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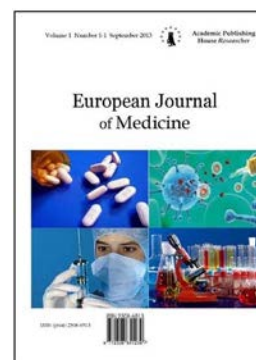
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### **The Effect of EEG Biofeedback Therapy on Motor Abilities of Children with Attention Deficit Hyperactivity Disorder**

<sup>1</sup>Elena Žiaková

<sup>2</sup>Stanislava Klobucká

<sup>1-2</sup> Department of physiotherapy, Faculty of Nursing and Professional Health Studies Slovak Medical University in Bratislava, Slovak Republic

<sup>1</sup>PhDr. Elena Žiaková, PhD

E-mail: elenaziakov@gmail.com

#### **Abstract**

**Background.** Currently, EEG biofeedback (Neurofeedback) is used in the rehabilitation of children with brain damage with the symptoms of attention deficit disorder, hyperactivity and impulsivity. After treatment improvements were observed not only in the control of attention and impulsivity but also in voluntary and involuntary movements. The aim of the prospective clinical study was to measure the impact of EEG biofeedback on motor abilities of children with ADHD (Attention Deficit Hyperactivity Disorder) and compare the effectiveness of EEG biofeedback with classical rehabilitation. It was assumed that in children with ADHD in combination with central motor disorders EEG biofeedback therapy will strengthen not only the control of impulsivity and attention but also motor skills.

**Material.** The observed group consisted of 60 (N = 60) children with mild central motor disorders with ADHD. They were randomly assigned to either the EEG biofeedback group (N = 30, mean age 8.9 years) or the classical rehabilitation group (N = 30, mean age 8.5 years).

**Methods.** Both groups received thirty 30-45 minute sessions of training, at a frequency of 2-3 times a week. Pre-post assessment included testing of motor skills with PANESS test (Physical and Neurological Examination for Subtle Signs) for both groups and the EEG biofeedback group were assessed also for changes in impulse and attention control using CPT (Continuous Performance Test) test AX version and changes observed by parents using TLC Subjective Assessment (The Learning Curve, 2004).

**Results.** Achieved overall score of EEG biofeedback group was lower after therapy (Mdn = 24.00) than before therapy (Mdn = 55.00),  $T = 0.00$ ,  $p < 0.01$ ,  $Z = -4.78$ ,  $r = -0.62$ . Values of significance (Asymp.Sig. 2-tailed = 0.000) and effect size (effect size  $r = -0.62$ ) indicate a statistical and factual significant positive effect of EEG biofeedback to improve overall motor skills (lower score is better).

**Conclusion.** EEG biofeedback therapy in children with ADHD improved control of attention, impulsivity and also improved motor skills. There were no significant differences in improvement of performance of timed movements between groups. Also, parents of children who received the EEG biofeedback therapy observed positive changes in behavior, learning and motor skills.

Improvement in motor skills was significantly higher in the EEG Biofeedback group than in the classical rehabilitation group.

**Keywords:** Effect of EEG, Biofeedback Therapy, Motor Abilities, children.

### **Introduction**

The incidences of mild cerebral dysfunction with motor and coordination disorders and cognitive and emotional deficits in children within the population are high. The American Academy of Pediatrics states that motor skills disorder also known as developmental coordination disorder is usually diagnosed only when motor skills problems significantly interfere with academic achievement or activities of daily living. Motor skills disorder involves a developmental delay of movement and posture that leaves children with coordination substantially below that of others of their age and intelligence level (American Academy of Pediatrics, 2010). These children seem clumsy and awkward and they have problems being accepted in the activities of their classmates. By adolescence, most children with motor skills disorder not only perform poorly in physical education classes, but may also have a poor physical self-image and perform below expectations academically. Therefore, new methods are being sought which will, together with classical rehabilitation, contribute to minimize the handicap of these children. One of these methods is EEG biofeedback. EEG biofeedback is a method, which specifically helps in the rehabilitation of neurological and psychological disorders. Its clinical application includes the treatment of attention deficit disorders, epilepsy, learning disorders, obsessive compulsive disorders and alcohol addiction. Meanwhile it has assumed a role in achieving optimal performance in optimizing musical and interpretative skills of students (Egner, a iní, 2003), in sports performance (Landers, et al., 1991) (Vernon, 2005), optimizing microsurgical skills in eye surgery (Ros, et al., 2009) and in NASA research aimed at minimizing pilot errors (Prinzel, et al., 2002).

