Modulation of Attention in Healthy Children Using a Course of EEG-Feedback Sessions

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We studied changes in the power spectra of EEG in the course of sessions of feedback by EEG characteristics (neurofeedback sessions) and estimated the effects of neurofeedback on psychological and EEG correlates of voluntary attention. Indices of the latter were estimated using Bourdon's test (a correcture test) and Schulte's tables. Twenty-nine reasonably healthy 10- to 13-year-old children took part in the study; they were divided into two groups, an experimental group (n = 12) and a control group (n = 15). The results obtained support the statement on noticeable changes in the functional state of the brain both immediately in the course of a neurofeedback session and after a course of such trainings. Changes in the ratios of the spectral powers of the $beta_1$ *vs* theta rhythms and the low-frequency beta *vs* theta rhythms were found in EEG recorded from the sensorimotor zone of the right hemisphere (C4). The observed changes in the spectral characteristics of EEG induced by the course of neurofeedback sessions were accompanied by the improvement of a few indices of voluntary attention.

Keywords: feedback by EEG characteristics (neurofeedback), EEG rhythms, attention, children.

INTRODUCTION

At present, a technique of feedback by EEG characteristics (neurotherapy, neurofeedback) is more and more extensively used in treatment of neurological diseases and in the case of undesirable shifts in the psychological and psychosomatic states [1-4]. Pioneering studies demonstrating the possibilities for modifications of electrical cerebral activity using such an approach were performed in the 1960s. In his studies, Sterman [5, 6] showed that training with the use of neurofeedback, when directed toward intensification of the so-called sensorimotor rhythm (12-14 Hz), considerably increased the threshold for initiation of seizure attacks [5, 6]. Within the subsequent period, the respective findings were used in the development of curative measures in treatment of epilepsy. Together with this, it was noticed that not only the number and duration of the above-mentioned attacks but also manifestations of hyperactivity underwent regression in the course of "sensorimotor" neurotraining. Lubar [7, 8] continued studies in the above direction, and it was found that the neurofeedback technique is rather effective in treatment of children with attention-deficit/hyperactivity disorders and patients with learning disabilities [7-11]. It was reported that the neurofeedback technique was used for improvement of indices of voluntary attention in healthy individuals [12, 13]. The number of such studies with the use of the neurofeedback technique remains, nonetheless, rather limited, and these tests were performed, as a rule, on adult subjects.

Studies of changes in the spectral powers (SPs) of EEG components in different neocortical regions in the course of neurofeedback sessions are also scarce. Lubar, when testing such sessions in children with attention-deficit/hyperactivity disorders, showed that, when such procedures were directed toward changes in the $beta_1$/theta SP ratio, this index, as compared with the index observed before neurofeedback sessions, significantly increased in all recording sites despite the fact that training was performed according to the data obtained in a single lead [8]. It should also be mentioned that changes of EEG in only one or two leads were usually subjected to analysis in such studies, i.e., the topographical aspect of EEG modifications was not examined.

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In our study, we estimated the efficacy of neurofeedback sessions according to the parameters of the $beta_1$ rhythm with respect to the characteristics of attention in 10- to 13-year-old children and also examined the topography of changes in SPs of the EEG frequency components in the course of such sessions.

METHODS

Twenty-nine reasonably healthy children, 10 to 13 years old, 17 boys and 12 girls, took part in the tests. Children were divided into two groups, an experimental group (n = 12) subjected to neurofeedback sessions and a control (sham-tested) group (n = 15) where EEG was recorded with no presentation of the feedback signal. The characteristics of the EEG were measured before the beginning of training and after the final neurofeedback session.

Recording of EEG and neurofeedback training were performed using two experimental sets and corresponding software. In the course of sessions, we used different variations of presentation of the neurofeedback signal; visual or acoustic signals were applied, or a game-based variant of the EEG self-control was used.

At the first stage of the tests, sessions of acoustic feedback were organized. For this purpose, an automated set, including an electroencephalograph, a laboratory interface, and a computer, was used. The EEG was recorded monopolarly from leads C3 and C4 according to the 10-20 system. Connected contacts localized above the *proc. mastoidei* were used as a reference electrode. The signals were digitized at a 100 sec^{-1} frequency.

