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## ERPs correlates of EEG relative beta training in ADHD children

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### Abstract

Eighty-six children (ages 9–14) with attention deficit hyperactivity disorder (ADHD) participated in this study. Event-related potentials (ERPs) were recorded in auditory GO/NOGO task before and after 15–22 sessions of EEG biofeedback. Each session consisted of 20 min of enhancing the ratio of the EEG power in 15–18 Hz band to the EEG power in the rest of spectrum, and 7–10 min of enhancing of the ratio of the EEG power in 12–15 Hz to the EEG power in the rest of spectrum with C3-Fz electrodes' placements for the first protocol and C4-Pz for the second protocol. On the basis of quality of performance during training sessions, the patients were divided into two groups: good performers and bad performers. ERPs of good performers to GO and NOGO cues gained positive components evoked within 180–420 ms latency. At the same time, no statistically significant differences between pre- and post-training ERPs were observed for bad performers. The ERP differences between post- and pretreatment conditions for good performers were distributed over frontal–central areas and appear to reflect an activation of frontal cortical areas associated with beta training.

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### 1. Introduction

Attention deficit/hyperactivity disorder (ADHD) is a childhood psychiatric disorder which, when carefully defined, affects around 1–5% of the school-age population (Swanson et al., 1998). The primary symptoms are distractibility, impulsivity and hyperactivity. They vary in degree and association, which led

DSM IV to propose three subgroups of ADHD patients: predominantly inattentive, predominantly impulsive/hyperactive and combined subtypes.

During the last three decades, EEG-based biofeedback (neurofeedback) was used as an alternative treatment for reducing symptoms of ADHD. The protocols of neurofeedback were based on an empirical observation of slowing EEG rhythms in ADHD children. This slowing is represented by increase of EEG power in theta band and corresponding decrease of EEG power in beta band (Mann et al., 1992; Janzen et al., 1995; Shabot and Serfontein, 1996; Clarke et al., 2001). In recent multi-center studies, theta/beta

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ratio measured at Cz was found highly sensitive for discriminating ADHD children from the mentally healthy population (Monastra et al., 1999).

In ADHD, a conventional neurofeedback protocol for reducing inattention and impulsivity consists of operant enhancement of beta activity and suppressing theta activity (Lubar et al., 1995a,b; Linden et al., 1996). To reduce hyperkinetic symptoms, enhancement of sensorymotor rhythm, SMR (low beta 12–15 Hz activity), is sometimes used in addition to the beta protocol.

Indexes of executive functions such as an index of inattention and an index of impulsivity as measured by TOVA (the Test of Variables of Attention, Greenberg and Waldman, 1993) were shown to change towards normative scores after intensive EEG training (Lubar et al., 1995a,b; Othmer et al., 2000; Monastra et al., 2002; Fuchs et al., 2003). In event-related potential (ERP) studies, executive functions are traditionally assessed in various modifications of GO/NOGO paradigm. ADHD children were shown to exhibit lower amplitudes of GO and NOGO P300 components in comparison to normal groups (Kropotov et al., 1999; Overtoom et al., 1998; van Leeuwen et al., 1998).

The goal of this study was to objectively assess the efficacy of biofeedback training by comparing ERPs measured before and after 20 sessions of neurotherapy in a group of ADHD children.

## 2. Methods

### 2.1. Subjects

Eighty-six children with ADHD symptoms (77 boys and 9 girls, ages 9–14 years, mean 11.4 years) voluntarily participated in this study. All subjects were Russian-speaking schoolchildren who attended normal secondary schools in St.-Petersburg, Russia. Children with ADHD were referred to the Neurotherapy Center at the Clinics of the Institute of the Human Brain of Russian Academy of Sciences in St.-Petersburg, Russia. Only right-handed children were included in the study. None of the children was receiving medication at the time of testing. Children with histories of epilepsy, drug abuse, head injury, or psychotic disorders were excluded. The patients were evaluated by a psychiatrist (Chutko, L.S., PhD, MD)

and received a primary DSM-IV (American Psychiatric Association, 1994) diagnosis of attention deficit hyperactivity disorder.

### 2.2. Assessment of behaviour

An adapted version of SNAP-4 parents' questionnaire (Swanson, 1992) was used for subjective estimation of the level of attention deficit, hyperactivity, and impulsiveness. These subjective assessments of behaviour were calculated from results of the parents' answers and then compared to the normative values.

