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Treatment of ADHD: comparison of EEG-biofeedback and methylphenidate

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Summary

Aim of the study: The purpose of the study was to evaluate the efficacy of the electroencephalogram (EEG)-biofeedback (NF) method in attention-deficit hyperactivity disorder (ADHD) treatment in each of the three basic DSM-IV-TR clinical types.

Materials and method: 85 patients aged 6 to 14 years treated in an outpatient department and a day care department (S) were qualified for the EEG-biofeedback therapy, whereas the control group consisted of 30 patients (C) who were treated with methylphenidate. For the purpose of evaluating the efficacy of treatment, a structured interview on the presence of the ADHD symptoms was used. The S group patients participated in 20 NF therapy sessions throughout a six-month period. An analysis of electrophysiological parameters of EEG was additionally conducted in group S – theta/sensorimotor rhythm (SMR) and theta/beta ratios in C3 and C4 channels at three points in time (at the beginning, during and at the end of the EEG-biofeedback therapy).

Results: Both types of S and C group therapies significantly reduce ($p<0.01$) the number of attention deficit, hyperactivity and impulsiveness symptoms in subgroups with attention deficit prevalence and mixed type ADHD. In all ADHD types a significant decrease in values of the examined theta/SMR and theta/beta ratios was noted between sessions 1 and 10.

Conclusions: The NF method proved similarly effective to methylphenidate in reducing the number of symptoms in two types of ADHD: ADHD with the prevalence of attention deficit and in mixed type ADHD.

EEG-biofeedback/ADHD/methylphenidate

INTRODUCTION

The prevalence of attention-deficit hyperactivity disorder (ADHD) (the DSM-IV classification criteria) reaches 3.9–8% in school-age children [1-3]. The electroencephalographic examinations showed that children with ADHD show an increased activity of theta waves [4-5] in frontal areas [6], an increased delta activity in the occipital area [5] and a decreased alpha and beta activity [7] in the posterior areas [5] of the brain. For diagnostic purposes, an analysis of the dynamics of changes in the theta/alpha ratio [5, 8] and the theta/beta ratio was conducted [5, 9]. The majority of such tests refer to cases with mixed-type ADHD with the prevalence of hyperactivity, less commonly to cases with the attention deficit ADHD type. In children with the latter

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form of ADHD, similar changes as in the mixed type ADHD [8] are observed (increased theta, decreased alpha and beta [5, 10] activity), however, they are not as explicit as in the hyperactivity type [5].

A comprehensive treatment of ADHD, in accordance with the standards applicable in Poland, consists in the use of psychoeducation, behavioural therapy, and in the case of their inefficacy – pharmacotherapy. Unfortunately, such treatment is more expensive and is not always sufficient. Moreover, psychostimulants cause a number of side-effects.

One of the non-standard, behavioural methods of ADHD treatment is electroencephalogram (EEG)-biofeedback (NF), which has been used for more than a decade in the USA, Great Britain, France and other countries. In Poland this method is relatively new and so far it has mainly been used in the treatment of epilepsy and within the so-called alternative medicine. International literature describes intensive development of the NF method in private practices, at the same time, however, emphasizing lack of research regarding its efficacy [12]. Therefore, we set out to evaluate the efficacy of NF in ADHD treatment in three basic clinical ADHD types ((1) with the prevalence of attention deficit, (2) with the prevalence of hyperactivity and impulsiveness and (3) mixed type) in comparison to methylphenidate.

MATERIAL AND METHODS

The study was conducted in the Neuromed Centre of Neuropsychiatry in Wrocław at a day care department and at a mental health outpatient clinic for children and young adults. Two groups that met similar criteria regarding age (6-14 years old) and the nature of the disorder were selected. A six-month observation period was established. The study group (S) consisted of 85 patients treated with EEG-biofeedback, whereas the control group (C) included 30 patients treated with methylphenidate.

The study received approval of the Bioethics Committee of the Wroclaw Medical University. The prerequisite for participation in EEG-biofeedback treatment was obtaining informed consent of a legal guardian.

