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Moderation of Increased Anxiety in Children and Teenagers with the Use of Neurotherapy: Estimation of the Efficacy

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We estimated the efficacy of using the technique of feedback (FB) by EEG characteristics (EEG-FB, neurotherapy) with the aim of reducing increased anxiety levels in healthy 10- to 14-year-old children. The anxiety level was estimated using the Prikhojan anxiety test, the Spielberger–Khanin questionnaire, and the House–Tree–Person projective drawing technique. Positive effects of series of neurotherapy sessions were obvious. After training was completed, we observed significant increases in the ratios of the amplitudes of alpha and theta rhythms, semsorimotor and theta rhythms, as well as of the modal frequency of the EEG alpha rhythm in tested persons of the experimental group (n = 7). In the control group (n = 10), changes in these values did not reach the significance level. In the experimental group of tested persons subjected to EEG-FB sessions, the anxiety level decreased appreciably; in addition, the indices "feeling of inferiority" and "frustration" decreased significantly. In the control group, alterations of these psychological indices were not unidirectional. Therefore, modifications of the EEG pattern, which occurred in the course of training and were accompanied by a decrease in the anxiety level in the experimental group, can be indicative of the expediency of EEG-FB for the reduction of high anxiety levels in children and teenagers.

Keywords: neurotherapy, EEG-FB protocols, anxiety, children, teenagers.

INTRODUCTION

Sessions of feedback (FB) by EEG characteristics (EEG-FB, neuroFB, neurotherapy) are at present extensively and successfully used for treatment of a number of psychological, neurological, and psychosomatic disorders [1-4], as well as for optimization of the psychoemotional status of healthy humans [5, 6]. It should, however, be noted that the technique for carrying out such sessions directed toward moderation of increased anxiety levels and treatment of the corresponding neuropsychological disorders is to a greater extent developed and actively applied only with respect to an adult contingent.

Recently, the use of EEG-FB in children was in general oriented toward correction of the attention deficit/hyperactivity disorder syndrome. Researchers found that this technique is rather highly effective with respect to the above syndrome and also to psychological aberrations resulting in difficulties in learning [7-10]. The question of the applicability of the EEG-FB technique for decreasing high anxiety levels in children and teenagers remains practically open [11].

The use of recent approaches in neuro-FB training directed toward correction of disorders related to abnormally increased anxiety in adult persons [11] and also our own data [12] allowed us to hypothesize that orientation on intensification of the EEG alpha rhythm, the ratio between the alpha/theta powers, and the ratio between the powers of the so-called sensorimotor rhythm (SMR) and theta oscillations can be considered an optimal strategy of realization of EEG-FB sessions with the aim of a decreasing high anxiety in children and teenagers.

The mode of presentation of FB signals is an important aspect. Such signals used in the EEG-FB procedures are, as a rule, visual or acoustic (rarely, tactile). The question of what EEG-FB protocol, i.e., the type of FB signals (together with the set of all parameters regulating the performance of a certain kind of training), is the most effective remains little studied.

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In the available literature, there are only isolated reports devoted to this circle of problems [13].

Taking into account the above data, we tried to estimate the expedience of the use of the EEG-FB technique for decreasing the anxiety level in healthy 10- to 14-year-old children. We also compared the efficiency of using different EEG-FB protocols in the above situation.

METHODS

Seventeen physically healthy 10- to 14-year-old children with clearly increased anxiety levels took part in the study. The children were divided into two groups: experimental ($n = 7$; four boys and three girls) and control ($n = 10$; five boys and five girls). The corresponding psychological testing was performed using the Spielberger–Khanin test system [17], the Prikhojan questionnaire allowing us to estimate the level of manifest anxiety and levels of different particular types of anxiety ("scholar," self-rating, interpersonal, and "magic" [18]), as well the House–Tree–Person projective drawing technique. Using the latter technique, we could obtain estimates of not only the anxiety level but also those of the feelings of inferiority and frustration [19]. Psychological techniques and principles of calculation of the corresponding indices were described in detail earlier [12, 20].