In addition, all patients performed the auditory two-stimulus GO/NOGO task. This continuous performance task included 480 trials. Two tones—high frequency tone of 1300 Hz (referred to as H) and low frequency tone of 1000 Hz (referred to as L)—were used as stimuli. Pairs of stimuli, LL and LH, were presented at random with a 50% probability. The stimuli duration was 100 ms, and the sound intensity was 75 dB. Intervals between stimuli within pairs and between pairs were 800 and 1500 ms, respectively. The task of a subject was to press a button with the right hand in response to the LL pair (target). The duration of the task was 20 min with two to three short intervals of 1–2 min for rest.

For each subject, the number of omission of targets and the number of commission of non-targets were measured. A subject was considered to make a correct response if he/she pressed a button during 200–1000 ms interval after the second stimulus presentation for the LL pair. The speed of information processing was evaluated by measuring the mean response time for correct responses to the LL pair. The standard deviation of response time for correct responses to the LL pair was used as a measure of consistency of attention.

### 2.3. ERP recordings

The ERPs in all patients were registered during performance of the auditory GO/NOGO task described above (Section 2.2).

Electroencephalogram (EEG) was recorded by the Telepat-104 24-channel EEG system (Potential, Russia) and by the Mitsar 21-channel EEG system (Mitsar, Russia). Nineteen silver-chloride electrodes were placed on the skull according the standard 10-20

system. The input signals referred to the tip of the nose were amplified (bandpass 0.5–30 Hz) and sampled at the rate of 250 Hz. The ground electrode was placed on the forehead. Impedance was kept below 10 k $\Omega$ . Oculogram was recorded from an electrode placed above the upper part of the orbicular muscle. EEG was continuously recorded on the hard disc.

ERPs were computed off line. The epoch of analysis included 300 ms before the first stimulus and 900 ms after the second stimulus. Trials containing electrooculogram artefacts (exceeding 100  $\mu$ V threshold) were discarded from further analysis. Five trials in the beginning of each recording and after each break were excluded from analysis to get rid of orienting response. Trials with omission and commission errors were also excluded from analysis. To get reliable ERPs, we needed more than 70 trials for each condition.

All patients performed GO/NOGO task twice: a pre-training testing usually took place 1–7 days before biofeedback course, and post-training testing, 1–7 days after the last training session.

#### 2.4. Statistical analysis

Three time segments corresponding to early components, N1 (80–130 ms) and P2 (130–180 ms), and to late ERP complexes (180–420 ms after the second stimulus) for both conditions (GO and NOGO) were selected for further analysis. Two-way ANOVAs for repeated measurement with factors TREATMENT (before and after training) and LOCATION (19 electrodes) were calculated to evaluate differences between ERP components for GO and NOGO conditions separately. The Greenhouse–Geisser procedure was used to compensate for violations of sphericity of circularity.

Sign test was used for estimation of treatment-related changes of SNAP scale and indexes of performance in GO/NOGO task (omission, commission errors, reaction time and its standard deviation).

#### 2.5. Procedure of neurofeedback

The EEG training was performed on the Telepat-104 or on the Mitsar EEG system. We used bipolar montage with C3-Fz or C4-Pz in the standard 10-20 system. Left-side (C3) and right-side (C4) training

involved rewarding activity in the 15–18 and 12–15 Hz, respectively. These two protocols were used in succession during a single training session with the following duration: 20 min of relative beta training, 7–10 min of relative SMR training. To reach muscular relaxation in our patients during the initial three to five sessions in addition to beta training, we used 5–10 min of alpha training with a bipolar recording from Oz-Fz.

The biofeedback procedure included the following computations. Power spectrum was calculated for a 1-s epoch every 250 ms using fast Fourier transformation. The ratio between the trained rhythm power and the power of low (1–11 Hz) and high (19–30 Hz) frequencies served as biofeedback parameter.

Visual feedback was provided by a blue bar against a grey background on a computer screen. The height of the bar followed the dynamics of the biofeedback parameter. Patient's task was to keep the bar above a threshold.

Video mode was used as another kind of visual presentation of the biofeedback signal. In this mode, the biofeedback parameter controlled the level of a noise generated by a separate electronic unit called Jammer (the unit was designed specifically for this purpose in the laboratory). The amplitude of the noise was maximal if the biofeedback parameter was minimal, and decreased gradually up to zero while the parameter approached a threshold. The noise was mixed with the videosignal of the video-player and was fed to the TV. Thus the patient actually controlled the quality of the picture on the screen by his/her brainwaves: when the biofeedback parameter was higher than threshold, the picture on the screen was clear, otherwise the TV picture was blurred by the noise. Usually during the first five to eight sessions, patients performed training with the bar. Then training in the video mode started.