Our facility is dedicated to the rehabilitation of children with different diagnoses. We are using a variety of rehabilitation equipment and devices. Also we are providing EEG biofeedback for attention, impulsivity and hyperactivity disorders. Children are sent to our facility by pediatrics when they have problems with behavior in school or their academic achievements are poor. Our results in this field are conforming to many studies that have examined the impact of EEG biofeedback on the improvement of attention and hyperactivity in children. Moreover we have also received positive feedback from the side of the parents. Parents reported not only about improvements in attention and hyperactivity but also in motor skills as well. We made measurements of motor skills and attention and hyperactivity before and after EEG biofeedback in order to confirm this. For motor skills we have used PANESS test (Physical and Neurological Examination for Subtle Signs – author M. Denckla, (1985)) and for attention and hyperactivity CPT (Continuous Performance Test) test AX version. Both tests have very good test re-test reliability and are very easy to perform.

The aim of the work was to measure the effect of EEG biofeedback therapy on motor, cognitive and emotional deficits of children with brain injury of different levels.

### **Material and methods**

#### **Material**

60 children of both sexes were included into the prospective clinical study. They were sent to our rehabilitation facility by pediatric neurologists having motor disorders in combination with a diagnosis of ADHD-HI (predominantly hyperactive-impulsive) and ADHD-PI (predominantly inattentive) (Ramsay, 2007). The whole set was divided by randomized selection into two groups: EEG Biofeedback group (N = 30, mean age 8.90 years and the range 7-12, SD=1.539) and a group receiving classical rehabilitation (N = 30, mean age 8.50 years and range 7-11, SD=1.306). Before starting the treatments we obtained written consent from the legal guardians of children for them to participate in the study as well as division into groups. In EEG biofeedback group there were 25 boys and 5 girls. In classical rehabilitation group there were 19 boys and 11 girls. 20 boys and 2 girls were diagnosed with ADHD-HI in EEG biofeedback group and 13 boys and 7 girls in group with classical rehabilitation. ADHD-PI diagnosis had 5 boys and 3 girls in EEG biofeedback group and 6 boys and 4 girls in group with classical rehabilitation.

**Inclusion criteria**

The clinical study included children having diagnoses according to ICD-10 - other abnormalities of gait and mobility (R26.8), other lack of coordination (R27.8), abnormal posture (R29.3), cerebral palsy (G80.0) light forms, attention-deficit hyperactivity disorders (F90.0), ADHD according to DSM III. respectively DSM IV. and aged from 7 to 12 years.

**Exclusion criteria**

Children with a positive history of head trauma, a history of epilepsy, metabolic syndrome, a severe form of cerebral palsy, medical therapy (based on the assessment of a pediatric neurologist or neurologist), children with average IQ undersized by WISC III. set by psychologist (Category B and C).

The study was conducted in accordance with ethical principles based on the Declaration of Helsinki (1964).

**Methods**

Research was conducted during the period of September 2008 to May 2011 at the Rehabilitation Centre Harmony, Kudlakova 2, Bratislava. Both groups received thirty 30-45 minutes sessions of training, at a frequency of 2-3 times a week.

**EEG biofeedback group**

We used the following training protocols with the children who have undergone EEG biofeedback rehabilitation. Protocols have been proven in controlled clinical studies (Monastra, et al., 2005).

**PROTOCOL 1: "SMR up/Theta down"**

Patients are learning to strengthen control of impulsivity by learning to increase the production of SMR (12-15 Hz, respectively from the zone of enhanced SMR 12-19 Hz) to C3 or C4 while at the same time suppressing theta rhythms (4-7 Hz or 4-8 Hz). Auditory (tones) and visual feedback (control of simple video game) is provided according to the patient's success in suppressing theta or increasing SMR (below the threshold theta or above the threshold SMR). This protocol was also used in the first controlled common study of the effectiveness of the EEG biofeedback for ADHD (Rossiter, et al., 1995).

**PROTOCOL 2: "SMR up/Beta2 down"**

In this protocol, patients with ADHD, predominantly hyperactive-impulsive type, were trained to increase SMR (12-15 Hz) while inhibiting beta2 (22-30 Hz). This protocol was administrated for 15 minutes in patients with combined type of ADHD. In the second half of the session was increased beta1 and suppressed theta activity on C3. This type of SMR training was tested in controlled study (Fuchs, et al., 2003).

**PROTOCOL 3: "Theta down/Beta1 up"**

In this training procedure, patients learn to increase the production of beta1 activity (16-20 Hz), whereas the theta activity (4-8 Hz) is inhibited. Fuchs et al. (2003) used a variation of this protocol in patients with ADHD predominantly inattentive type while training inhibition of theta and beta strengthening on C3. If the in-training found increased aggression or hyperactivity in the range of 13 to 35 training protocol was assessed as "hyper stimulated" and indicated a SMR training with the strengthening of 13-15 Hz and suppression of 2-7 Hz. This protocol has been studied in published works by Linden, Habib, Radojevic, (1996); Monastra, Monastra, & George, (2002); Rossiter & LaVaque (1995).