The acoustic feedback was provided by simultaneous presentation of a musical background and acoustic noise to the subject via earphones. The intensity of white noise was the controlled parameter; this intensity changed depending on the ratio of the amplitude (SP) of the $beta_1$ rhythm to the amplitude (SP) of the theta rhythm. The greater the value of this ratio, the lower the loudness of white noise, i.e., the dependence between the noise intensity and the value of the ratio of SPs of the controlled rhythms was inversely proportional. The baseline of the ratio of these rhythms could be changed by the experimenter in the course of the session depending on the initial parameters and successfulness of self-regulation of the state of the subject.

In the subsequent courses of sessions, with visual feedback signals, a 16-channel electroencephalograph was used. The EEG activities were recorded monopolarly from leads FP1, FP2, F3, F4, F7, F8, C3, C4, T3, T4, T5, T6, P3, P4, O1, and O2 according to the international 10-20 system; the frequency of digitization of the signals was 200 sec^{-1}.

In the course of visual neurofeedback sessions, the subject was in a comfortable armchair at a 1 m distance from a monitor displaying the feedback signal, a colored rectangle whose height depended on the ratio of the SPs of the operated rhythms. The current value of this index, %, was displayed below the above symbol; the initial value of the ratio of the SP of the so-called sensorimotor rhythm, SMR, *vs* that of the theta rhythm was taken as 100%.

The software of visual neurofeedback also included a module for sessions of game EEG feedback. The child was asked to play a special “race of beetles” game where the velocity of movement or “power” of the main game character changed depending on the current SP values of the operated EEG rhythms. Therefore, the child could win the game or provide a positive direction in the development of the action only after he/she succeeded in shifting the ratio of the SPs of the EEG rhythms toward the desirable side.

Two protocols were used for the training. All children involved in the sessions of acoustic neurofeedback (n = 12) were subjected to the course corresponding to the $beta_1$ protocol. According to the latter, the SP of the $beta_1$ rhythm (16 to 20 Hz) should increase, while the theta rhythm (4 to 8 Hz) should be suppressed. Two children took part in the sessions of visual neurofeedback and game EEG self-control. The task was to increase the SP of the SMR (12 to 15 Hz) and to suppress the theta rhythm (4 to 8 Hz). In these cases, we recorded EEG from the sensorimotor cortex (C4) of the right hemisphere. The duration of the session (recording of EEG with presentation of the feedback signal) within one day was 10 to 15 min. Such a session included several (5 to 7) episodes of recording divided by short resting intervals.

Processing of EEG in the course of sessions was based on using digital Butterworth’s filters of the fourth order. The feedback signal was renewed each 10 msec. The subject was asked to try to memorize his/her state at the moment where values of the SP of the $beta_1$ rhythm or SMR were higher than pre-set thresholds, while the SP of the theta rhythm was lower than its threshold value. These threshold values for the operated rhythms were determined in the course of each session as mean amplitude values in the course of the EEG record obtained before training. Thus, current SP values of the directed rhythms were each 10 msec compared to the program with their threshold values, and the respective value of the feedback signal was calculated. This current value of the signal was equal to 100% when the SPs of the directed rhythms were equal to their threshold values; values of the feedback signal below 100% corresponded to a negative estimate of the task performance, while values greater than or equal to 100% corresponded to a positive estimate. To control the difficulty of the task performance, an automatic system of control of the EEG rhythms was included in the program. This system changed primary pre-set threshold values in the course of recording (in real time) if the number of signals informing the subject on a negative or a positive estimate of the task performance within the latest 4-sec-long interval exceeded 80%.

Before training, the necessary information on the testing procedure was presented to the subject, and the dependence of parameters of the feedback signal on the level of attention was explained. The neurofeedback course included 10 to 15 sessions repeated twice or three times per week.

