdon test [20, 21]. Calculation of the indices of attention using the above tests (Schulte’s tables and the Bourdon test) was described in more detail earlier [15, 16].

Data of electrophysiological recordings and psychological tests were processed using standard methods of variation statistics. To characterize correlations between the measured indices, we used Pearson's coefficient of correlation; Student's *t*-test was used for characterization of the intergroup differences.

RESULTS AND DISCUSSION

The most significant correlations of the efficiency of attention index characterizing the rate of cognitive processes and correctness of problem fulfillment were found for the alpha rhythm (Fig. 1).

It was reported that the modal frequency of the alpha rhythm positively correlates with the indices of voluntary attention [8]. In addition, it is believed that an increase in the frequency of this EEG component is indicative of an increase in the general level of activation of the cerebral mechanisms, while a decrease in this frequency correlates with general suppression of cerebral activity [8, 22]. Thus, an increase in the frequency of alpha oscillations induced by various functional loadings can be interpreted as an indication of the shift of the functional state of the brain toward excitation. It was reported that intellectual activity related to resolving complex problems results in an increase in the frequency of the alpha rhythm [23]. Clinical observations also support the viewpoint that the performance of a cognitive task can be related to shifts in the alpha frequency. There are data on a drop in the alpha-rhythm frequency with aging [24] and on a smaller value of this parameter in patients suffering from dementia, as compared with that in healthy individuals [25].

Significant correlations were also found between the CR value and such indices as "concentration of attention" and "efficacy of attention" (Fig. 2). Positive correlations in this case demonstrate that subjects with better concentration of attention are characterized by greater CR values than children with lower values of this index. Figure 3 shows spectral characteristics of EEG of two children significantly differing from each other in the level of concentration of attention. Our results show that desynchronization of the alpha rhythm in children with extensive resources of attention is expressed much better than in children with low indices of concentration of voluntary attention. The index characterizing impulsivity showed negative correlations with the ratio of alpha-rhythm SP *vs* theta-rhythm SP in the occipital regions with eyes closed (for O1 $r = -0.40$, $P < 0.05$; for O2 $r = -0.43$, $P < 0.05$) and with the frequency of the alpha rhythm in the occipital part of the left hemisphere with eyes open (for O1 $r = -0.38$, $P < 0.05$). Under conditions

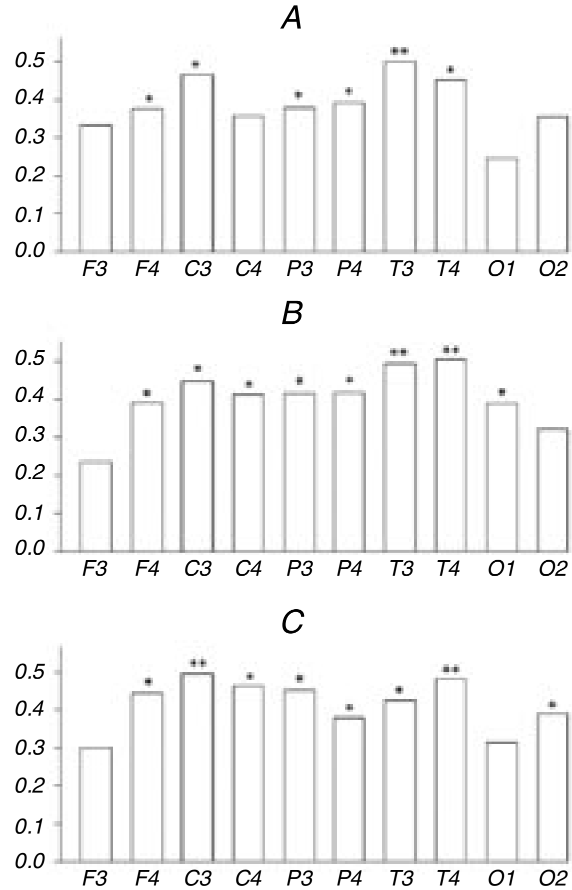

Fig. 1 Coefficients of correlation between the "efficiency of attention" index and the modal frequency of the alpha rhythm in EEG recordings from different loci with eyes closed (A), eyes open (B), and at resolving an arithmetic problem (C) in 30 children (12 to 13 years old). Leads are shown below. Vertical scale) Values of the correlation coefficients. One and two asterisks show significance of correlation with $P < 0.05$ and $P < 0.01$, respectively.