The threshold for the biofeedback parameter was defined by the prefeedback baseline mean measure taken during a 2.5-min feedback-free period with eyes opened at the beginning of the first session in a way to grant that the biofeedback parameter exceeds the threshold about 50% of the time. During the rest of the sessions, we tried not to change the threshold. However, in 20% of children, the background activity changed in time so that the threshold set at the first day became too low in the following sessions

making the whole task quite easy for a child. In such cases, we tailored the threshold during sessions. Threshold was typically set in the range of about 0.03–0.05 and 0.05–0.1 for junior and senior age groups, respectively.

The patient was instructed about the rationale of the procedure, as well as about the dependence of the biofeedback signal on the brain activity and attention. Before the procedure, the patient tried to relax, decrease muscular tension, and maintain regular diaphragmatic breath. Patient was asked to assess his or her own internal state and feelings when the biofeedback parameter surpassed the threshold and to reproduce this

state. Different patients used different strategies with a common numerator of concentrating on a particular external object.

The number of training sessions for each patient varied on several factors such as age, type of ADHD, learning curves, parent reports, and varied from 15 to 22 (mean 17). The termination criteria was (1) stabilization of training performance (assessed by the dynamics of the trained parameter, see Section 2.6) during the last three to five sessions, and (2) stabilization of patient's behaviour according to parent reports. Sessions were administrated two to five times per week for 5–8 weeks.

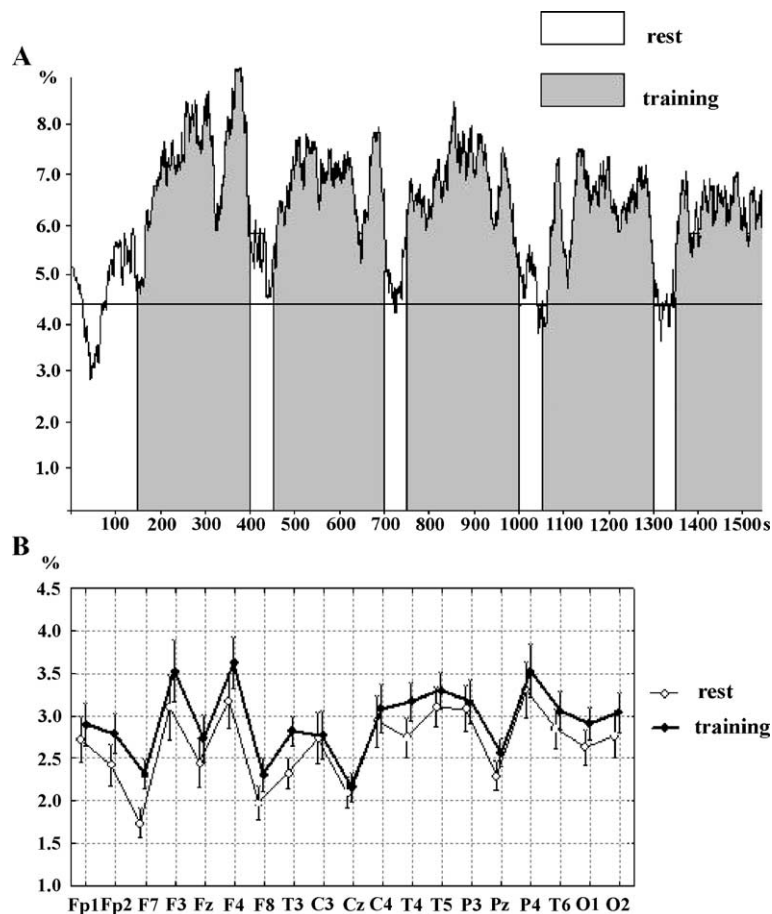


Fig. 1. Relative beta power during a training session. (A) Dynamics of the biofeedback parameter during a single training session in an ADHD boy. Horizontal axis: time in ms; vertical axis: beta relative power in percent. (B) Mean values (averaged over 22 patients) of relative beta power at rest and training periods computed in 19 electrodes for a single session at the end of the training course. Horizontal axis: electrode locations; vertical axis: means and standard deviations of beta relative power in percent.