**Group with classical rehabilitation**

Children received kinesiotherapy, which included relaxation exercises, strengthening exercises, exercises for developing pattern movement quality, proprioceptive stimulation of soles of the legs.

Pre-post assessments of motor skills of the children in both groups were assessed with revised Physical And Neurological Examination for Soft Signs by Martha Denckla (1985) – **PANESS**. This test is very easy to use - examiner needs only stopwatch and assessment form and it takes only about 30 minutes. Test variables are: lateral preference, gaits, balance, motor persistence, coordination, overflow, dysrhythmia, and timed movements (repetitive and patterned).

Pre-post assessment of EEG Biofeedback group was enhanced with following tests:

1. Attention and impulsivity – Continuous Performance Test AX version (AX-CPT) provides data on attention deficit disorder and impulsivity control (Rosvold, et al., 1956).
2. The TLC Subjective Assessment (The Learning Curve, 2004) - parents subjective assessment of the problems of the child. The test contains 144 items.
3. The TLC Objective Assessment (The Learning Curve, 2004) - the process of objective assessment of EEG.

### **PANESS test**

Lateral preference.

Lateral preference (hand, foot, and eye) was assessed by asking the child to demonstrate various lateralized tasks:

- the hand (show me how you: comb your hair, brush your teeth, cut with scissors, throw a ball, hit a ball with a bat, hit a ball with a racket, use a hammer, use a screwdriver, use a saw, flip a coin, and open a door with a key,
- the foot (show me how you: kick a soccer ball and stamp out a fire),
- the eye (show me how you: look through the lens of a camera).

### **Gaits**

Children were asked to walk 10 steps over the line on toe, heels, sides of feet and tandem walk forward and backward (toe to heel).

### **Balance**

Children were asked to hop on one foot (maximum 50 times) and stand on one foot for 20 seconds.

### **Attention and impulsivity – Continuous Performance Test AX version (AX-CPT)**

The original CPT was developed in 1956 by Rosvold with his colleagues and although the original X-CPT had adequate classification accuracy, the classification accuracy improved with the more difficult AX-CPT version. We used AX version in our study. Children had to hit the keyboard when the letter X appeared but only if the X was immediately preceded by the letter A. Achieved points were converted to respective age (years) and compared (higher achieved age by output test is better).

### **The TLC Subjective Assessment**

The test contains 144 items and assesses psychosocial characteristics of the child using a seven-point scale. Parents filled the questionnaire before and after EEG biofeedback rehabilitation. Questionnaire provides: suggestions for training protocols, subjective assessment of the problems of the child and impact of the therapy from the perspective of parent or guardian.

### **The TLC Objective Assessment**

Because it is simple and relatively unassuming (30-45 minutes), the process of objective assessment can be repeated as often as needed. Using this assessment tool we can obtain important information for initial diagnosis and planning of the training. In our research we used software BioExplorer with the device "Pendant EEG" supplied by Australian "Pocket Neurobics" for data collection and the training EEG biofeedback. Pendant EEG is connected to a PC via USB or wireless over a short distance (3m), with dual-channel wiring electrodes.

### **Statistical analysis**

We tested data for normality with Kolmogorov-Smirnov test and variation with Leven test. According to the results of these tests we used the Student pair t-test for parametric statistic and Wilcoxon signed rank test for non-parametric statistic. The same was applied for correlation – Pearson´s test for parametric and Spearman´s test for non-parametric statistic. Finally we calculated effect size.

### **Theory**

In recent years EEG biofeedback training has been applied to an increasing number of psychological, neurological, and psychosomatic conditions. Sensorimotor (SMR) and Beta

neurofeedback (one of the training forms focused on immediate enhancement intermediate frequency amplitude) achieved very good results in treatment of not only epilepsy, but also in attention deficit hyperactivity disorder, specific learning disorders and several other conditions associated with ADHD, for example bruxism, tics, mood swings. Subjectively SMR approaches the alpha rhythm, but it is more centered on the body feeling - awareness of the body in a particular environment and readiness, which interact with the environment. High levels of SMR are a characteristic of motion talented and trained people. In the absence of SMR problems may occur with body sensations (low pain threshold, less control of the body functions). The obvious indicator of the minimum SMR is sleeping without physical exhaustion. SMR is described as a key frequency for effective performance of the mind and body (Faber, 2001). SMR training stimulates self-regulation and control functions (particularly motor control, sensors and affectivity, which stabilizes and facilitates perceptual-cognitive skills) and beta training executive functions (Tyl, et al., 2002). Head injury, multiple sclerosis, autism, chronic fatigue syndrome and the premenstrual syndrome, are only a few examples of the still growing list of conditions reported by clinicians to be partly or fully remediated by SMR-beta neurofeedback training.