Children of the experimental group were subjected to training series, which included 10 to 12 EEG-FB sessions. To our great regret, the question of the optimal total duration of the training course remains practically open [14]. In some studies, however, it was demonstrated that the number of sessions used in our investigation is quite sufficient for a significant reduction of anxiety levels in adults [4] and also for correction of the psychoemotional status in teenagers [15].

Before and after training sessions, we recorded EEGs with the eyes open and closed and estimated the initial and final anxiety levels using psychological testing. In children of the control group, EEG recording and diagnosing of the anxiety level were performed within intervals corresponding to the duration of training session in children of the experimental group. In general, children of the control and experimental groups were involved in 108 experimental testings, including EEG-FB sessions and analysis of the initial and final EEG patterns and psychological indices.

Recording and analysis of EEG were performed using generally accepted routine techniques with the help of a computerized telemetric electroencephalograph

TABLE 1. Protocol Alternatives in Sessions of Feedback by the EEG Characteristics Used in the Course of Trainings

Protocol name	"Trained" EEG parameters	Description of the protocol
Loudness control of white noise	alpha rhythm/theta rhythm amplitudes	the intensity of white noise varies inversely with the ratio between the averaged amplitude of the alpha rhythm and that of the theta rhythm; the greater this ratio, the lower the loudness of white noise
Loudness control of white noise against the musical background	alpha rhythm/theta rhythm amplitudes	the intensity of white noise against the musical background of a constant loudness varies inversely with the ratio between the averaged amplitude of the alpha rhythm and that of the theta rhythm; the greater this ratio, the lower the loudness of white noise
Loudness control of music	alpha rhythm/theta rhythm amplitudes	the loudness of music varies directly with the ratio between the amplitudes of the alpha and theta rhythms; the higher this ratio, the louder the music
Control of the intensity of color in pictures	alpha rhythm amplitude	pictures are images of nature. The intensity of color of the main details of pictures (e.g., fruits on the tree, sun, or flowers) varies directly with the values of the averaged amplitude of the alpha rhythm; the higher this value, the more intense the colors
Control of the intensity level of colors in Madyar's charts	alpha rhythm amplitude	the chart *per se* is a composition of colored squares and rectangles spaced in a certain order [16]. The intensity of colors in the chart varies directly with the averaged amplitude of the alpha rhythm; the higher this value, the more intense the colors
"Playing" protocol	Sensorimotor rhythm (SMR)/theta rhythm amplitudes	the rate of motion or "force" of the main playing character varies directly with the ratio between the averaged amplitude of the SMR and that of the theta rhythm; the greater this value, the higher the rate or force of the playing character

(Tredeks, Ukraine). As a working program, we used the program EEG Mapping 3 (programmer E. Zinchenko). EEG potentials were recorded monopolarly from leads Fp1, Fp2, F3, F4, F7, Fz, F8, C3, C4, Cz, T3, T4, T5, T6, P3, P4, Pz, O1, O2, and Oz according to the international 10-20 system. As the reference electrode, we used all electrodes connected together with each other, except for the active one. A neutral ("grounding") electrode was positioned between leads Fz and Cz. The frequency band of amplifiers was 1.5 to 35 Hz; the digitization frequency of EEG signals was 250 sec^{-1}.

Thirty-minute-long EEG-FB sessions were performed twice per week. A session included several (six to eight) segments of EEG recordings with the use of different EEG-FB protocols realized in randomized order. In the course of the test session, the person sat in a comfortable chair. In the course of presentation of acoustic protocols, the tested person sat with the eyes closed, and an acoustic signal was presented via loudspeakers. In the case where visual protocols were used, the tested person sat in front of a computer display where different variants of visual FB signals were presented. In all protocols, the FB signal was changed depending on the parameters of "training" EEG rhythms in lead C4. Preliminary processing of EEG for estimation of modifications of the characteristics EEG rhythm in the course of EEG-FB sessions included filtration with the use of digital four-order Butterworth filters.