The following exclusion criteria were adopted: lack of a child's consent, if the child had proper understanding of the essence of the treatment; epilepsy mentioned in the medical history and/or confirmed by EEG; mental retardation; use of pharmacotherapy; intercurrent disorders (specific developmental disorders and developmental disorders of scholastic skills, behavioural disorders, oppositional defiant disorders, emotional disturbances, anxiety, misuse of psychoactive substances).

TOOLS

Aggravation of ADHD symptoms was evaluated based on a structured interview concerning the presence of the ADHD symptoms according to DSM-IV, which allows for an assessment of a number of existing symptoms (fulfillment of diagnostic criteria) and evaluation of their aggravation [12].

A computer system provided by ALIEN with a 4-channel module was used during the NF training sessions. All patients underwent universal training that followed the C3/theta/beta model and C4/theta/sensory motor rhythm (SMR), improving their attention and reducing levels of anxiety.

Patients were qualified for treatment based on the diagnosis of hyperkinetic disorder, in accordance with the diagnostic classification in DSM-IV. The study group (S, n=85 patients) and the control group (C, n=30 patients) were further divided into three subgroups characterized by the prevalence of one of the three basic clinical types of ADHD according to DSM-IV: subgroup 1 – with attention deficit prevalence; subgroup 2 – with hyperactivity and impulsiveness prevalence; and subgroup 3 – mixed type. After conducting the EEG in the study group (to exclude epilepsy) in all three subgroups, 20 EEG-biofeedback therapy sessions were conducted at weekly intervals – 10 training sessions for each hemisphere (according to Lubar 20 EEG-biofeedback training sessions are sufficient) [9]. Every session lasted 30 minutes. The difficulty level of the training was modified by delaying the provocative stimuli. The treatment was conducted by a person holding a certificate in clinical neurophysiology who has the competences required

to conduct the EEG-biofeedback treatment. Patients from the control group were routinely treated pharmacologically with methylphenidate products in adequate doses adjusted to their age (Medikinet 10–30 mg/d, Concerta 18–36 mg/d). After 6 months of treatment both the study group and the control group were subjected to re-evaluation of ADHD symptoms aggravation. Additionally, an analysis of electrophysiological parameters of the EEG was conducted in the study group – theta/SMR and theta/beta ratios in C3 and C4 channels at the beginning, in the course of and at the end of EEG-biofeedback therapy. It was aimed at evaluating changes in these ratios after the EEG-biofeedback treatment.

STATISTICAL ANALYSES

The examined features were continuous random variables and discrete random variables, which may assume values from an at most countable set. There were also nominal variables (non-measurable), such as the type of therapy.

The nature of changes in EEG parameters in subsequent NF sessions was determined by estimating a non-linear mathematical model – polynomial of a second degree. The quality of the model fitting the experimental data was assessed by calculating the coefficient of determination, R^2.

The analysis of those variables whose ranks were measurable (sum of symptoms points, number of symptoms) was done by calculating the order statistics: Me – median, Q_1 – lower quartile and Q_3 – upper quartile. The significance of differences between medians in three groups of children with different ADHD types was verified by the Kruskal-Wallis test, which is a non-parametric equivalent of variance analysis. In the cases in which there were only two groups (S vs C) the Mann-Whitney *U*-test was used. In all cases, the statistically important differences between ranked characteristics were assumed as $p<0.05$. The comparison of medians in two related groups of patients (result before vs after the therapy) was conducted using the non-parametric Wilcoxon's test.

Calculations were made with the use of STATISTICA statistical software package (v. 9) as well as an MS Excel spreadsheet [13-17].

RESULTS

Group size

Table 1. ADHD types in the study group and the control group before the treatment

ADHD type	Before the treatment		p
	Study group (S)	Control group (C)	
Subgroup 1 – type with attention deficit prevalence	35 (41.2%)	7 (23.3%)	0.083
Subgroup 2 – type with hyperactivity + impulsiveness prevalence	4 (4,7%)	0 (0,0%)	0.223
Subgroup 3 – mixed type	46 (54.1%)	23 (76.7%)	0.032
Total 1 + 2 + 3	85 (100%)	30 (100%)	

The percentage of patients with mixed ADHD in the S group was lower than in the control group ($p<0.05$), but at the same time it was the largest ADHD subgroup. The least numerous was the subgroup with hyperactivity and impulsiveness prevalence.