Table 1  
Mean standard scores for SNAP-4 and GO/NOGO test measures before and after biofeedback course

Dependent measure		Before treatment	After treatment
<i>SNAP-4</i>			
Inattention	standard scores	2.3 ± 0.3	1.75 ± 0.4**
Hyperactivity		1.45 ± 0.3	1.1 ± 0.4*
<i>GO/NOGO test</i>			
Inattention	% of omissions	45.05 ± 33.81	22.43 ± 14.1**
Impulsivity	% of commissions	20.05 ± 15.49	8.67 ± 5.19**
Response time	ms	618 ± 92.7	576 ± 94.5**
Standard error of response time	ms	11.7 ± 1.74	4.19 ± 1.72**

\*  $p < 0.05$ —level of significance of difference between “before” and “after” condition.

\*\*  $p < 0.01$ —level of significance of difference between “before” and “after” condition.

### 2.6. Assessment of performance during training

The dynamics of the biofeedback parameter was analyzed for each patient and for each session. Fig. 1A shows a typical curve for a single patient taken at the 15th session. One can see that the patient was able to elevate the parameter during periods of training while the parameter dropped at the pre-training level during rest periods.

Fig. 1B shows comparison of mean values of relative beta power (averaged across 22 patients) at 19 electrodes between rest and training periods. The recordings were made during one session at the end of treatment. A registration of EEG from 19 electrodes during a biofeedback training session is a time-consuming procedure; therefore, we randomly selected only 22 patients for this investigation. Again, one can see a statistically significant ( $F(1,119) = 6,117$ ),  $p < 0.015$ ) difference of EEG power in beta range between rest and training periods.

Further, the quality of patient’s performance, i.e. the ability of a patient to increase the biofeedback parameter during training periods, was assessed. We considered the training session to be successful if a patient was able to increase the biofeedback parameter during training periods at more than 25% in comparison to resting periods. Patients were referred to as

good performers if they were successful in more than 60% of sessions. Seventy-one patients (82.5%) belonged to the good performance group. Those patients who had less than 60% successful training sessions were referred to as bad performers. Fifteen patients (17.5%) belonged to the bad performance group. This group was considered as a kind of control group in the following data analysis.

## 3. Results

### 3.1. Pre-training assessment

Table 1 (left columns) shows mean pretreatment scores of behavior computed for the group of 71 good performers. Table 2 (left columns) shows mean pretreatment scores of behavior computed for the group of 15 bad performers. SNAP-4 scores were based on the results of fulfilling the SNAP-4 questionnaire by one of the parents. GO/NOGO scores were based on the results of the performance of GO/NOGO tasks by patients.

Figs. 2 and 3 (thin lines) present the averaged ERPs recorded in auditory GO/NOGO task in response to second stimuli (GO (Fig. 2) and NOGO (Fig. 3)) before the neurofeedback sessions in the good performers group. At least four different com-

Table 2  
Mean standard scores for SNAP-4 and GO/NOGO test measures before and after biofeedback course for 15 poor performers

Dependent measure		Before treatment	After treatment
<i>SNAP-4</i>			
Inattention	Standard scores	2.1 ± 0.3	2.15 ± 0.3
Hyperactivity		1.3 ± 0.3	1.25 ± 0.3
<i>GO/NOGO test</i>			
Inattention	% of omissions	44.4 ± 22.5	24.9 ± 17.5**
Impulsivity	% of commissions	23.71 ± 19.07	10.5 ± 8.15*
Response time	ms	622 ± 100.74	615 ± 85.81
Standard error of response time	ms	11.0 ± 1.87	9.8 ± 2.54

\*  $p < 0.05$ —level of significance of difference between “before” and “after” condition.

\*\*  $p < 0.01$ —level of significance of difference between “before” and “after” condition.