of resolving an arithmetic problem, correlations were found for the ratio of low-frequency beta SP *vs* theta SP (for P4 $r = -0.38$, $P < 0.05$; for O1 $r = -0.42$, $P < 0.05$) and for the frequency of the alpha rhythm (for P4 $r = -0.46$, $P < 0.05$; for O1 $r = -0.39$, $P < 0.05$; and for O2 $r = -0.4$, $P < 0.05$). Thus, these results show that children with a relatively low alpha-rhythm frequency in the occipital regions and low values of the low-frequency beta SP/theta SP in the parietal part of the right hemisphere and occipital part of the left hemisphere are, as a rule, characterized by a higher impulsivity.

In the course of neurofeedback sessions, when trying to correct the impulsivity and hyperactivity of a child, the protocol was directed toward an increase in the amplitude of the low-frequency beta rhythm and suppression of the theta rhythm [26, 27]. It should be

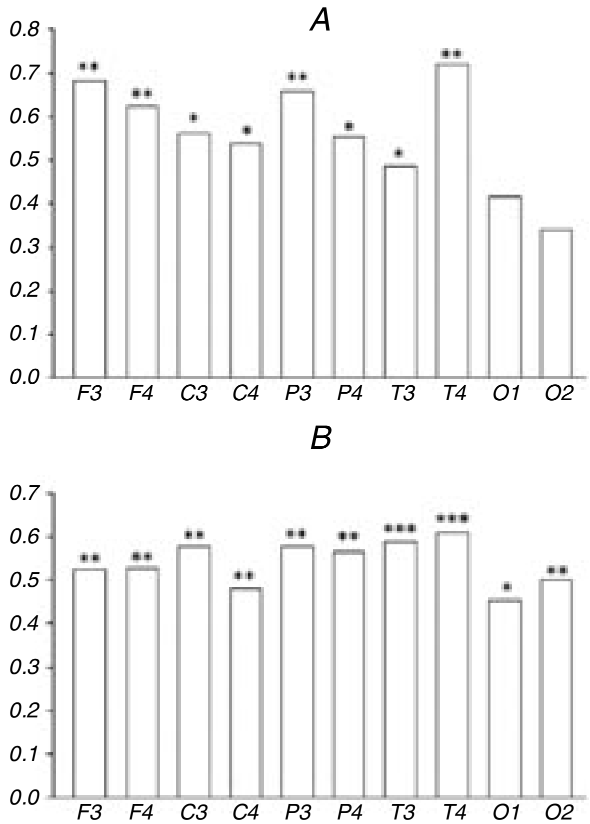

Fig. 2. Coefficients of correlation between the indices of “concentration of attention” (A) and “efficiency of attention” (B), and the coefficient of EEG reactivity in 30 children (12 to 13 year old). Three asterisks show cases with $P < 0.001$. Other designations are the same as in Fig. 1.