Two 2-min-long samples of the background EEG, with the eyes open and closed, were recorded before and after each neurofeedback session. The SPs of the following frequency components were calculated in the course of spectral analysis of EEG: delta (1-4 Hz), theta (4-8 Hz), alpha (8-13 Hz), SMR (12-15 Hz), $beta_1$ (16-20 Hz), and $beta_2$ (21-30 Hz). The SMR recorded mostly from the central leads (where it usually dominates) will, similarly to Egner, be called a low-frequency beta rhythm [11]. The software used allowed us to calculate on-line ratios of the low-frequency beta SP *vs* theta SP and $beta_1$ SP *vs* theta SP.

Estimates of the attention indices were obtained using the following techniques. The indices "efficiency of working," "working-in," and "mental stability" were estimated using Schulte's tables. According to this test system [14], the lower the values of the above estimates, the better the developed attention. To calculate the indices "productivity of attention" and "accuracy of attention," we used a letter version of the Bourdon's correcture test [15]. Details of calculation of the attention indices with the use of Schulte's tables and Bourdon's test were described earlier [16].

Data of the electrophysiological recordings and indices of the psychological tests were quantitatively treated using standard techniques of variation statistics. To estimate differences between the indices under study in the experimental and control groups and differences between the indices of attention and spectral EEG characteristics before and after training, we used the range criteria of Mann–Witney and Wilcoxon, respectively.

RESULTS AND DISCUSSION

Neurofeedback sessions in the experimental group led to significant improvement of some indices of voluntary attention. Mean values of these indices in children of the experimental and control groups before and after the course of neurofeedback sessions are shown in Table 1. Children of the control group were unable to provide significant improvement of the attention indices according to the above-mentioned Schulte's and Bourdon's tests, while a significant increase in the "productivity of attention" index and a decrease in the "working efficiency" index were observed (remember that the smaller the latter index, the more developed the attention in the tested child).

The ongoing EEG and a graph showing changes in the $beta_1$/theta ratio were displayed in real time in the course of acoustic neurofeedback sessions.

TABLE 1. Indices of Voluntary Attention in Children of the Experimental and Control Groups (Groups I and II, Respectively) before and after the Course of EEG-Feedback Sessions

Indices of attention	Group I		Group II	
	before	after	before	after
"Working efficiency," sec	51.66 ± 3.47	44.02 ± 1.90 *	49.44 ± 3.08	57.39 ± 3.18
"Working-in"	0.98 ± 0.04	0.95 ± 0.04	1.00 ± 0.06	0.93 ± 0.04
"Mental stability"	1.03 ± 0.03	1.01 ± 0.03	1.08 ± 0.04	1.03 ± 0.04
"Productivity of attention," symbols	740.07 ± 34.25	893.35 ± 29.91**	831.6 ± 21.09	816.26 ± 21.33
"Concentration of attention," %	94.62 ± 1.01	96.14 ± 0.82	96.91 ± 0.52	96.96 ± 0.45

Footnotes. Intragroup means ± s.e.m. are shown. One and two asterisks indicate cases of significant differences between attention indices after EEG-feedback sessions and indices before the course of the latter with $P < 0.05$ and $P < 0.01$, respectively.

When sessions of visual neurofeedback or sessions in the game mode were carried out, the EEG activity recorded from 16 standard leads, the feedback signal, and ongoing values of the SPs of controlled rhythms, their threshold values, and their ratio were displayed on the monitor. Such visualization allowed us to estimate practically in time the efficiency of the neurofeedback session and to continuously observe changes manifested in the course of training and within resting periods. Figure 1 illustrates the dynamics of the ratio of the low-frequency beta SP to the theta SP immediately within the neurotraining period and within the resting (post-session) period, when the feedback signal was not presented to the subject.

To take into account the high interindividual variability of the EEG spectra and to adequately detect changes in the SPs of EEG rhythms occurring before and after neurofeedback sessions, we used normalized values characterizing the SPs of these rhythms (taking initial, observed before the course of the above sessions, powers of the rhythms as 100%).