Prior to the training session, the tested person was provided with necessary explanations on the experimental procedure and the dependence of one parameter of FB signals or another on changes in the psychoemotional state. The tested person was asked to memorize his/her state at just the moment when the controlled parameter was altered in the desirable direction.

Description of the versions of EEG-FB protocols used in the course of sessions is presented in Table 1.

The data of EEG recordings in each protocol version were processed and analyzed independently of each other. Such an approach allowed us to perform a comparative estimate of the efficiency of each of the neuroFB protocols used. Signals were processed using fast Fourier transform; smoothing by the Blackman technique was used. As a characteristic of the spectral power (SP) of one EEG rhythm or another, we estimated the value of the mean amplitude (μV) within the following frequency ranges: theta (4-8 Hz), alpha (9-13 Hz), sensorimotor rhythm, SMR (12-15 Hz), beta1 (16-20 Hz), and beta2 (21-30 Hz). The modal frequency of the alpha rhythm was calculated as an arithmetic mean of the frequencies corresponding to the maximum amplitudes of the given frequency range in the 20 to 25 recorded EEG segments (duration of each segment, 2.56 sec). We also calculated the ratios between the amplitudes of the alpha and theta rhythms, SMR and theta rhythm, beta1 and theta rhythms, and beta2 and theta rhythms.

Numerical data of the electrophysiological study and indices of the psychological tests were treated using standard statistics techniques. For intergroup comparison, we used the parametric Student test or the nonparametric Mann–Whitney and Wilcoxon tests depending on the kind of distribution of the values.

RESULTS AND DISCUSSION

The use of various EEG-FB protocols in trainings demonstrated their dissimilar efficiency. We found a rather high efficiency of the use of the protocol "control of the intensity of white noise." Under the respective conditions, we observed, in practically all the tested persons, increases in the amplitude of the alpha rhythm and of the ratio between the amplitudes of the alpha and theta rhythms in most leads (Fig. 1).

To find changes in the amplitudes of EEG rhythms in a comparison of the first and tenth EEG-FB sessions, we used normalized values of the amplitudes of EEG rhythms; the amplitudes of these rhythms during the first session were taken as 100%. Maximum increments of the ratio between the amplitudes of the alpha and theta rhythms were found in the following leads: F3 (38.0%), F4 (38.8%), C3 (21.4%), C4 (28.7%), P3 (18.6%), O1 (59.6%), and O2 (31.5%). In some comparable studies, but carried out on adult persons, such an order of the values of relative increments of

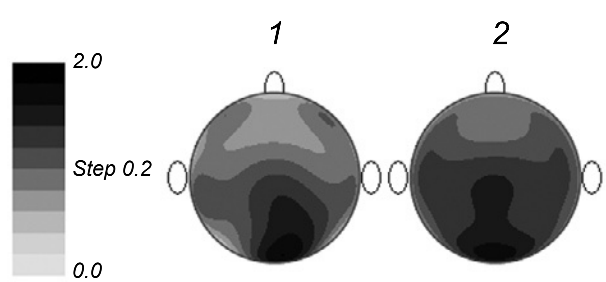

Fig. 1. Averaged topograms of values of the ratio of the alpha- and theta-rhythm amplitudes in the course of the first (1) and tenth (2) sessions with the use of the protocol of "loudness control of while noise" in the experimental group of tested subjects (n = 7). Scale at the left) Calibration of the values of the ratio between the amplitudes of the above-mentioned rhythms (arbitrary units).