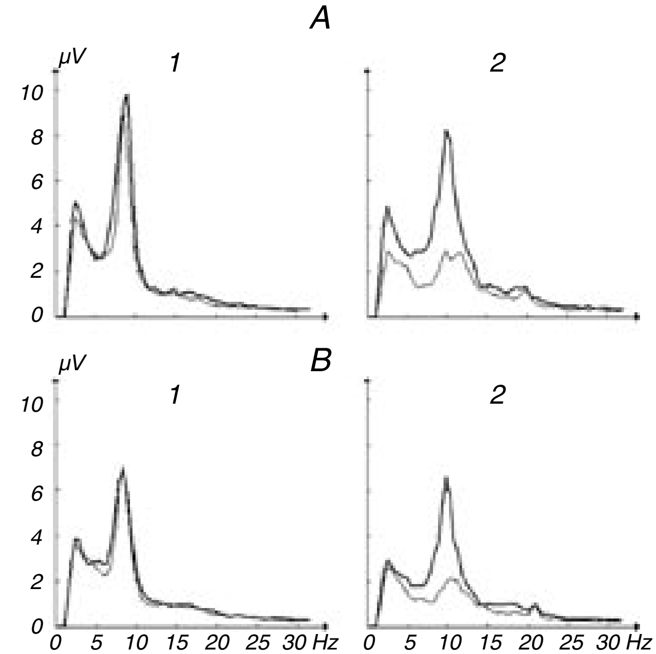

Fig. 3. Averaged EEG spectra for recordings from occipital regions of the right (A) and left (B) cerebral hemispheres of two children, with a low (1) and a high (2) value of the “concentration of attention” index. Thick and thin lines in the graphs correspond to the EEG spectra with eyes closed and open. Abscissa) Frequency, Hz; ordinate) amplitude, μV.

taken into account, however, that this index, in addition to the observed correlation of the ratio of SPs of the above rhythms with impulsivity in healthy children, is also related to some characteristics of voluntary attention. The “efficiency of work” index negatively correlated with the ratio of SPs of the low-frequency beta rhythm and theta rhythm. The smaller the value of the above index, the better the developed attention. Results of the analysis of correlation between the above-mentioned indices are illustrated by Fig. 4.

The “accuracy of attention” index positively correlated with the ratio of SPs of the low-frequency beta rhythm *vs* theta rhythm in EEG recorded with eyes closed (for F3 $r = 0.40$, $P < 0.05$; for F4 $r = 0.43$, $P < 0.05$; for C3 $r = 0.38$, $P < 0.05$; and for C4 $r = 0.46$, $P < 0.05$). This was also observed when resolving the arithmetic problem (for P4 $r = 0.43$, $P < 0.05$). In addition, the “accuracy of attention” index also positively correlated with the SP of the low-frequency beta rhythm, (for F4 $r = 0.38$, $P < 0.05$, and for C4 $r = 0.39$, $P < 0.05$). Therefore, these observations show that children with the highest values of the above-mentioned ratio are able to rather accurately perform the tasks they are faced with, and they are characterized by a high rate of the cognitive processes.

The pattern of relations between the EEG rhythmics of the 12-15 Hz range (the so-called “sensorimotor activity”) and the efficiency of processing of information has not been elucidated in detail. Sterman [28] reported that motor activity accompanied by suppression of this EEG component (a low-frequency beta activity) can interfere with perceptive and integrative components of the processes of information processing. Therefore, the enhancement of the activity within the low-frequency beta range can correspond to facilitation of processing of information due to a decrease of such interference.

Values of the SP of the beta 1 rhythm positively correlated with the index of “attention productivity” when EEG was recorded with the eyes open (for C4 $r = 0.41$, $P < 0.05$; and for P3 $r = 0.42$, $P < 0.05$) and when it was recorded in the course of resolving of the

