Training of Slow Cortical Potentials in Attention-Deficit/Hyperactivity Disorder: Evidence for Positive Behavioral and Neurophysiological Effects

Hartmut Heinrich, Holger Gevensleben, Franz Joseph Freisleder, Gunther H. Moll, and Aribert Rothenberger

Background: *Learned self-control of slow cortical potentials (SCPs) may lead to behavioral improvement in attention-deficit/hyperactivity disorder (ADHD). Hence, training effects should also be reflected at the neurophysiological level.*

Methods: *Thirteen children with ADHD, aged 7–13 years, performed 25 SCP training sessions within 3 weeks. Before and after training, the German ADHD rating scale was completed by parents, and event-related potentials were recorded in a cued continuous performance test (CPT). For a waiting-list group of nine children with ADHD, the same testing was applied.*

Results: *ADHD symptomatology was reduced by approximately 25% after SCP training. Moreover, a decrease of impulsivity errors and an increase of the contingent negative variation were observed in the CPT task.*

Conclusions: *This study provides first evidence for both positive behavioral and specific neurophysiological effects of SCP training in children with ADHD.*

Key Words: Neurofeedback, slow cortical potentials, attention-deficit/hyperactivity disorder, continuous performance test

Slow cortical potentials (SCPs; changes of cortical electrical activity lasting from several hundred milliseconds to several seconds) are related to the excitability level of underlying cortical regions. Negative SCP shifts represent higher excitability; positive SCP shifts reflect reduced excitability or even inhibition. In cognitive tasks, the amplitude of slow negative waves is thought to be related to the allocation of neuronal resources (Birbaumer et al 1990).

In a biofeedback condition, healthy subjects are able to learn to modulate their SCPs (Elbert et al 1984). For patients with neuropsychiatric disorders characterized by deficient cortical self-regulation, positive clinical effects may be expected from extended SCP training in which patients learn to increase and decrease their cortical excitability. For epilepsy, this has been confirmed in a series of studies (e.g., Rockstroh et al 1993, Kotchoubey et al 1996).

Deficits in cortical self-regulation are also assumed in attention-deficit/hyperactivity disorder (ADHD), which is characterized by inattention, impulsivity, and hyperactivity. Reduced self-regulation abilities in ADHD may arise from deficient regulation of energetic resources as the primary deficit (Sergeant et al 1999) but may also be seen as impairments secondary to an underlying general deficit in behavioral inhibition (Barkley 1997; Moll et al 2001).

For a typical SCP, the contingent negative variation (CNV), a reduced amplitude was measured during cued continuous performance tests (CPTs) in children with ADHD (Banaschewski et al 2003; Sartory et al 2002). Children with attentional problems who performed two SCP training sessions learned to regulate their SCPs when continuous feedback was given but had difficulty modulating their SCPs systematically when feedback was absent (Rockstroh et al 1990). Thus, reduced self-regulation abilities in ADHD were confirmed, which may be increased by extended SCP training.

In this study, we investigated neurophysiological and behavioral effects of extended SCP training in children with ADHD. Event-related potentials (ERPs) recorded in a cued CPT task were analyzed before and after training. We hypothesized that effective SCP training mainly affects the CNV in cue trials, reflecting the build-up of attentional resources for adequate performance of the task, in addition to causing a reduction of ADHD symptoms at the behavioral level.

Methods and Materials

Subjects

Thirteen children with ADHD, aged 7–13 years, participated in SCP training during their summer holiday. The training effects of this group were compared with those of a waiting-list group of 9 children with ADHD. Both groups were comparable with respect to age, gender, and intelligence (German version of the Wechsler Intelligence Scale for Children III); Tewes et al 2000); see Table 1.

All patients fulfilled DSM-IV criteria for ADHD (American Psychiatric Association 1994). Diagnoses were based on a semi-structured clinical interview (Clinical Assessment Scale of Child and Adolescent Psychopathology; Döpfner et al 1999) and confirmed with the Diagnostic Checklist for Hyperkinetic Disorders/ADHD (Döpfner and Lehmkuhl 2000) by a clinical psychologist. Children with comorbid disorders other than oppositional defiant disorder and dyslexia were not allowed to take part in the study. All children lacked gross neurologic or other organic disorders. Stimulant medication could be continued in the same dosage during the training course. Subjects were randomly assigned to both groups.

The study was approved by the Ethics Committee of the

From the Department of Child and Adolescent Psychiatry (HH, HG, GHM, AR), University of Göttingen, Göttingen; Heckscher Klinik (HH, FJF), Munich; and Department of Child and Adolescent Psychiatry (HH, GHM), University of Erlangen-Nürnberg, Erlangen, Germany.