The apparent diversity of disorders impacted by SMR-beta neurofeedback training suggests a commonality of mechanisms for these conditions, a fact that should be addressed by any theory that attempts to identify the therapeutic mechanism of SMR-beta neurofeedback. Sterman (1982) proposed that SMR neurofeedback may restore regulated function of thalamocortical mechanisms associated with arousal. In particular, abnormal sensorimotor arousal or excitability may interfere with higher cognitive functions in a resource-limited competitive model (Sterman, 1996). Abarbanel (1995) formulated a similar model of self-regulation in which attentional processing were modulated by thalamocortical and limbic circuitry. In his model long-term potentiation was responsible for any functional permanence associated with training. Both models presume SMR-beta neurofeedback impacts functions that modulate arousal (Sterman, 1982); (Abarbanel, 1995). Both models readily address the symptomatology and possible mechanisms of ADHD and epilepsy. The primary symptoms of ADHD, inattention, impulsivity, or hyperactivity, are associated with decreased arousal in frontal cortex and subcortical regions (Zametkin, et al., 1990); (Mann, et al., 1992). The cortical hyperexcitability associated with epilepsy may reflect an arousal dysfunction, possibly due to a loss of integrity in the thalamic gating mechanism (Sterman, 1982). In addition to motor or vocal tics, sufferers of Tourette's Syndrome often exhibit somnambulism, night terrors, and other disorders of arousal (Barabas, 1984). Attentional processes in particular appear to be uniquely sensitive to problems of arousal, and thus they serve to be a good measure of effectiveness in restoring such functions.

A pioneering collaboration between two laboratories from the University of London has provided the evidence of neuroplastic changes occurring directly after natural brainwave training. Researchers from Goldsmiths and the Institute of Neurology have demonstrated that half an hour of voluntary control of brain rhythms is sufficient to induce a lasting shift in cortical excitability and intracortical function. These after-effects are comparable in magnitude to those observed following interventions with artificial forms of brain stimulation involving magnetic or electrical pulses (Ros, et al., 2010).

## Results

### Laterality

In the group of children with EEG biofeedback (EEG group) were 29 right-handers (97%) and 1 mixed (3%). In the group of children with classical rehabilitation (control group) were 27 right-handers (90%), 2 left-handers (7%) and 1 mixed (3%).

### Gaits and station

Results in gaits and station were better in EEG group then in the control group. Children in EEG group made fewer errors and involuntary movements after EEG biofeedback training as children in the control group. EEG biofeedback group achieved significantly lower score ( $M=16.17$ ,  $SD=6.46$ ) after therapy than before therapy ( $M=28.90$ ,  $SD=8.72$ ),  $t(29)=9.81$ ,  $p<0.05$ ,  $r=0.88$ . Significance value (Sig. 2-tailed=0.000) and effect size ( $r=0.88$ ) indicates a high positive effect of EEG biofeedback in reduction of errors, involuntary movements and increased motor persistence. Control group achieved score after therapy was higher ( $M=23.83$ ,  $SD=5.97$ ) than before therapy ( $M=21.27$ ,  $SD=5.89$ ),  $t(29)=-2.13$ ,  $p<0.05$ ,  $r=0.37$ . Children in control group did not show any improvement after rehabilitation.

TABLE 1: GAITS AND STATION

		N	Mean	Std. Error	Median	Std. Deviation	Min.	Max.
EEG group	before therapy	30	28.9	1.592	29.5	8.719	11	60
	after	30	16.17	1.178	16	6.455	3	30
Control group	before therapy	30	21.27	1.075	21	5.889	9	32
	after	30	23.83	1.089	23.5	5.966	12	36

### Dysrhythmia

Results in Dysrhythmia were better in EEG group then in the control group. EEG biofeedback group achieved a score after therapy that was significantly lower (Mdn=1.00, SD=1.80) than the score before therapy (Mdn=2.50, SD=2.97),  $T=38.00$ ,  $p<0.05$ ,  $Z=-3.23$ ,  $r=-0.42$ . Significance value (Sig. 2-tailed=0.001) and effect size ( $r=-0.42$ ) indicates a positive effect of EEG biofeedback in reduction of symptoms of dysrhythmia. Control group achieved a score after therapy that was lower (Mdn=1.50, SD=3.19) than the score before therapy (Mdn=2.00, SD=2.39),  $T=163.50$ ,  $p>0.05$ ,  $Z=-0.78$ ,  $r=-0.10$ . The result of classical rehabilitation in reduction of symptoms of dysrhythmia is statistically not significant.