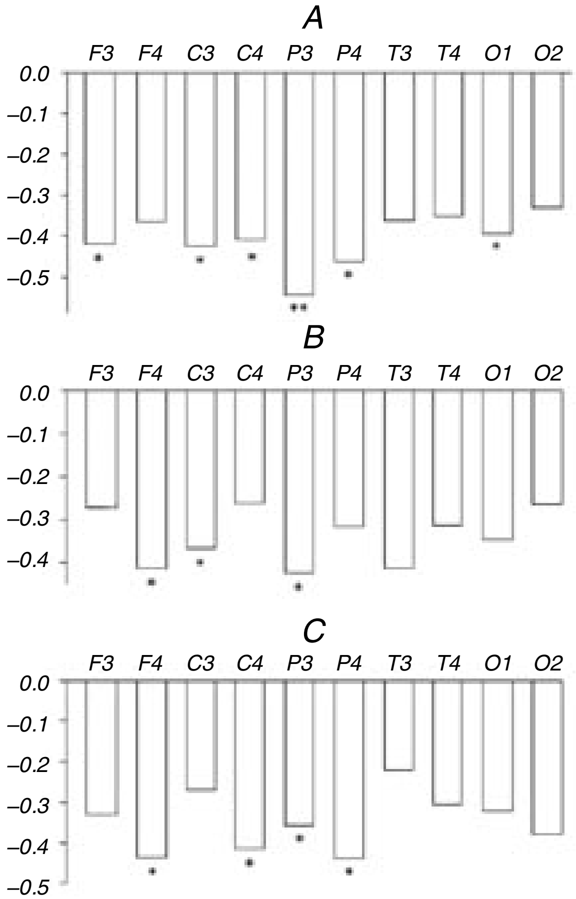

Fig. 4. Coefficients of correlation between the "efficiency of work" index and the ratio of spectral powers (SPs) of the low-frequency beta *vs* theta rhythms in EEG recordings from different loci with eyes closed (A), eyes open (B), and at resolving an arithmetic problem (C). Designations are similar to those in Fig. 1.

arithmetic problem (for P3 $r = 0.39$, $P < 0.05$). The SP of the beta activity is believed to correlate with the intensity of cognitive processes, in particular with the processing of stimuli in the frontal cortical zones [29, 30].

Results of analysis of interrelations between the ratio of SPs of the beta 1 *vs* theta rhythm and the stability of attention are illustrated by Fig. 5. We also found positive correlations of the above ratio with the "productivity of attention" at EEG recording with the eyes open (for F3 $r = 0.37$, $P < 0.05$, for C4 $r = 0.39$, $P < 0.05$, and for L3 $r = 0.38$, $P < 0.05$). The mentioned index, together with the attention stability, characterizes the ability of the subject to fix attention on an object within a long time interval.

Figure 6 shows topograms of the ratios of the low-frequency beta *vs* theta rhythm SPs (A) and beta 1 *vs* theta rhythm SPs (B) observed in two tested children

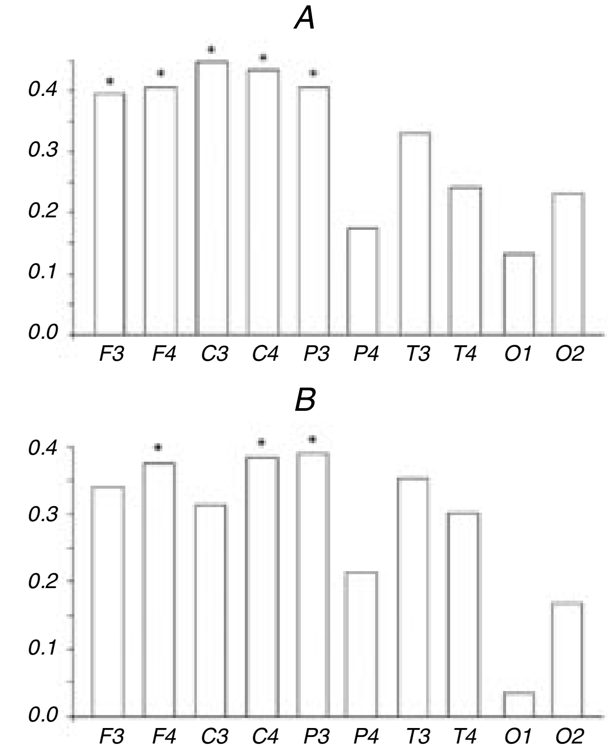

Fig. 5. Coefficients of correlation between the "stability of attention" index and the ratio of the SPs of the beta 1 *vs* theta rhythms in EEG recordings with eyes open (A) and at resolving an arithmetic problem (B). Designations are similar to those in Fig. 1.

with high (1) and low (1) indices of stability and concentration of attention in the course of resolving the arithmetic problem. In the course of the problem performance, the subject with high indices of the development of voluntary attention (in contrast to the subject with these low indices) demonstrated transformations of the activity within various cortical zones. The SPs of high-frequency EEG components increased, while low-frequency components were suppressed in these regions. The suppression of the slow-wave activity is considered by a few researchers as one of the most typical markers of general intensification of the cerebral activity [31-33].