After such a course, the SPs of the EEG frequency components in children of the experimental group changed, as compared with the respective indices before the sessions. Statistically significant shifts were found in the central region of the left (C3) and right (C4) cerebral hemispheres for the SP of the theta rhythm (in both leads, $P < 0.05$) and for the ratio between the SPs of the $beta_1$ *vs* theta rhythm (C3, $P < 0.05$ and C4, $P < 0.01$) when EEG was recorded with the eyes open. The means of the SPs of the above rhythms and the $beta_1$/theta ratios are illustrated in Fig. 2B. The latter ratio increased mostly due to a decrease in the SP of the theta rhythm. In general, we note that the theta SP is rather well controlled within the framework of the paradigm used. In children of the control group, a significant decrease in the SP within the theta range and/or an increase in the $beta_1$/theta SP ratio were not observed.

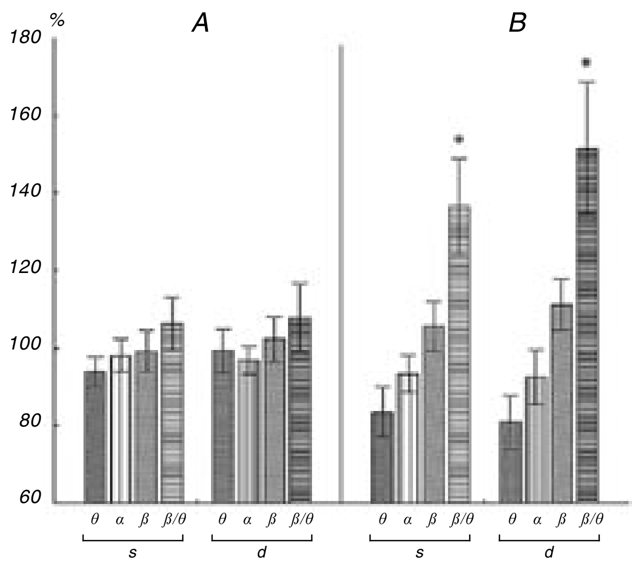

Fig. 2. Diagrams of the power of the EEG rhythms recorded from the central leads of the left and right hemispheres (s and d, respectively) in children of the control (A) and experimental (B) groups with the eyes open (final recording). Normalized values of the spectral powers, %, are shown; initial powers of the EEG rhythms and their ratio are taken as 100% (shown below the columns). Asterisks show cases of significant differences between the indices in the control and experimental groups with $P < 0.05$.

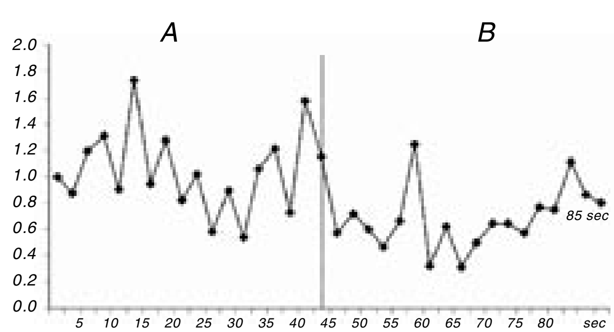

Fig. 1. Dynamics of the ratio of the spectral powers (SPs) of the low-frequency $beta_1$ *vs* theta rhythm in the course of a neurotraining session (A) and within the resting period (B). Abscissa) Time, sec; ordinate) values of the ratio of SPs of the low-frequency $beta_1$ *vs* theta rhythm, arbitrary units.

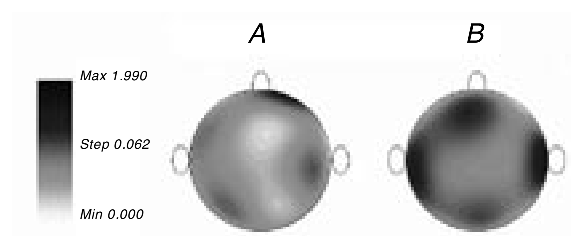

Fig. 3. Changes in the topography in the ratio of spectral powers (SPs) of the low-frequency beta *vs* theta rhythm. EEG was recorded before (A) and after (B) of EEG-feedback (neurofeedback) session in one child with the eyes open. The scale of values of the ratio of SPs of the low-frequency beta *vs* theta rhythm is shown at the left. Each topogram corresponds to 16-sec-long recording segment.