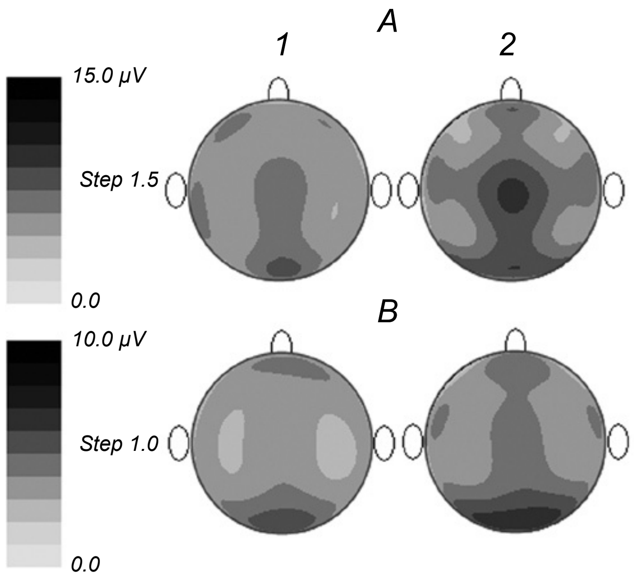

Fig. 2. Averaged topograms of the mean amplitudes of the alpha (A) and sensorimotor (B) rhythms in the course of the first (A) and tenth (2) sessions with the use of the protocol of "loudness control of color in pictures" in experimental group (n = 7). Scales at the left) Calibration of the amplitudes of the corresponding rhythms (μV).

the "training" index has been considered as evidence of the rather high efficiency of training [4, 11].

It should be noted that the ratio between the amplitudes of alpha and theta rhythms increased at the expense of both a rise in the mean amplitude of the alpha rhythm and a drop in the amplitude of the theta rhythm. The maximum increment of the amplitude of the alpha rhythm was observed in leads F3 (increment 17.7%), F4 (18.8%), C4 (14.4%), T6 (11.2%), and P3 (28.9%). Maximum decreases in the amplitude of the theta rhythm were observed in the following leads: F3 (decrease 15.5%), F4 (14.3%), Fp1 (17.7%), and O2 (13.8%). The comparative efficiency of this protocol is, apparently, related mostly to the fact that the level of noise is a simple, univocal, and understandable signal of the FB. It seems probable that this signal is perceived (in any case, by most tested persons) as emotionally negative, and the subjects made more efforts to make such a comparatively unpleasant acoustic signal less intense.

In the case where we used the above protocol, we also observed a rise in the ratio between the amplitudes of the SMR and theta rhythm. The mean increments of this index in leads F3, F4, C4, O1, and O2 were 18.5, 19.7, 18.6, 34.4, and 24.6%, respectively.

As to other protocols with the use of acoustic signals, positive effects in these cases were less expressed. The "trained" value increased only in some leads. The maximum increase in the ratio between the alpha/theta amplitudes in the case where we used the protocol of "loudness control of white noise against a