Address reprint requests to Dr. Hartmut Heinrich, Heckscher Klinik, Deisenhofener Straβe 28, D-81539 München, Germany.

Received March 17, 2003; revised August 22, 2003; revised November 11, 2003; accepted November 19, 2003.

0006-3223/04/$30.00
doi:10.1016/j.biopsych.2003.11.013

BIOL PSYCHIATRY 2004;55:772–775

Table 1. Group Characteristics and Diagnostic Data

	ADHD Training Group (n = 13)	ADHD Waiting-List Group (n = 9)
Age (years/months)	11/1 ± 1/7	10/5 ± 2/1
Range	7 years 6 months–13 years 5 months	7 years 9 months–13 years 9 months
Sex (Boys/Girls)	12/1	9/0
IQ (HAWIK-III)	114.5 ± 18.3	110.6 ± 11.3
ADHD Subtype		
Mixed	9	7
Inattentive	4	2
Medication		
Unmedicated	7	5
Medicated	6	4

70 ADHD children, whose parents had heard about the project in newspapers, on the internet, and by local professionals, applied to take part in the study. In their applications, families could say if they were also available for the waiting list group. Subjects were randomly selected to both groups. Children, who were drug-free for at least one week before their training courses started, were considered as unmedicated.

ADHD, attention-deficit/hyperactivity disorder; IQ, intelligence quotient; HAWIK-III, Hamburg-Wechsler-Intelligenztest für Kinder III.

University of Göttingen. Assent was obtained from the children and written informed consent from their parents.

SCP Training

The neurofeedback system “GöFI” (Göttinger Feedback) was used for training. It contains several feedback animations, so that the training was diversified and especially appropriate for children. During training, children sat in front of a monitor and played a kind of computer game. Their task was to find appropriate strategies to change the color of an object on the screen from white to red in negativity trials and from white to blue in positivity trials by modulating their brain electrical activity. The children were told that the color red may be achieved by raising attention, whereas the color blue may be associated with a relaxed state.

Each training course lasted for 3 weeks. Pretraining and posttraining testing was done on the first and last days, respectively, both at the same time of day. From day 2 to day 14, children of the training group completed 25 training sessions of about 50 min, administered by a clinical psychologist.

In each training session 120 trials were performed. Negativity (50%) and positivity trials (50%) were presented in random order. A trial lasted for 8 sec (baseline period: 2 sec; feedback period: 6 sec). The intertrial interval was set to 5 ± 1 sec. Feedback was calculated from Cz (reference: mastoids; bandwith: .01–30 Hz; sampling rate: 250 Hz). Vertical eye movements, which were recorded with electrodes above and below the left eye, were corrected online (Kotchoubey et al 1997). For segments containing artifacts exceeding ±100 μV in the electroencephalogram channel and ±200 μV in the electro-oculogram channel, no feedback was calculated.

Transfer trials (trials without contingent and continuous feedback; 40–60 per session) were also conducted. Starting from the second week, children were instructed to practice their strategies for negativities and positivities at home (e.g., while reading a book) to facilitate transfer into daily life, and practice was to be documented in a protocol.

Pre- and Posttesting

The German ADHD rating scale (Fremdbeurteilungsbogen für hyperkinetische Störungen [FBB-HKS]; Döpfner and Lehmkuhl 2000), a 20-item questionnaire related to DSM-IV and ICD-10 criteria for ADHD and hyperkinetic disorders, respectively, was completed by parents. The severity of each item was rated from 0–3. The FBB-HKS score (the mean value of all items), was the outcome measure at the behavioral level.

According to the same time schedule, ERPs were recorded in a cued CPT (van Leeuwen et al 1998). The CPT consisted of 400 stimuli (letters) that were presented at the center of a monitor for 200 msec each, with an interstimulus interval of 1400 msec. Children were instructed to respond to a letter X occurring after the cue letter O (probabilities for the sequences O–X and O–not-X were 10% each).

Concerning performance measures, number of hits, commission errors, and impulsivity (O–not-X) errors were analyzed.

Electroencephalogram (10–20 system electrodes, Fpz, and Oz; reference: mastoids; bandwith: .1–50 Hz) and vertical and horizontal electro-oculogram were recorded (see Banaschewski et al 2003 for details of data recording and preprocessing). The mean amplitude of the CNV in the 1100–1600-msec interval at Cz in cue trials and the mean amplitude of the P300 in the 250–500-msec interval at Pz in target trials were computed.

For the waiting-list group, the same instruments (parent-rated FBB-HKS, cued CPT) were also applied twice, with the measurements approximately 3 weeks apart.