The comparison of the mean SPs of the EEG rhythms in the experimental and control groups showed significant intergroup differences between the $beta_1$/theta SP ratios in central leads of both hemispheres (Fig. 2).

A few studies demonstrated that the value of the above-mentioned ratio is one of the main EEG markers allowing one to estimate the level of development of the cognitive brain resources and to diagnose an attention-deficit/hyperactivity syndrome [17, 18]. Children with the above disorders are usually distinguished by a high power of the slow-wave activity (within the theta range) [19-21] and/or a low power of oscillations within the 12 to 21 Hz range, mostly in the frontal/central leads [21, 22]. It was reported that intensification of the slow-wave EEG activity is one of the crucial signs of generalized suppression of the cerebral activity [23-25]. The power of the beta oscillations is considered by most experimenters an EEG correlate of the intensity of cognitive processes and of focusing of attention [26, 27].

Therefore, some increase in the level of cerebral activity observed in the course of neurofeedback sessions and reflected in a decrease in the power of the slow-wave activity and an increase in the power of higher-frequency components (within the $beta_1$ range) correlated with intensification of attention and an increase in the rate of cognitive processes; this allowed children of the experimental group to demonstrate better results in attention-oriented tests.

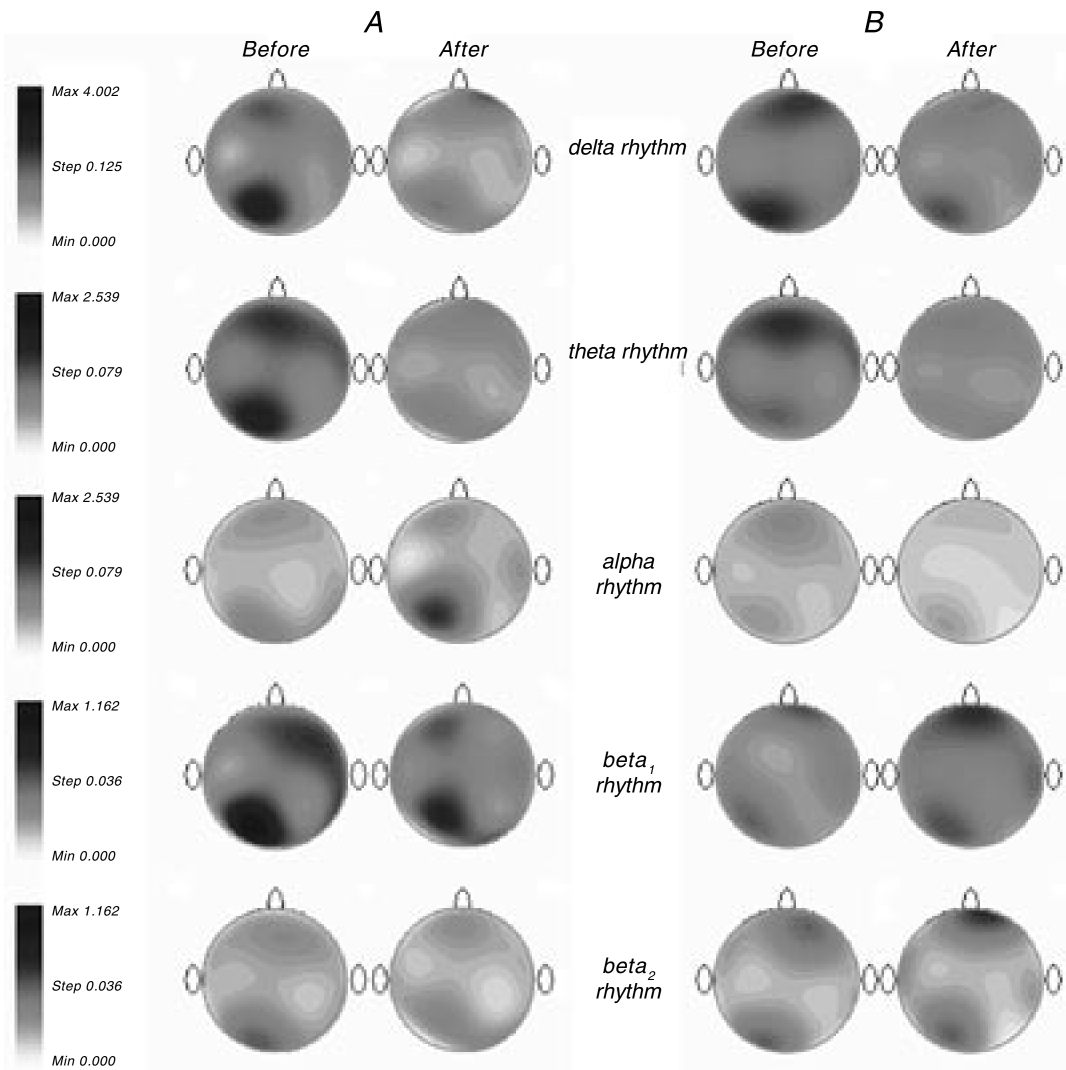

Fig. 4. Changes in the topography of the mean spectral powers (SPs) of the EEG rhythms in one child; EEG was recorded with the eyes closed (A) and open (B) before and after EEG-feedback sessions directed toward an increase in the ratio of SPs of the low-frequency beta *vs* theta rhythm. Other designations are similar to those in Fig. 3.

As the data obtained show, neurofeedback sessions can lead to objective changes reflected in the EEG pattern and accompanied by positive changes in the indices of attention. In this case, the observed changes do represent the result of training and cannot be considered “a placebo effect.”

Examination of the topography of the SPs of the EEG rhythms before and after a series of the neurofeedback sessions was one of the aims of our study. In two children, the EEG activity was simultaneously recorded in the course of such sessions from 16 leads.