AGE

Participants of the tests included children from the age of 6 to 14years (mean 10.7; SD = 2.5). Core age statistics have been presented in Table 2.

Table 2. Age of participants in groups S and C

Parameter	Total n = 125	Study group (S) n = 93	Control group (C) n = 32	S vs C p
Age [years]:				0.112[a]
average± SD	10.7 ± 2.5	11.0 ± 2.6	10.1 ± 2.3	
Me <Q1; Q3>	11 <9; 12>	11 <9; 13>	10 <8; 12>	

a – Student's t-test

The age difference among children in both groups was statistically non-significant ($p>0.05$).

GENDER

Table 4. Patient structure in the control group (methylphenidate) according to sex in groups differing in the type of ADHD before treatment.

	Control group (C)			Total	Test results
	1	2	3		
L group size	n = 7	n = 0	n = 23	n = 30	
Sex					
girls	0 (0.0%)	0 (0.0%)	1 (4.3%)	1 (3.3%)	$\chi^2 = 0.41$
boys	7 (100.0%)	0 (0.0%)	22 (95.7%)	29 (96.7%)	p = 0,521

No statistically important relationship between the ADHD type and the patients' gender in the study group (EEG-biofeedback) or in the control group was observed. Both groups are consistent in terms of gender structure (p>0.05) with a prevalence of boys.

Number of attention deficit symptoms.

Table 5. Statistics of the number of attention deficit symptoms in the study group and the subgroup 1 and 3 consisting of patients treated with methylphenidate, as well as the Mann-Whitney's test results

	Subgroup 1		p	Subgroup 3		p
	Group S	Group C		Group S	Group C	
Number of attention deficit symptoms before the treatment						
Me	8	8	0.142	9	9	0.949
$Q_1 – Q_3$	7 ÷ 9	8 ÷ 9		8 ÷ 9	8 ÷ 9	
Number of attention deficit symptoms after the treatment						
Me	5	5	0.933	8	6.5	0.300
$Q_1 – Q_3$	3 ÷ 8	4 ÷ 7		6 ÷ 9	5 ÷ 8	
Difference in the number of attention deficit symptoms before and after the treatment						
Me	2	3	0.428	1	2	0.203
$Q_1 – Q_3$	0 ÷ 4	2 ÷ 4		0 ÷ 2	1 ÷ 3	

Me – median, Q1 – lower quartile and Q3 – upper quartile.