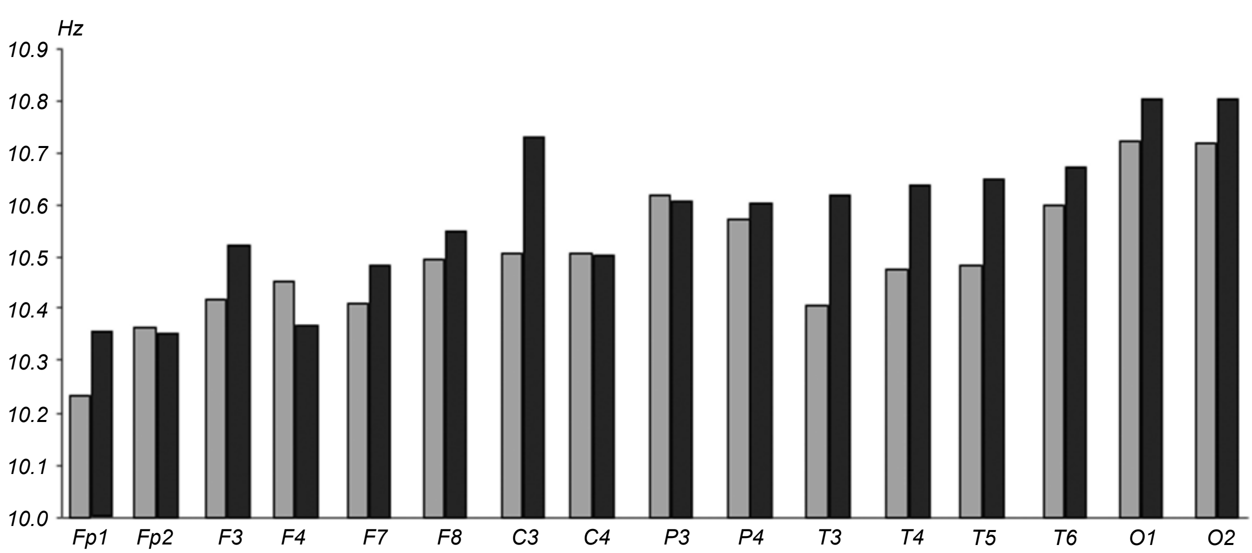

Fig. 3. Diagrams of the mean values of the alpha rhythm modal frequency with the use of the "playing" protocol in the course of the first (open columns) and tenth (filled columns) sessions in the experimental group of subjects (n = 7). Horizontal scale) Leads; vertical scale) frequency, Hz.

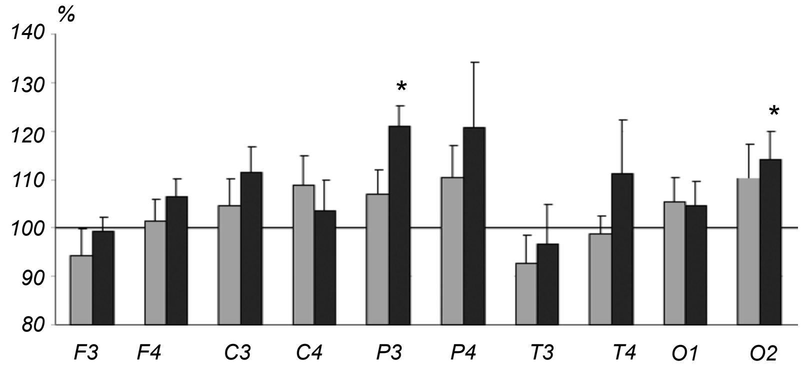

Fig. 4. Diagrams of the values of the ratio between averaged amplitudes of the alpha and theta rhythms in the course of resultant EEG recording with the eyes closed in tested subjects of the control (open columns) and experimental (filled columns) groups. Normalized values (mean ± s.e.m.) of the ratio between the amplitudes of the mentioned rhythms (%) are shown; initial values of this ratio are taken as 100%. Horizontal scale) Leads. Asterisks indicate cases of significant intragroup differences between the values before and after training ($P < 0.05$).

musical background" was recorded in leads C4 and T4 (these increases were 7.4 and 7.3%, respectively). In the case of the use of the protocol "loudness control of music," some increase in this index (5.0%) was observed only in lead F3. In the above cases, a rise in the ratio between the amplitudes of SMR and theta rhythm was not observed. Thus, the effects of use of the protocols "loudness control of music" and "loudness control of white noise against a musical background" were appreciably more local and weak.

We believe that the relative low efficiency of the use of the protocol "loudness control of music" is related, first all, to the fact that loudness of music changes does not depend exclusively on the pattern of current EEG; this parameter inevitably is modulated independently of the efforts of the person who listens to canned music. The loudness of music is permanently altered depending on the melody (tune) and acoustic characteristics of a given musical composition. As a result, the tested person cannot always differentiate whether modification of the loudness is related to his own mental efforts directed toward alteration of one EEG rhythm or another or whether such modification is due to the peculiarities of the specific organization of the music composition *per se*. It is possible that background (low-intensity) music *per se* exerts a positive emotional influence on the tested persons (in the course of test sessions, we used only musical compositions inducing exclusively positively colored emotions and was perceived as pleasing or harmonious by each person individually). This is why the tested persons were to a lesser extent motivated to try to direct their conscious efforts toward intensification of the loudness of music.