Topograms of the value of the low-frequency beta/theta SP ratio in one child before and after the neurofeedback course are shown in Fig. 3. Analysis of the power spectrum of EEG showed that the ratio of SPs of the low-frequency beta *vs* theta rhythms increased in practically all recorded loci. The maximum changes of this ratio were observed in the frontocentral and temporal cortical regions. Psychological testing revealed the improvement of the “concentration of attention” index (in this child, from 92 before to 97% after the neurofeedback course). A few authors reported that an increase in the power of the low-frequency beta rhythm (12-15 Hz) in the course of neurofeedback sessions was related to a decrease in the number of erroneous reactions, according to the “Test of Variables of Attention” and also to an increase in the amplitude of the P300 wave [3]. The actual pattern of relations between the power of EEG activity within a 12-15 Hz range and the efficacy of information processing has not been estimated. Nonetheless, the following hypothesis was proposed. Processing, which underlies the control of excessive motor activity (correlated with a drop in the power of the low-frequency beta rhythm), can interfere with perceptive and integrative components of the information processing [28]. Therefore, intensification of the activity within the low-frequency beta range reflects, to a certain extent, facilitation of processing of information due to the weakening of such interference.

Figure 4 illustrates changes in the topography of mean SPs of EEG rhythms upon recording with the eyes closed and open in one child before and after the course of neurofeedback sessions. In general, such training resulted in decreases in the SPs of the delta and theta rhythms in both states, with the eyes open and closed. Post-neurofeedback recordings demonstrated domination of the alpha rhythm in occipital regions with the eyes closed. A higher level of manifestation of these oscillations in the EEG is indicative of a calm and stabilized general state of the CNS [29]. When the EEG was recorded with the eyes open, the SP of the alpha rhythm considerably dropped, and a high-frequency activity began to dominate in the EEG. Changes in the $beta_1$ rhythm were most intensely expressed in the frontal and central regions.

Thus, results of our study support the possibility of changing the general functional state of the brain both immediately during the neurofeedback session and after the course of such sessions. Training with feedback by the SP of the SMR was accompanied by noticeable changes in the ratios of the $beta_1$/theta SPs and the low-frequency beta/theta SPs. The recorded changes in the power spectrum of EEG after the neurofeedback course were accompanied by improvement of some indices of voluntary attention; thus, it is logical to conclude that EEG neurofeedback-based training is capable of considerably influencing the cerebral mechanisms responsible for the level of attention.

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