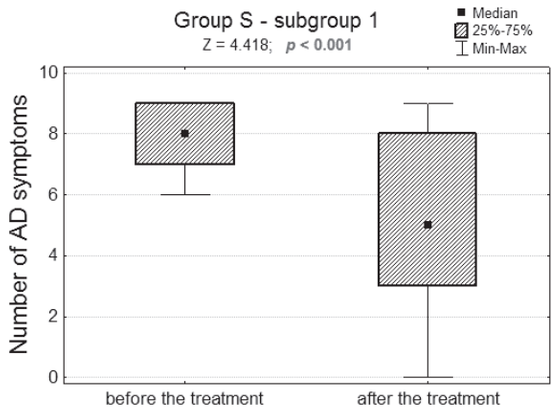

Fig. 1

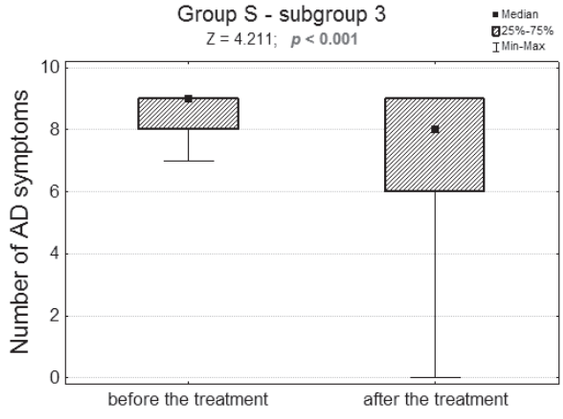

Fig 2

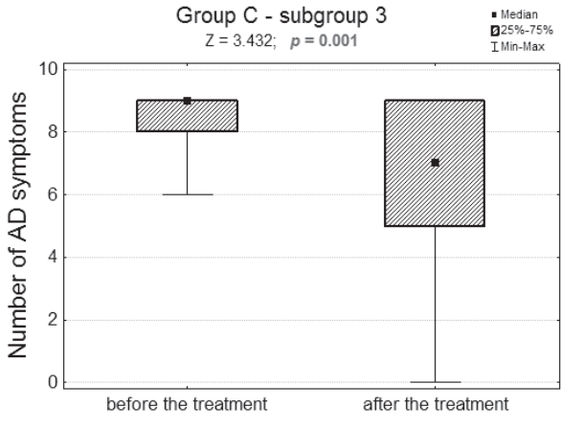

Fig 3

Treatment effects measured by the number of attention deficit symptoms in both S and C groups are similar (p>0.05).

Both types of therapies significantly reduce (p<0.01) the number of attention deficit symptoms (Fig. 1 and 2) in subgroups 1 and 3.

Number of hyperactivity and impulsiveness symptoms

Table 6. Statistics of the number of hyperactivity and impulsiveness symptoms (N+I) in the study group and the control group of patients in the subgroups 1 and 3, as well as the Mann-Whitney's test result

	Subgroup 1		p	Subgroup 3		p
	Group S	Group C		Group S	Group C	
Number of N+I symptoms before the treatment						
Me	3	3	0.566	8	9	0.102
$Q_1 – Q_3$	0 ÷ 5	1 ÷ 5		7 ÷ 9	8 ÷ 9	
Number of N+I symptoms after the treatment						
Me	1	1	0.840	7	6	0.239
$Q_1 – Q_3$	0 ÷ 3	0 ÷ 3		5 ÷ 8	1 ÷ 8	
Difference between the number of N+I symptoms before and after treatment.						
Me	0	1	0.510	1	3	0.075
$Q_1 – Q_3$	0 ÷ 2	0 ÷ 2		0 ÷ 3	0 ÷ 6	

Me – median, Q1 – lower quartile and Q3 – upper quartile.