Our study demonstrated that the SP of the theta rhythm positively correlated with the "efficiency of work" index when EEG was recorded with the eyes closed (for C3 $r = 0.37$, $P < 0.05$), with the eyes open (for C3 $r = 0.43$, $P < 0.05$; for C4 $r = 0.39$, $P < 0.05$; and for T4 $r = 0.41$, $P < 0.05$), and at resolving the arithmetic problem (for C3 $r = 0.38$, $P < 0.05$, for C4 $r = 0.39$, $P < 0.05$; and for T4 $r = 0.39$, $P < 0.05$). These findings show that low values of the theta SP, mostly in central leads, correlate

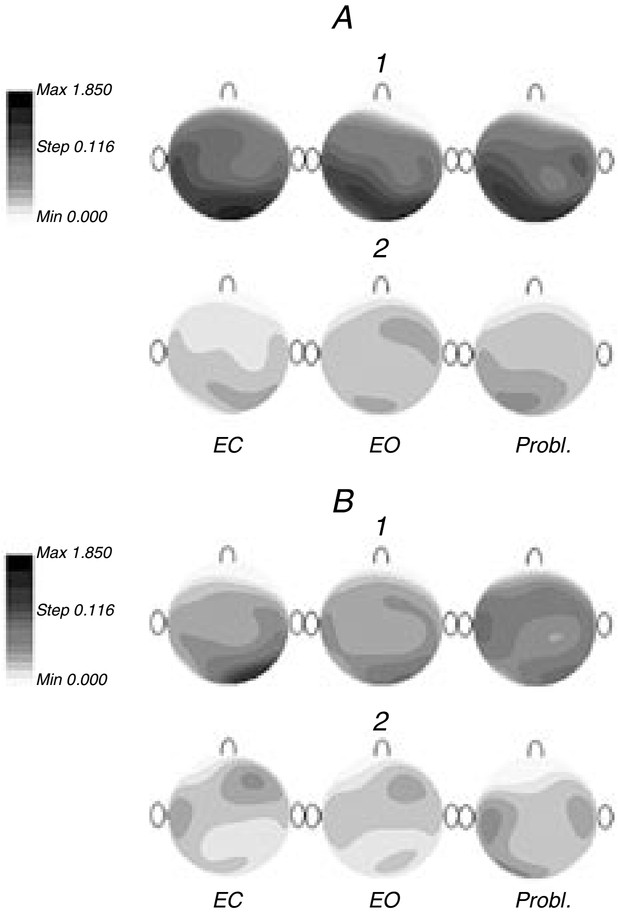

Fig. 6. Topography of changes in the ratios of the spectral powers of the low-frequency beta *vs* theta rhythms (A) and of the beta 1 *vs* theta rhythms (B) in two children with high (1) and low (2) values of stability and concentration of attention. EEG was recorded with eyes closed (EC), eyes open (EO), and at resolving a cognitive problem (Probl.). On the left) Calibrations of the above-mentioned ratios (A and B), arbitrary units. Each topogram corresponds to a 16-sec-long segment of EEG.

with the ability of the subject to accurately perform the proposed problem.

Results of the psychological tests were compared with the respective normative age standards [1]. Based on these data, all the tested children were divided into two subgroups depending on whether their indices of attention exceeded the mean normative values or whether they were below these values. The first subgroup (n = 29) included children with relative low indices of attention, while subgroup 2 (n = 31) consisted of subjects with better indices. The mean values of the indices under study for the entire examined group and for each subgroup are shown in Table 1. Figure 7 illustrates the means of the ratio of the low-frequency beta *vs* theta SPs and of the beta 1 *vs* theta SPs in subgroups 1 and 2.

Intergroup differences between these indices were greater in the frontal, central, and parietal areas of the brain. It should be emphasized that the values of the above relations between the SPs of the EEG rhythms were greater in the right hemisphere. This fact can be related to a greater contribution of neuronal mechanisms of this hemisphere in the formation of voluntary attention. It is believed that the right hemisphere mostly provides the general mobilization readiness of the person and the maintenance of the necessary level of awakeness, but the activity of this hemisphere is to a limited extent related to the peculiarities of the concrete activity. At the same time, the left hemisphere is to a greater extent responsible for the specialized organization of attention adequate to the peculiarities of the problem [34].