TABLE 2: DYSRHYTHMIA

		N	Mean	Std. Error	Median	Std. Deviation	Min.	Max.
EEG group	before therapy	30	3.53	0.542	2.5	2.968	0	10
	after	30	1.7	0.329	1	1.803	0	5
Control group	before therapy	30	2.87	0.436	2	2.389	0	9
	after	30	2.6	0.583	1.5	3.191	0	12

### Overflow movements

Results in overflow movements were better in EEG group then in control group. EEG biofeedback group achieved score after therapy was significantly lower (Mdn=6.00) than the score before therapy (Mdn=12.50),  $T=13.50$ ,  $p<0.05$ ,  $Z=-4.51$ ,  $r=-0.58$ . Significance value (Sig. 2-tailed=0.000) and effect size ( $r=-0.58$ ) indicates a positive effect of EEG biofeedback in reduction of overflow. Control group achieved score after therapy was lower (Mdn=15.50, SD=6.10) than the score before therapy (Mdn=16.00, SD=5.39),  $T=167.50$ ,  $p>0.05$ ,  $Z=-4.52$ ,  $r=-0.07$ . The result of classical rehabilitation in reduction of overflow movements is statistically not significant.

TABLE 3: OVERFLOW MOVEMENTS

		N	Mean	Std. Error	Median	Std. Deviation	Min.	Max.
EEG group	before therapy	30	13.53	1.194	12.5	6.538	2	29
	after	30	6.33	0.667	6	3.651	0	17
Control group	before therapy	30	16.03	0.983	16	5.385	3	28
	after	30	16.57	1.114	15.5	6.101	7	32

### Repetitive movements

Results in repetitive movements were better in EEG group then in the control group. EEG biofeedback group achieved an after therapy score that was significantly lower (Mdn=3.00) than the before therapy score (Mdn=7.00),  $T=20.50$ ,  $p<0.05$ ,  $Z=-4.16$ ,  $r=-0.54$ . Significance value (Sig. 2-tailed=0.000) and effect size ( $r=-0.58$ ) indicates a positive effect of EEG biofeedback in reduction of errors in repetitive movements. The control group achieved an after therapy score that

was higher (Mdn=7.50, SD=4.35) than before therapy score (Mdn=7.00, SD=3.17), T=126.50,  $p > 0.05$ , Z= -1.75,  $r = -0.22$ . The result of classical rehabilitation in reduction of errors in repetitive movements is statistically not significant.

TABLE 4: REPETITIVE MOVEMENTS

		N	Mean	Std. Error	Median	Std. Deviation	Min.	Max.
EEG group	before therapy	30	8.23	1.079	7	5.911	0	26
	after	30	3.1	0.427	3	2.339	0	10
Control group	before therapy	30	6.73	0.579	7	3.172	1	13
	after	30	8.03	0.794	7.5	4.351	1	18

Patterned movements

Results in patterned movements were better in EEG group than in the control group. EEG biofeedback group achieved an after therapy score that was significantly lower (Mdn=5.00, SD=4.50) than the before therapy score (Mdn=19.50, SD=13.52), T=6.00,  $p < 0.01$ , Z=-4.66,  $r = -0.60$ . Significance value (Sig. 2-tailed=0.000) and effect size ( $r = -0.60$ ) indicates a positive effect of EEG biofeedback in reduction of errors in patterned movements. The Control group achieved an after therapy score that was higher (Mdn=13.50, SD=4.81) than the before therapy score (Mdn=13.00, SD=4.51), T=175.50,  $p > 0.05$ , Z= -0.325,  $r = -0.22$ . The result of classical rehabilitation in reduction of errors in patterned movements is statistically not significant.

TABLE 5: PATTERNED MOVEMENTS

		N	Mean	Std. Error	Median	Std. Deviation	Min.	Max.
EEG group	before therapy	30	21.43	2.469	19.5	13.521	6	67
	after	30	6.6	0.822	5	4.5	0	17
Control group	before therapy	30	13.9	0.824	13	4.513	8	31
	after	30	13.97	0.878	13.5	4.81	7	28

Overall time of timed movements

Overall time comprises the time of repetitive and patterned movements and tongue wagging. EEG biofeedback group achieved time after therapy was significantly lower (Mdn=88.95, SD=18.26) than before therapy (Mdn=101.60, SD=25.84), T=36.00,  $p < 0.01$ , Z=-4.04,  $r = -0.52$ . Significance value (Sig. 2-tailed=0.000) and effect size ( $r = -0.52$ ) indicates a positive effect of EEG biofeedback on decreasing of achieved time. The control group achieved time after therapy was significantly lower (Mdn=107.85, SD=21.93) than before therapy (Mdn=137.06, SD=23.57), T=16.00,  $p < 0.05$ , Z= -0.325,  $r = -0.22$  indicates a positive effect of classical rehabilitation on decreasing of achieved time.