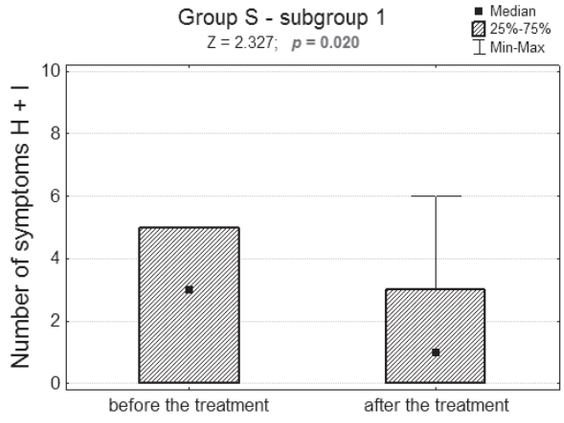

Fig. 4

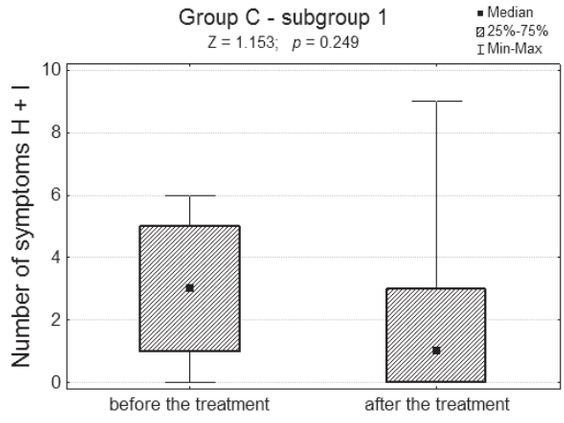

Fig. 5

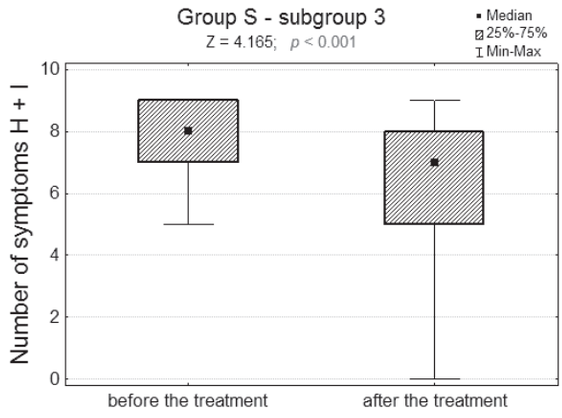

Fig. 6

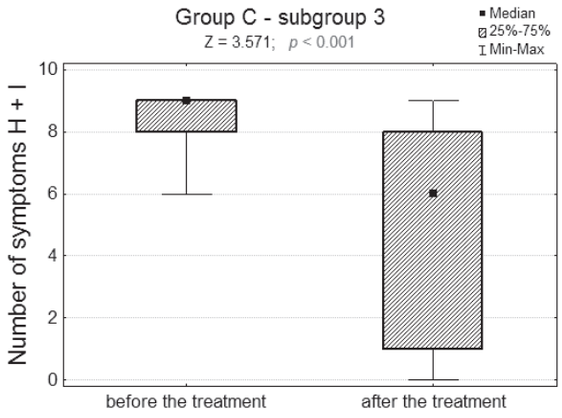

Fig. 7

Treatment effects measured by the number of hyperactivity and impulsiveness symptoms in both compared groups are similar (p>0.05).

Both types of therapies significantly reduce (p<0.01) the number of hyperactivity and impulsiveness symptoms (Fig. 3 and 4) in subgroups 1 and 3.

EEG parameters

The basic statistics of EEG parameters (with division into ADHD type subgroups) have been collected in table 7. The table also contains the results of the variance analysis.

Table 7. Core statistics of EEG parameters in the study group (EEG-biofeedback) and subgroups differing in the ADHD type, and results of the comparison

Parameter	Subgroup S			Total n = 85	ANOVA Result
	1 n = 35	2 n = 4	3 n = 46		
Electrode C4 (Th/SMR) – session 1					
± SD	2.91 ± 0.65	3.48 ± 0.50	2.95 ± 0.71	2.95 ± 0.67	F = 1.288
Me	2.83	3.37	2.95	2.93	p = 0.282
$Q_1 – Q_3$	2.46 – 3.31	3.17 – 3.79	2.56 – 3.46	2.57 – 3.41	
Electrode C4 (Th/SMR) – session 10					
± SD	2.65 ± 0.46	3.02 ± 0.22	2.65 ± 0.53	2.65 ± 0.49	F = 1.055
Me	2.62	2.96	2.63	2.65	p = 0.353
$Q_1 – Q_3$	2.39 – 3.01	2.88 – 3.16	2.38 – 3.01	2.35 – 3.01	
Electrode C3 (Th/SMR) – session 1					
± SD	3.10 ± 0.72	3.85 ± 0.65	3.25 ± 0.87	3.21 ± 0.79	F = 1.659
Me	2.99	3.69	3.25	3.18	p = 0.197
$Q_1 – Q_3$	2.59 – 3.52	3.36 – 4.35	2.71 – 3.79	2.71 – 3.69	
Electrode C3 (Th/SMR) – session 10					
± SD	2.74 ± 0.46	3.08 ± 0.49	2.76 ± 0.57	2.77 ± 0.53	F = 0.745
Me	2.70	2.92	2.77	2.72	p = 0.478
$Q_1 – Q_3$	2.39 – 3.04	2.74 – 3.41	2.42 – 3.15	2.39 – 3.15	

– arithmetic mean, SD – standard deviation, Me – median, Q1 – lower quartile, Q3 – upper quartile

In subgroup 2 (ADHD with hyperactivity and impulsiveness prevalence) the value of the signal

from all electrodes is higher than in subgroups 1 and 3, however, those differences are statistically non-significant (p>0.05).