The protocol of the "loudness control of white noise against a musical background" appeared less effective than the "pure", i.e., with no musical accompaniment, protocol "loudness control of white noise." Noise, as was already mentioned, should be considered *per se* a maximally simple and understandable FB signal. The protocol of the "loudness control of white noise against a musical background" is more complicated, since the noise signal is presented together with musical composition, and the tested subject cannot in all cases notice the moment when just the noise becomes lower or higher. It seems probable that the attention of the tested person is alternatively concentrated, in a voluntary or involuntary manner, on listening to the musical composition or perception of the loudness of noise.

Among visual protocols, the use of the protocol

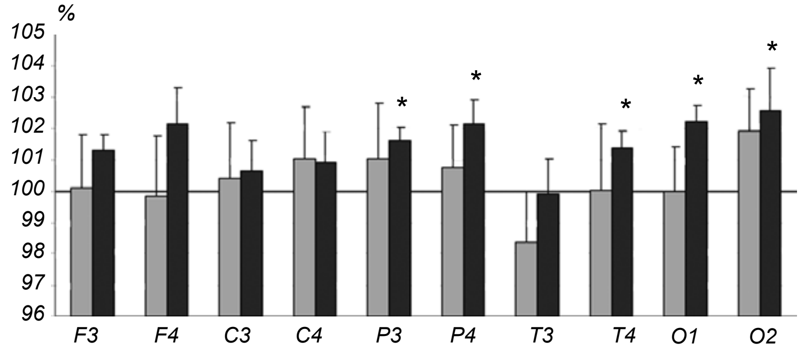

Fig. 5. Diagrams of the modal frequency of the alpha rhythm in the course of resultant EEG recording with the eyes closed in subjects of the control (open columns) and experimental (filled columns) groups. Normalized values of the parameter (%) are shown; initial values of the frequency are taken as 100%. Other designations are the same as in Fig. 4.

TABLE 2. Estimates of Psychological Indices According to the Results of Final Testing in the Control and Experimental Groups

Indices	Values of indices obtained in the course of final testing, %, of the relative initial level	
	Control group	Experimental group
Manifest anxiety (according to the scale of the Prikhojan's test)	105.2 ± 14.5	83.5 ± 14.3
Anxiety test, by Spielberger		
Situational	96.0 ± 7.1	91.4 ± 8.1
Personal	103.7 ± 4.3	92.9 ± 5.5
Anxiety test of Prikhojan		
"Scholastic"	87.5 ±13.1	72.8 ± 15.0
Self-rating	91.7 ± 10.9	87.9 ± 14.8
Interpersonal	107.9 ± 11.4	76.0 ± 11.6
"Magic"	96.7 ± 20.6	73.1 ± 14.9
General	92.7 ± 8.9	75.6 ± 11.0
House–Tree–Person projective drawing technique		
Anxiety	119.6 ± 14.7	91.6 ± 5.8
Feeling of inferiority	126.9 ± 13.4	70.6 ± 13.3*+
Frustration	134.7 ± 33.1	75.6 ± 12.7*

Footnotes. Means ± s.e.m. are shown. Asterisks indicate significant intragroup differences prior to and after training ($P < 0.05$); cross indicates significant differences between tested persons of the control and experimental groups ($P < 0.05$).

"regulation of the intensity of color in pictures (shade)" was highly effective. In the course of application of this protocol, positive dynamics of the value of the "trained" rhythm were observed in the frontal, central, parietal, and occipital zones of both hemispheres. In addition to the "trained" values, the amplitude of SMR increased (Fig. 2). The ratio between the amplitudes of the alpha and theta rhythms also increased. The maximum rise of the ratio between the amplitudes of these EEG components was observed in leads C3 and C4, where it was 36.1 and 20.9%, respectively.

The use of the "playing" protocol led to relatively local EEG modifications. This fact can be explained in the following way: the "playing" protocol is directed toward an increase in the ratio between the amplitudes of SMR and theta rhythm, while the SMR is mostly recorded in central regions [21]. The maximum increase (10.8%) in the ratio between the amplitudes of the SMR and theta rhythms was observed in lead C3.