TABLE 6: OVERALL TIME OF TIMED MOVEMENTS

		N	Mean	Std. Error	Median	Std. Deviation	Min.	Max.
EEG group	before therapy	30	111.78	4.72	101.6	25.84	81.1	188.9
	after	30	95.02	3.33	88.95	18.26	74.8	145
Control group	before therapy	30	132.79	4.3	137.06	23.57	84.8	189.7
	after	30	110.58	4	107.85	21.93	76.9	157.7

**Attention and impulsivity – Continuous Performance Test AX version (AX-CP)**

Continuous performance test AX version was only performed on children from the EEG biofeedback group. Achieved age of attention was significantly higher after therapy (Mdn = 11.00) than before therapy (Mdn = 9.00),  $T = 0.00$ ,  $p < 0.01$ ,  $Z = -4.349$ ,  $r = -0.56$ . Values of significance (Asymp.Sig. 2-tailed = 0.000) and effect size (effect size  $r = -0.56$ ) indicate positive effect of EEG biofeedback on improvement of attention.

Achieved age of impulsivity was significantly higher after therapy (Mdn = 9.00) than before therapy (Mdn = 7.00),  $T = 0.00$ ,  $p < 0.01$ ,  $Z = -4.417$ ,  $r = -0.57$ . Values of significance (Asymp.Sig. 2-tailed = 0.000) and effect size (effect size  $r = -0.57$ ) indicate positive effect of EEG biofeedback on improvement of impulsivity control.

TABLE 7: CONTINUOUS PERFORMANCE TEST AX VERSION

	N	Mean	Std. Error	Median	Std. Deviation	Min.	Max.
Before - attention	30	9.23	0.278	9.00	1.524	6	13
After - attention	30	10.97	0.341	11.00	1.866	6	13
Before impulsivity	30	7.73	0.310	7.00	1.701	6	11
After - impulsivity	30	9.57	0.361	9.00	1.977	6	13

**The TLC Subjective Assessment (The Learning Curve. 2004)**

The subjective assessment was only performed on children from EEG Biofeedback group. Achieved score was significantly lower after (Mdn = 344.00) than before therapy (Mdn = 386.50),  $T = 2.00$ ,  $Z = -4.74$ ,  $p < 0.05$ ,  $r = -0.61$ . Value of significance and effect size (effect size  $r = -0.57$ ) indicate positive effect of EEG biofeedback on improvement from the point of view of their parents.

TABLE 8: PARENTS SUBJECTIVE ASSESSMENT

	N	Mean	Std. Error	Median	Std. Deviation	Min.	Max.
Input	30	415.83	12.168	386.50	66.647	319	552
Output	30	350.63	13.188	344.00	72.234	212	503

**Overall score of PANESS test**

We have assessed achieved scores of all subtests before and after EEG biofeedback therapy and kinesiotherapy except laterality.

TABLE 9: OVERALL SCORE OF PANESS TEST

	N	Mean	Std. Error	Median	Std. Deviation	Min.	Max.	
EEG group	before training	30	58.57	3.675	55	20.128	26	108
	after	30	25.87	1.894	24	10.371	4	49
Control group	before training	30	41.9	1.371	42.5	7.508	20	59
	after	30	45.83	2.077	42.5	11.378	29	72

Overall scores were better in EEG group then in the control group. EEG biofeedback group achieved significantly lower scores after neurofeedback therapy (Mdn=24.00) than before therapy (Mdn=55.00),  $T=0.00$ ,  $p < 0.01$ ,  $Z = -4.78$ ,  $r = -0.62$ . Significance value (Sig. 2-tailed=0.000) and effect size ( $r = -0.62$ ) indicates a positive effect of EEG biofeedback in overall improvement in motor skills. Control group achieved scores before and after kinesiotherapy that were the same



(Mdn=42.50, SD=4.35),  $T=144.50$ ,  $p>0.05$ ,  $Z= -1.58$ ,  $r=-0.20$ . There were no improvements in followed parameters.

### Discussion

The aim of the prospective clinical study was to measure the impact of EEG biofeedback on motor abilities of children with ADHD (Attention Deficit Hyperactivity Disorder) and compare the effectiveness of EEG biofeedback with classical rehabilitation. EEG biofeedback therapy in children with ADHD improved control of attention, impulsivity and also improved motor skills. Improvement in motor skills was significantly higher in the EEG Biofeedback group than in the classical rehabilitation group.

Up to 52 % of children with ADHD are characterized as children with impaired motor coordination (Barkley, et al., 1990a) (Barkley, 1990c), (Hartsough, et al., 1985), (Szatmari, et al., 1989b), which particularly relates to tasks requiring fine motor movements. In healthy children and adults inhibition and facilitation mechanisms are in balance, used to control and regulate the voluntary and involuntary movements, but also emotions and other manifestations. If these mechanisms do not work properly, voluntary and automatic motoric will deteriorate and, moreover, subtle or pronounced uncontrollable movements, hyperkinesia and overflow movements appear (Samson, 2011).