Thus, correlations of the spectral characteristics of EEG with the indices of voluntary attention we have found (Figs. 1, 2, 4, and 5) show that an increase in the level of EEG activity observed practically in all brain regions is related to activation of the mechanisms of voluntary attention. Our tests allowed us to discover the following interrelations between the indices of voluntary attention and amplitude/frequency characteristics of the EEG rhythms. Children characterized by a high ability to work according to the results of the go/no-go test and Bourdon test demonstrated high values of the ratio between the SPs of the beta 1 and theta rhythms. The values of the above ratio were greater in the right hemisphere, which

TABLE 1. Indices of Voluntary Attention in 12- to 13-Year-Old Children

Indices of attention	Group under study in general (n = 60)	Subgroup 1 (n = 29)	Subgroup 2 (n = 31)
“Efficiency of attention,” %	96.90 ± 0.51	95.40 ± 0.70	98.70 ± 0.71
“Impulsivity,” %	6.56 ± 1.52	9.26 ± 2.50	5.10 ± 1.85
Productivity of attention, number of symbols	825.96 ± 24.79	729.80 ± 28.80	876.57 ± 28.80
“Accuracy of attention,” %	96.70 ± 0.48	94.10 ± 0.52	97.70 ± 0.41
“Efficiency of work,” sec	43.30 ± 1.26	46.50 ± 1.62	41.60 ± 1.63

Footnote. Means ± s.e.m. are shown.

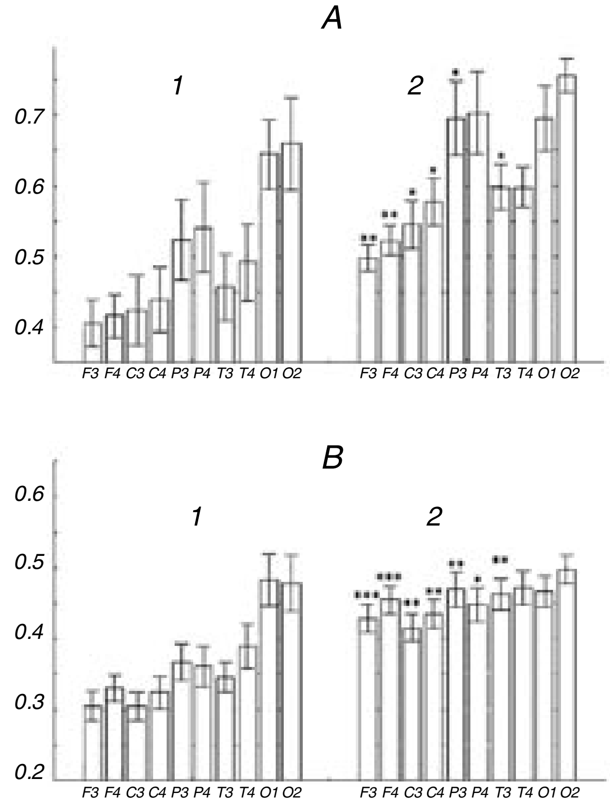

Fig. 7. Diagrams of the values of the ratios between the spectral powers of the low-frequency beta *vs* theta rhythms (A) and beta 1 *vs* theta rhythms (B) in subgroups of the children with relatively low (1; $n = 29$) and high (2; $n = 31$) indices of voluntary attention. EEG was recorded with eyes open. Means ± s.e.m. in the subgroup are shown. Leads are shown below. Vertical scale) The above ratios (A and B). Other designations are similar to those in Figs. 1 and 2.

is probably indicative of a higher contribution of this hemisphere in providing watchfulness and stability of attention. Children with increased impulsivity (according to the results of the go/no-go test) were characterized by low values of the modal frequency of the alpha rhythm in the occipital regions of the brain, while children with high values of the above frequency within the alpha range in different loci of the brain were characterized by high attentiveness and a high rate of cognitive processes. In addition, those children who especially accurately performed the tasks were characterized by high values of the ratio of SPs of the low-frequency beta rhythms and theta rhythm (mostly in the central and parietal regions of both hemispheres).

The approach used in our tests can be applied when obtaining objective indices characterizing the development of the attention sphere in children.

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