Increases in the modal frequency of the alpha rhythm in different cerebral regions of mainly the left hemisphere were a distinctive feature of the results of "playing" trainings (Fig. 3). It is known that the process of maturation of the brain in children is accompanied by some increase in the frequency of alpha oscillations [21]. It is believed that such an increase (just typical of the alpha rhythm) is indicative of a rise in the integral level of activation of cerebral mechanisms, while a decrease in this rhythm indicates that such an integral level becomes lower [22].

In the case where we used the protocol of "regulation of the intensity of colors in the Madyar's chart," we observed a decrease in the amplitude of the theta rhythm in practically all recording sites. The maximum decrease in this index was observed in leads Fp2, T3, and T5, where it was 20.8, 11.3, and 11.7%, respectively. In this case, the modal frequency of the alpha rhythm increased (in lead T3, $P < 0.01$). Under conditions of the use of the protocol with the color chart, we also observed a decrease in the amplitude of the beta2 rhythm in nearly all leads of EEG recording. The averaged amplitude of the beta2 rhythm demonstrated a maximum drop in the following cerebral regions: right frontal (by 31.3%), left central (by 12.4%), and parietotemporal of the left hemisphere (by 14.7%).

As is known from the published data, the expression of the theta rhythm closely correlates with the level of neuro-emotional tension, emotions, and activation of a nuber of structures of the autonomic nervous system [23]. In the respective literature, it is also noted that a parallel increase in the powers of the theta and beta rhythms is indicative of manifestations of distraction, fatigue, and mental tension [24]. It is also known that a relative increase in the amplitude of the beta2 rhythm is frequently typical of tested persons in the state of anxiety or characterized by increased personal anxiety [25-27]. Based on studies carried out in our laboratory [28], we concluded that a significant intensity of the beta2 rhythm can be considered a clear correlate of high situational and personal anxiety in adult healthy

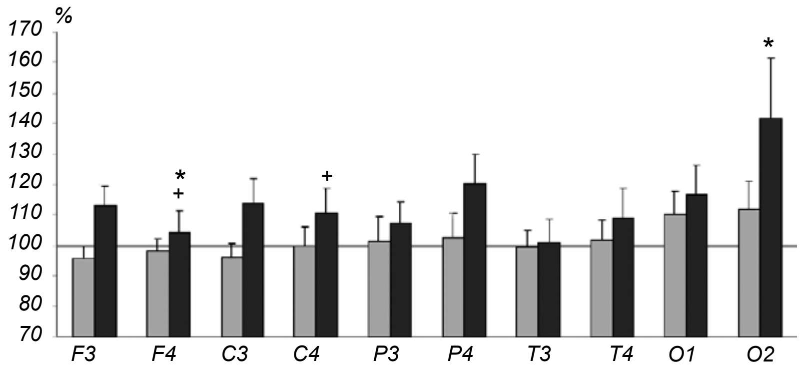

Fig. 6. Diagrams of the values of the ratio between the averaged amplitudes of the sensorimotor rhythm and theta rhythms in the course of resultant EEG recording with the eyes open in subjects of the control (open columns) and experimental (filled columns) groups. Crosses indicate cases of significant differences between the control and experimental groups ($P < 0.05$). Other designations are the same as in Fig. 4.

persons.

Recently, it was shown that visual perception of Madyar's color charts results in general in the development of the relaxation state [29]. In the study with participation of adult persons [30], even short-lasting presentation of such color charts after intense work on a personal computer reduced the emotional tension, which was accompanied by more rapid recovery of the initial ratios of EEG rhythms recorded prior to the action of functional loading.

Therefore, a decrease in the amplitudes of the theta and beta2 rhythms under conditions of the EEG-FB protocol with Madyar's color charts, which was observed in our study, can be indicative of modifications of the functional state of the CNS; such modifications correspond to a decrease in the total level of psychological tension.