Larson (2007) defined the overflow movement as co-movement of body that is not needed to perform the task. As typically children mature, they manifest less imprecise movements (Largo, et al., 2003). Among overflow movements, the most studied are mirror movements (also referred to as synkinesis). The presence of mirror overflow movements in adolescents and adults with disorders of both the motor cortex and the corpus callosum suggests that the ability to perform unilateral fine motor movements is dependent upon intact interhemispheric and corticospinal connections (Knyazeva, et al., 1997); (Meyer, et al., 1998); (Nass, 1985)). Using transcranial magnetic stimulation (TMS) investigators have demonstrated that transcallosal inhibition is absent in children under 6 years of age and that it gradually matures to adult levels by early adolescence (Garvey, et al., 2003) (Heinen, et al., 1998). Thus, when intra and inter-cortical inhibitory and excitatory systems are immature, overflow movements in children are at their peak; as these cortical systems mature, overflow movements are more difficult to elicit. The persistence of overflow into late childhood and adolescence, often seen in children with ADHD (Morris, et al., 2001); (Mostofsky, et al., 2003) and other developmental disabilities suggests a neurodevelopmental lag in systems supporting the inhibition of overflow. Choreiform movements are characterized by involuntary random, jerking motions, most often in the extremities (Delgado, et al., 2003), and often described as “dance-like” movements. Choreiform movements suggest lapses in postural control and implicate immaturity of the postural system. They can affect execution of motor tasks, contributing to dysgraphia and fatigue during writing (Denckla, 1997). Wolff and Hurwitz (1973) found choreiform movements to be more prevalent in children who were reported to be inattentive, disorganized and immature, positing that the presence of this subtle sign may implicate “minimal brain dysfunction.”

Overflow movements were recorded by all tests. A summary of all overflow movements pre and post treatment gave us information concerning their reduction. When comparing groups of children treated with EEG biofeedback and children treated with conventional rehabilitation, we observed significant differences in favor of EEG biofeedback.

#### Pattern movements

Mostofsky (2003) used the functional magnetic resonance imaging (fMRI) to determine differences in the brain activation during finger sequences in children with ADHD and children with normal development. The group consisted of 11 children with ADHD and 11 children with normal development. All children have a right-handed laterality. Groups showed no significant difference when measuring the speed of finger sequence but contralateral primary motor cortex (Brodmann Area 4) and right parietal cortex, showed significantly less activity throughout the fMRI during finger sequences with left and right hand in children with ADHD. This finding shows that children with ADHD have anomalous cortical development system needed to implement the pattern movement. This finding correlates with our results where in subtest pattern movement of PANESS was the sum of all errors high.

### Gaits and station

Hammond (2005) presents the results of successful treatment of balance disorders in 4 patients. Two patients aged 32 and 50 years after a light head injury and two patients after suffering a stroke aged 45 and 46 years had trouble keeping their balance. In case reports were observed improvement in motor skills in standing, standing with closed eyes and tandem walking after EEG biofeedback. Similar results were also found in our study, except that it was a) a larger group of patients, b) significantly younger age set, c) set with a different diagnosis, d) set with mild disabilities, e) set with disabilities both hemispheres.

### Dysrhythmia

Dysrhythmia is an abnormality in an otherwise normal pattern of movements; it can be seen as an improper rhythm or timing of the movement. Dysmetria is the failure to focus the trajectory of an intentional movement (extremity coordination) and whereas an intention tremor, produced by goal-directed motor movements, involves increased rhythmic oscillation at a right angle to the line of movement as the target is approached (Larson, et al., 2007). In our study, we evaluated dysrhythmia separately. Achieved scores of children after EEG biofeedback was significantly lower after treatment (Mdn = 1.00) than before treatment (Mdn = 2.50).

### Timed movements

Speed of repetitive movements (toe tap, hand pat and finger tap) and patterned movements (heel-toe, hand pronate/supinate and finger sequences) we interpreted either as a sign of delayed development or manifestation of impaired development in the context of the causes that led to the formation of cerebral palsy (damage during pregnancy, hypoxia during labor, postpartum damage etc.). Wolff (1985) reported age-related improvement in the speed of repetitive and patterned movement tasks executed with hand, foot and fingers. Examining the same timed repetitive movements, Denckla (1973); (1974) found that speed of performance improves with age and begins to plateau between ages 8–10 years. Largo et al. (2003) also reported age-related improvement performance of repetitive and patterned hand and finger movements; however, their findings suggested that speed of hand movements does not plateau until puberty, and speed of sequenced finger movements continues to improve beyond 18 years of age. In our study we didn't observe any major differences in timed movements between the group with EEG biofeedback and the group with classical rehabilitation. Both groups performed better after therapies. However, we have noticed that in EEG group in some cases the speed of performance dropped but on the other hand also errors dropped. It is obvious that these children paid more attention to performing the tasks without any errors than to increase the speed of performance.