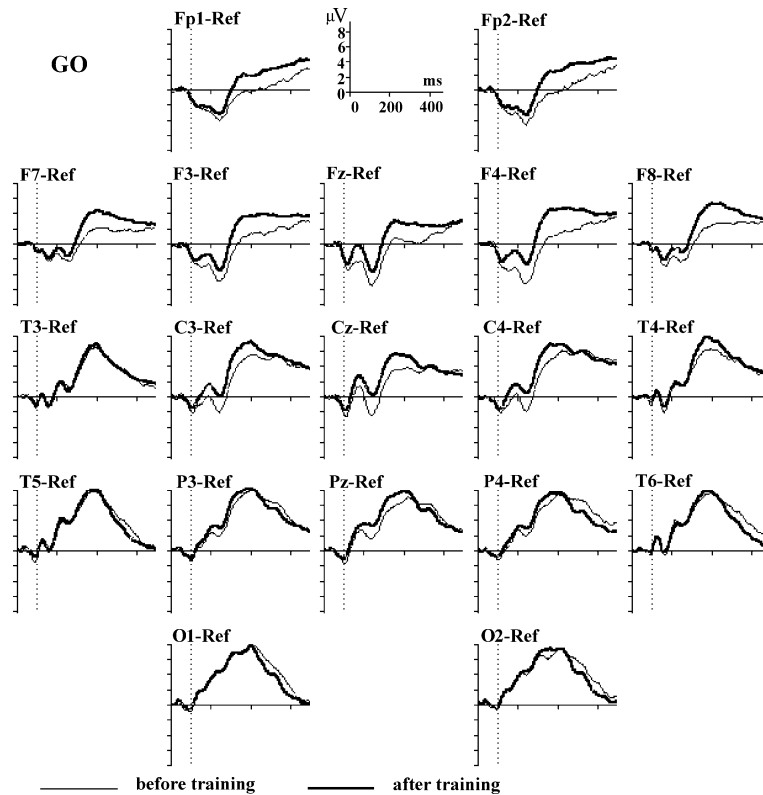


Fig. 2. Grand average GO ERPs in the two stimulus auditory GO/NOGO test for the group of good performers before and after 20 sessions of the relative beta training. Horizontal axis: time in ms; vertical axis: averaged scalp potentials recorded in different electrode locations (Fp1, Fp2, ..., O1, O2). Thin line: ERPs taken before training; thick line: ERPs taken after 20 sessions of training.

ponents of ERPs could be visually separated. The earliest (N100) is a negative component with a peak latency at about 100 ms. It was distributed over frontal and central cortical areas. The P200 component, defined as a positive fluctuation after the N100 component, has its peak latency between 130 and 210 ms in different patients. It is distributed over parietal and central areas of the cortex. A negative fluctuation following the P200 component was labelled as N200 component. It had peak latency at about 200–250 ms in different patients. This component was distributed over central–frontal regions of the cortex. No statistically significant differences for N100 and P200 components were observed between GO and NOGO conditions.

The N200 component was followed by P300 components. The P300 to GO stimuli will be referred to as GO component, while the P300 to NOGO stimuli will be referred to as NOGO component. As

one can see from the figures, NOGO component had more anterior distribution in comparison to GO component. Comparison of values of positive GO and NOGO components gave a statistically significant interaction of factors “electrode location” and “GO, NOGO conditions” ( $F(18,972)=11.2, p<0.0001$ ).

### 3.2. Post-training assessment

On the basis of assessment of the quality of performance during biofeedback training, 71 of 86 (82.5%) children were referred to as good performers (see Section 2.6). The parents of good performers reported that they became more assiduous and concentrated during school lessons and preparing homework, performed their schoolwork more quickly, improved their grades, showed more motivation for school subjects, and improved relationship with their friends and family, especially in conflicting situations.