Results of the final psychological testing in the control and experimental groups are presented in Table 2. It can be seen that, after EEG-FB sessions, estimates of the anxiety level decreased at all scales of the psychological tests in the experimental group. These shifts did not reach the level of significance; however, trends toward such a decrease at scales of interpersonal, "scholastic," and general anxiety were rather obvious ($0.06 \leq P \leq 0.1$). A significant decrease in the indices was also observed at the scales "feeling of inferiority" and "frustration." In the control group, the psychological indices changed in different unpredictable directions. Significant differences (according to the results of final testing in persons of both groups) were observed at the scale "feeling of inferiority," while a clear trend toward a decrease was found for the values of interpersonal anxiety ($P = 0.07$). According to the reports of parents, self-rating and emotional stability increased in children after EEG-FB training sessions, which can also be indicative of optimization of the psychoemotional state of these children.

Final recording of EEG gave the following results. After training sessions, the tested persons were characterized by a significant increase in the ratio between the amplitudes of the alpha and theta rhythms, as well as a rise in the modal frequency of the alpha rhythm in EEG recorded with the eyes closed (Figs. 4 and 5). The ratio between the amplitudes of the SMR and theta rhythm also increased under conditions of EEG recording with the eyes open. Despite the fact that the training was performed according to the EEG characteristics observed in lead C4, positive changes in the "trained" values were found in a number of cerebral regions. In the control group, as compared with the experimental group of the tested persons, increments of these values were usually insignificant and were observed in a smaller number of recording sites. The mean values of the ratio between the SMR and theta rhythm amplitudes in EEG recorded with the eyes open differed significantly in the persons of the control and experimental groups; greater values were observed in the experimental group (Fig. 6).

According of the data of our recent study [12], teenagers with a low anxiety level are characterized by higher values of the ratio between the powers of the alpha and theta rhythms, SMR and theta rhythm, as well as by increased modal frequency of the alpha rhythm compared to the analogous indices in persons of the same age with high anxiety levels. Thus, a significant increase in the above indices after the performance of trainings is indicative of appreciable positive effects of repeated EEG-FB sessions on the functional state of the CNS and psychoemotional state of the children.

We believe that the limited number of significant detected differences between the final EEG characteristics and psychological indices of the tested persons in the control and experimental groups can mostly be related to the fact that the sampling of the tested persons was relatively small and/or to the necessity of a greater number of EEG-FB sessions with the aim of attaining a more expressed positive effect.

Suppositions of neuronal mechanisms underlying the influence of EEG-FB sessions on the anxiety level are based on the following facts. Changes in the efficacy of signal transmission in the brain neuronal networks are, to a considerable extent, determined by modifications of the activity of cerebral aminergic systems. Rearrangements in the system of resonant loops in cortical-subcortical connections are closely related to such a modification, which is inevitably accompanied by alteration of the total EEG pattern and specific parameters of its frequency components [31]. As was demonstrated in experiments on animals, the level of impulse activity of dopaminergic neurons of the ventral tegmentum in the course of EEG-FB sessions decreases noticeably [32]. It is known that the dopaminergic system, via modulation of the activity of neuronal networks in the thalamus, limbic system, and neocortex, is actively involved in triggering of processes leading to general enhancement of the efficacy of synaptic transmission in these networks [33, 34]. This is manifested in the pattern of the current EEG mainly as an increase in the power of the alpha rhythm [35]. By and large, repeated EEG-FB sessions result in improvement of the psychophysiological state of the tested persons and also in a decrease in the general level of tension and anxiety in such persons.

It is obvious that our study is only the initial step in the investigation of the possibility of using the EEG-FB technique for moderation of the anxiety level in children and teenagers. Modifications of the EEG pattern, which developed in the course of trainings and were accompanied by an appreciable decrease in the anxiety level in the experimental group, are indicative of the positive effect of repeated sessions of neurotherapy using different EEG-FB protocols and also the reason for using this technique for decreasing the high anxiety level in children and teenagers. Our data also present more reasons to select a definite protocol for such procedures.

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