### Attention and impulsivity

The positive effect of EEG biofeedback to influence attention, impulsivity and hyperactivity has been studied over the years by a number of authors. Arns (2009) reported a meta-analysis of fifth level, comparing studies published in scientific journals or as part of a dissertation. (To meet the criteria for fifth level classification it is necessary to show that the treatment is in terms of statistics better than placebo therapy, reliable medical therapy or other treatments regarded as positive in at least two independent studies.) There was included prospective controlled studies ((Rossiter, et al., 1995); (Monastra, et al., 2002); (Fuchs, et al., 2003); (Heinrich, et al., 2004); (Levesque, et al., 2006); (Bakhshayesh, 2007); (Drechsler, et al., 2007); (Gevensleben, et al., 2009), (Holtman, et al., 2006)) and studies using pre-post design (Kropotov, et al., 2005); (Xiong, et al., 2005); (Strehl, et al., 2006); (Leins, et al., 2007). Both groups of studies confirmed statistically significant effect size (ES) of EEG biofeedback on impulsivity and attention and middle ES on hyperactivity. Average ES for attention was 0.8097 and for impulsivity 0.6862. These results are identical with our findings because ES for attention was ( $r = -0.56$ ) and for impulsivity ( $r = -0.57$ ) with statistical significance ( $p < 0.01$ ) for both parameters in our group of children with EEG biofeedback.

### Overall score of PANESS test

We know so far of case reports that describe the efficiency of the motor skills in children but with severe motor deficits (Hammond, 2007); (Ayers, 2004); (Bachers, 2004). Empirical experience (achievement of walk alone of a 5 year old child after EEG biofeedback, which walked with compensation aids) led us to investigate the effect of EEG biofeedback on motor function. Due to the fact that we wanted to verify the quality level we have chosen as the material children with mild degrees of central motor disorders and also cognitive deficits. The results achieved in

individual subtests of Paness test we have summarized in the total score, which reflects the overall effect of EEG biofeedback on child's motor skills. Final score of EEG biofeedback group was lower at the end of therapy (Mdn = 24.00) than in the beginning of therapy (Mdn = 55.00). The values of significance (Asymp.Sig. 2-tailed = 0,000) and the effect size ( $r = -0.62$ ) indicate a very good factual and statistical significant positive effect of EEG biofeedback on overall improvement. Group with classical rehabilitation achieved scores was the same after therapy (Mdn = 42.50) as before therapy (Mdn = 42.50) - there were no improvement.

#### Parent's subjective assessment

Core light brain dysfunction (attention deficit disorder and hyperactive syndrome) is diagnosed by behavioral markers. Bragdon (2006) reports diagnosis by the American Diagnostic and Statistical Manual of Mental Disorders (DSM IV), which is the result of numerous epidemiological and clinical studies and gives for determination diagnosis an exact list of characters. Diagnosis of ADHD according to DSM IV is based on historical data, withdraw from a parent or guardian, or teacher. Subjective assessment of the child's behavior before EEG biofeedback therapy and after 30 sessions we evaluated on the basis of an 144 item questionnaire. Individual items of the questionnaire surveyed in detail cognitive, behavioral and motor aspects of the child from the parent's perspective. From their perspective there has been an improvement after the end of EEG treatment in the cognitive and behavioral aspects as well as motor skills of the child.

### Conclusions

Rehabilitation of children with central motor disorders is one of the fundamental measures in their comprehensive care. Kinesiotherapy, however, is not the only system in the framework of the rehabilitation. A holistic approach is necessary, and the right knowledge about behavioral disorders combined with motor deficit can significantly affect the success of rehabilitation. The aim of the work was to determine whether the use of EEG biofeedback will strengthen the control of the impulsivity and the attention and at the same time will have an effect on motor skills. The results of the study demonstrated:

1. strengthening control of attention and impulsivity in a group of children between 7 and 12 years with a central motor disorders in combination with ADD and ADHD,
2. improvement of motor skills in postural functions (walking, standing and balance), voluntary movements (repetitive movements and pattern), the involuntary movements (reducing errors and overflow movements) and speed of movement
3. in the group of classical rehabilitation, improvement was observed only in the timed movement,
4. from child's parent perspective there was positive changes in behavioral and motor disorders after EEG biofeedback therapy,
5. EEG biofeedback is a method that clearly makes the process of rehabilitation more efficient, contributes to the patient care, and improves his health and quality of life.

This is the first study that uses mutual comparison of neurofeedback with classical rehabilitation, and clearly demonstrated the effectiveness of neurofeedback. This result can be interpreted as a result of the creation of new neural connections and demonstration of the plasticity of the nervous system. Its result is a significant improvement in motor and coordination abilities of the patient as well as significant improvement in impulsivity and attention.

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