In the training sessions that followed, decrease in the signal value from electrodes C4 and C3 was observed. The changes are of non-linear nature, and a sufficiently good model for the signal from both electrodes proved to be polynomial of a second degree (Fig. 1). The R^2 coefficient, which is the measure of model fit to the experimental data is in both cases higher than 0.9

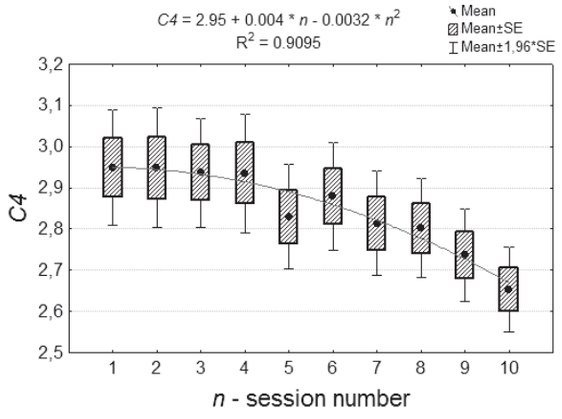

Fig. 8

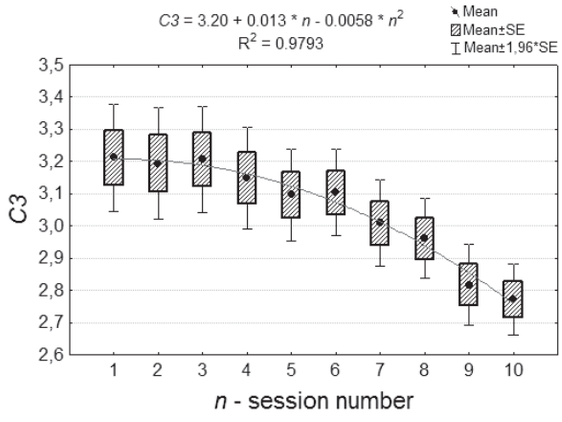

Fig. 9

Based on the analysis, it can be established that the efficacy of EEG-biofeedback training sessions in our study proved to be comparable to the efficacy of the treatment with methylphenidate. It was observed in the reduction of the number of symptoms provided in the ADHD questionnaire (attention deficit, hyperactivity and impulsiveness) in subgroup 1 (ADHD with the prevalence of attention deficit) and subgroup 3 (mixed type ADHD). An additional efficacy indicator of the NF method was the analysis of neurophysiological ratios. In all ADHD types a significant decrease in values of the examined theta/SMR and theta/beta ratios was noted between sessions 1 and 10 (10 for each hemisphere), which proves a reduction in theta slow waves activity and an acceleration of the SMR and beta rhythm in every ADHD type.

DISCUSSION

Results of the studies conducted so far evaluating the efficacy of ADHD treatment by the NF method with the use of electrophysiological factors (theta/SMR and theta/beta) show its positive effect observed in the brain wave activity [4-6]. They indirectly match the achieved clinical improvement evaluated with the use of a structured interview. It is also confirmed by other authors' research results. The EEG-biofeedback effect was observed both in the number of positive answers (83%) [18] and in the beneficial influence on the control of impulses and attention [19], which was noted in parents' [20] and teachers' [21] observations. Lévesque et al. [22] note that apart from the improvement in attention, there was a significant activation of the right anterior cingulate cortex. According to Arns et al. [23] the NF method is effective and specific for ADHD. However, based on the analysis of literature, Lofthouse et al. (2012) issued some criticism of those results, pointing out that the majority of studies did not meet the criteria of methodological soundness (lack of a randomly selected control group, lack of a model protocol of NF training sessions, influence of other therapeutic methods was not considered) [24, 25]. Explicit evidence that the effect of training sessions is noticeable in patients' improvement of everyday functioning is also lacking, as are data about any possible side-effects. Based on the analysis of controlled trials, van As et al. [11] and Sonuga-Barke et al. [26] noted that given the current state of scientific knowledge, NF cannot be with all certainty considered a method of choice for ADHD treatment. Despite

the differences in opinions, the majority of authors state that NF is a valuable method in ADHD treatment, supplementing other forms of therapy.

CONCLUSIONS

The results of the study are promising, since the EEG-biofeedback therapy was similarly effective to methylphenidate in reducing the aggravation of ADHD symptoms in ADHD with attention deficit prevalence and in mixed type ADHD.

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