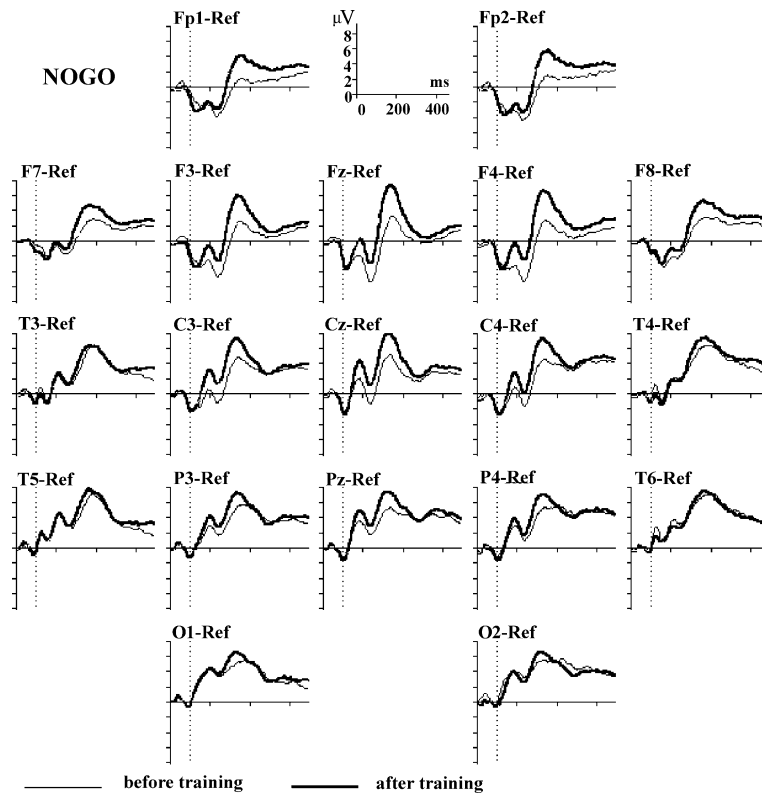


Fig. 3. Grand average NOGO ERPs in the two-stimulus auditory GO/NOGO test for the group of good performers before and after 20 sessions of the relative beta training. Horizontal axis: time in ms; vertical axis: averaged scalp potentials recorded in different electrode locations (Fp1, Fp2, ..., O1, O2). Thin line: ERPs taken before training; thick line: ERPs taken after 20 sessions of training.

According to SNAP-4 parents' questionnaire, the average degree of inattention in good performers decreased from 2.3 to 1.75 ( $p < 0.01$ ), whereas the mean impulsiveness/hyperactivity level decreased from 1.45 to 1.20 ( $p < 0.05$ ) after the training course (Table 1).

In these, 71 patients' indexes of performance in GO/NOGO test were significantly improved after training (Table 1). Significant decreases were observed in the number of target omissions ( $Z(37) = 4.6$ ,  $p < 0.001$ ), non-target commissions ( $Z(34) = 3.9$ ,  $p < 0.001$ ), response time ( $Z(37) = 3.6$ ,  $p < 0.001$ ) and the variability of the response time ( $Z(37) = 3.6$ ,  $p < 0.001$ ).

No statistically reliable changes were found for SNAP-4 scores in the bad performers group (Table 2). However, a sign test revealed statistically significant decrease in the number of omission ( $Z(13) = 2.7$ ,  $p < 0.01$ ) and commission errors

( $Z(13) = 2.2$ ,  $p < 0.05$ ) in GO/NOGO task in the bad performers group, but in contrast to the good performers group, no changes were found for reaction time and its standard deviation.

### 3.3. Electrophysiological parameters

To get reliable ERPs for each condition, we needed a sufficient number of trials for averaging. Recall that the background EEG was about 50–70  $\mu\text{V}$  while GO and NOGO components are about 10  $\mu\text{V}$ , so to get a good signal to noise ratio more than 70 trials required. The total number of trials for each category was 240. Children with ADHD made errors in about 20% of trials (see Tables 1 and 2) and had quite a lot of EOG artefacts during EEG recording. For these reasons, the number of patients with reliable ERPs was 50 (37 good performers and 13 bad performers).

Figs. 2 and 3 demonstrate changes induced in ERPs by neurofeedback training in the group of good performers.

No statistically reliable changes were found for early components (80–130 and 130–180 ms). Late positive components (180–420 ms) exhibited significant changes.

For GO condition in good performers, two-way ANOVA (before/after treatment) for 19 electrodes did not reveal significant difference in the amplitude of late additional complex in 180–420 ms interval after the second stimulus ( $F(1,72)=2.3994$ ,  $p<0.126$ ). However, a significant interaction of two factors (before/after treatment) and electrode localization were observed ( $F(18,1296)=2.3844$ ,  $p<0.0001$ ). Further, two-way ANOVA (before/after treatment) for F3, Fz, F4 recordings revealed significant differences in the amplitude of late additional complex in 180–420 ms interval in GO condition ( $F(1,72)=6.2348$ ,  $p<0.015$ ). For NOGO condition, two-way ANOVA (before/after treatment) for 19 electrodes revealed a significant difference in the amplitude of late additional complex

in the 180–420 ms interval after the second stimulus ( $F(1,72)=4.1998$ ,  $p<0.044$ ) parallel with significant interaction of factors (before/after treatment) and electrode localization ( $F(18,1296)=6.7154$ ,  $p<0.00001$ ). For F3, Fz, F4 recordings, the difference was even more statistically significant ( $F(1,72)=12.4665$ ,  $p<0.00073$ ) than for GO condition.

Fig. 4 compares ERP differences induced by 20 sessions of neurofeedback in two groups: 37 good performers and 13 bad performers. In contrast to good performers, two-way ANOVA (before/after treatment) in bad performers did not reveal any significant difference in amplitude of late additional complex for both GO and NOGO conditions (for GO condition for 19 electrodes  $F(1,24)=0.0356$ ,  $p<0.852$ , for F3, Fz, F4 electrodes  $F(1,24)=1.2453$ ,  $p<0.276$ ; for NOGO condition for 19 electrodes  $F(1,24)=0.0284$ ,  $p<0.868$ , for F3, Fz, F4 recordings  $F(1,24)=0.7882$ ,  $p<0.384$ ).

In addition, two-way ANOVA with a “group” factor (group of good performers/group of bad performers) was used to compare the ERP dynamics in

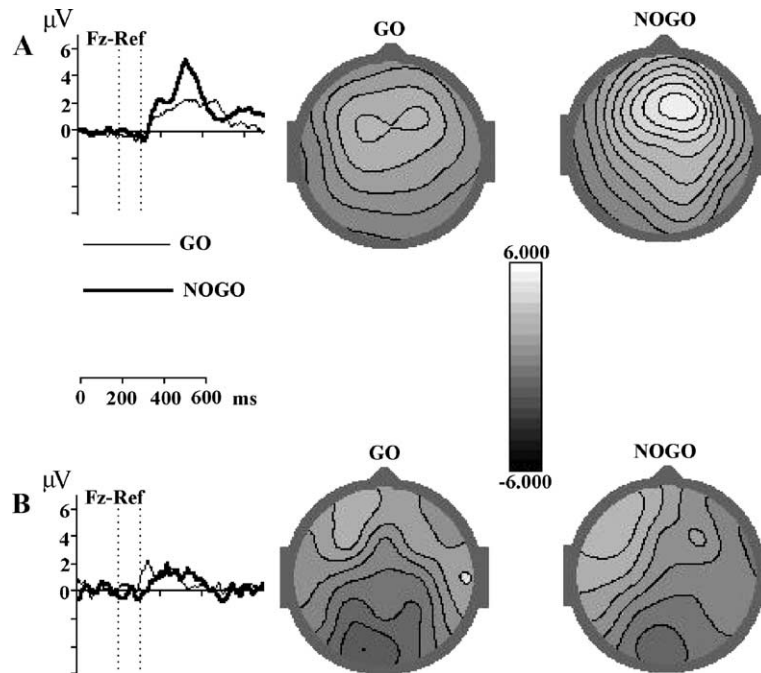


Fig. 4. Comparison of ERPs differences induced by 20 sessions of neurofeedback in the groups of good (A) and bad (B) performers. At the left: grand average ERP differences for GO (thin line) and NOGO (thick line) stimuli taken for Fz location. At the right: maps of grand average ERP differences for GO and NOGO stimuli taken at 310 ms after stimulus. Mapping scale is presented in the middle.

those two groups. With this goal, ERP dynamics (computed as ERP after treatment minus ERP before treatment) were used as the input data. Significant differences of ERP treatment-related dynamics between two groups were observed only for NOGO condition ( $F(18,882)=1.72, p<0.05$ ).

## 4. Discussions

### 4.1. Selection of protocol

In our study, we selected a protocol that implemented a relative beta power as a biofeedback parameter. This parameter was defined as a ratio of EEG power in beta frequency range to the EEG power in the rest of the frequency range. Most of conventional protocols use simultaneous elevation of beta activity and suppression of theta activity (Lubar et al., 1995a,b; Linden et al., 1996; Othmer et al., 2000).

Theoretically, our protocol differs from conventional protocols, because elevation of the biofeedback parameter in our study could be achieved by increasing beta power, and/or by decreasing theta as well as alpha power. However, as the results of the present study indicate, the application of our protocol turns out to be as effective as conventional protocols. Indeed, 82.5% of our patients were able to significantly increase (for more than 30%) their biofeedback parameter in more than 60% of sessions. Moreover, according to parents' assessment by SNAP-IV, 20 sessions of this type of neurofeedback significantly improved behavior (indexes of inattention and impulsivity) in our patients. These results are comparable with the data of previously reported studies (Alhambra et al., 1995; Lubar et al., 1995a,b).

### 4.2. GO/NOGO task

Extensive research has shown that ADHD children perform worse than normal children on a wide range of continuous performance tasks—CPTs (Douglas and Parry, 1983). TOVA is considered as a variant of CPT and is widely used for objective assessment of parameters of attention. Previous research showed that neurofeedback training improved TOVA variables such as variables of attention, impulsivity control, processing speed and consistence of response (Lubar

et al., 1995a,b; Rossiter and LaVaque, 1995; Othmer et al., 2000).

In our study, we used auditory two-stimulus GO/NOGO task for objective assessment of parameters of attention. This task is a type of continuous performance test with equal probabilities of GO and NOGO cues (note that in TOVA the probabilities of GO and NOGO cues are different at the first and second parts of testing). And again, our results are in good agreement with the previous research: 20 sessions of relative beta training in the present study significantly decreased commission and omission errors, response time and its variability.

There are several ways to explain decrease of omission and commission errors in GO/NOGO task scores in bad performers group after treatment. First of all, in spite of the absence of clinical improvement according to parents' reports and insignificant ERP changes, children from the bad performance group still fulfilled neurofeedback training during 15–20 sessions and performed successfully in at least 30% of sessions. Second, after regularly visiting the clinic for 1.5–2 months, the children became accustomed to the clinical environment and were less stressed during performance of GO/NOGO task in comparison with pretreatment investigation which might lead to more effective performance during the task.

### 4.3. ERPs data

The main goal of this study was to observe changes in ERPs induced by neurofeedback. We found that relative beta training does not change early (with latencies of 80–180 ms) components of ERPs but leads to significant enhancement of later components.

The early ERP components in our study include N1 and P2 waves. The N1 component is distributed over the frontal areas and seems to reflect a volume conducted potentials generated in auditory cortical areas of the temporal cortex (Naatanen, 1992). Thus, our data indicate that relative beta training does not effect auditory information processing in the human brain.

Late ERP components that follow N1 and P2 components have been traditionally associated with executive functions—engagement and disengagement operations in control of behavior (Simson et al., 1977; Roberts et al., 1994; Kropotov et al., 1997, 1999). In

visual modality NOGO N2 component seems to reflect a frontal inhibition mechanism (Ritter et al., 1982; Jodo and Kayama, 1992; Falkenstein et al., 1999), while in auditory modality no evidence of significant NOGO N2 was found (Simson et al., 1977; Falkenstein et al., 1995). The topographical assessment of the P300 fields (Fallgatter and Strik, 1999) as well as their LORETA images (Bokura et al., 2001) yielded a robust result consisting of more anterior distribution of NOGO component compared to GO component. Our data are in good agreement with these findings.

Our study shows that neurofeedback sessions of relative beta training lead to enhancement of both GO and NOGO components. This enhancement is represented in a form of a difference wave (“ERPs after” minus “ERPs before”). Egner and Gruzelier (2001) reported significant increases in odd-ball P300 of healthy volunteers after neurofeedback training directed to enhancement of 12–15 and 15–18 Hz activities. Taking into account that P300b recorded in odd-ball tasks and GO P300 recorded in GO/NOGO tasks have similar spatial distribution, our studies appear to support these previous findings: intensive beta training leads to enhancement of target P300 components of ERPs.

A vast amount of empirical knowledge has shown that executive functions, such as attention and motor control, are maintained by neuronal circuits including the frontal lobes and the basal ganglia thalamo-cortical pathways (Castellanos, 1997; Kropotov et al., 1997, 1999). These circuits also participate in self-regulation of the frontal cortex (Alexander et al., 1986; Brunia, 1992). On the other hand, ADHD children are reported to exhibit abnormalities in both the frontal cortex and the basal ganglia. These abnormalities include lower metabolic activity, smaller sizes and higher concentration of dopamine transporter (DAT) receptors in the basal ganglia (Lou et al., 1984; Zametkin et al., 1990, 1993; Castellanos, 1997; Dresel et al., 2000).

The decrease of metabolic activity in the frontal cortex of ADHD children seems to be associated with thalamo-cortical dysrhythmia: increase of theta activity and decrease of beta activity in ADHD children (Mann et al., 1992; Janzen et al., 1995; Shabot and Serfontein, 1996; Monastra et al., 1999; Clarke et al., 2001). This association is directly supported by the

recent studies that found a strong positive correlation between perfusion measured by PET and EEG power in beta band, so that decreased level of beta activity in frontal region would correspond to a lower level of metabolic activity of this area (Cook et al., 1998).

According to this assumption, relative beta training with electrodes located above the frontal areas is associated with activation of the underlying frontal cortex. In our study, the differences in ERP waves (“ERPs after” minus “ERPs before”) induced by neurofeedback training are distributed over the frontal lobes. Consequently, the emergence of late additional ERP component in response to both GO and NOGO stimuli after beta training might be a correlate of training-related activation of the frontal cortex. This activation seems to indicate the recovery of normal functioning of the executive system.

The present study was the first to reveal ERP correlates of relative beta training. It shows that not only psychophysical parameters of attention are improved by the neurotherapy but also objective neurophysiological parameters are changed reflecting improvement of behavior control in ADHD after neurotherapy.

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