Statistics

First, pretraining measures of the training group and the waiting-list group were compared with two-tailed Student t tests. For pre- and posttraining comparisons of parent ratings and CPT measures, group (training, waiting list) × time (pretraining, posttraining) repeated-measures analyses of variance were performed. Performance measures were log-transformed to reduce positive skewness of the parameters. In case of significant group × time interactions, paired t tests were computed for each group separately. Bonferroni-corrected p values are reported. For all statistical procedures, significance was set at $p < .05$.

Results

There were no pretraining differences between the training group and waiting-list group on any of the behavioral, performance, and ERP variables [$t(1,20) < 1.2$; ns].

Pre- and posttraining comparisons are summarized in Table 2. For the FBB-HKS score, a significant group × time interaction resulted [$F(1,20) = 4.4$; $p < .05$]. In the training group, the FBB-HKS score was decreased by approximately 25% after training [pretraining–posttraining: .38 ± .35; $t(1,12) = 3.9$; $p < .004$]. The waiting-list group did not show a reduction of the FBB-HKS score [pretraining–posttraining: .02 ± .43; $t(1,8) = .2$; ns].

For hits and total commission errors, no significant effect was found.

Analysis of impulsivity errors revealed a significant group × time effect [$F(1,20) = 3.3$; $p < .03$]. The training group committed less impulsivity errors in the posttraining CPT session [pretraining–posttraining: 1.69 ± 2.06; $t(1,12) = 3.4$, $p < .01$]. In the waiting-list group, impulsivity errors of both CPT sessions did not differ significantly [pretraining–posttraining: .11 ± 1.97; $t(1,8) = -.02$, ns].

Table 2. Summary of the Results for Behavioral, Performance, and Event-Related Potential Measures

	ADHD Training Group (n = 13)		ADHD Waiting-List Group (n = 9)		
	Pre	Post	Pre	Post	Statistics[a]
FBB-HKS Score–Parents	1.62 ± .35	1.23 ± .45	1.72 ± .51	1.70 ± .62	G × T: $p < .05$; T: $p < .02$
Continuous Performance Test Performance Measures					
Hits	38.6 ± 1.8	37.8 ± 2.6	37.3 ± 3.3	37.4 ± 2.1	
Commissions	3.46 ± 5.36	1.38 ± 1.45	4.22 ± 5.87	4.33 ± 4.39	
Impulsivity Errors	1.92 ± 1.98	.23 ± .44	2.22 ± 2.28	2.11 ± 1.83	G × T: $p < .03$; G: $p < .04$; T: $p < .03$
Continuous Performance Test Event-Related Potentials					
Cue–CNV (μV)	−2.71 ± 2.54	−5.79 ± 3.58	−3.39 ± 3.44	−3.64 ± 2.45	G × T: $p < .02$; T: $p < .01$
Target–P300 (μV)	15.59 ± 5.22	14.45 ± 6.04	13.71 ± 8.07	13.51 ± 7.95	

ADHD, attention-deficit/hyperactivity disorder; FBB-HKS, Fremdbeurteilungsbogen für hyperkinetische Störungen (German ADHD rating scale); Pre, pretraining; Post, posttraining; CNV, contingent negative variation; G, group; T, time.

[a] df = 1,20.

For the mean amplitude of the CNV at Cz in the cue condition, a significant group × time interaction resulted [$F(1,20) = 6.1$; $p < .02$]. A marked CNV increase was found in the training group [pretraining–posttraining: 3.07 ± 3.04; $t(1,12) = 3.6$, $p < .006$; see Figure 1] in contrast to the waiting list group [pretraining–posttraining: .25 ± 1.88; $t(1,8) = .4$, ns].

No significant effect was found for the mean amplitude of the P300 at Pz in the target condition [group × time interaction: $F(1,20) = .2$, ns].

Discussion

In this study, the effects of a 25-session SCP training were investigated in children with ADHD compared with a waiting-list group.

To evaluate training effects, performance and ERP measures of a cued CPT task were studied. In cue trials, children in the training group showed a pronounced CNV increase after SCP training. Because no pretraining–posttraining CNV effect was found for the waiting-list group, a practice effect may be excluded. The CNV is thought to be related to the negativities that had to be generated during feedback training. After SCP training, children with ADHD may be able to allocate more resources, expecting the succeeding relevant stimulus. As a consequence, behaviorally, a decrease of impulsivity errors was observed. Hence, the CNV increase may be interpreted as a neurophysiological correlate of improved self-regulatory capabilities. In contrast, processes underlying P300 generation (e.g., memory updating, Polich 1998) do not seem to be affected by SCP training.

The reduction of the FBB-HKS score by approximately 25% after training seems promising. In further studies, nonspecific effects (e.g., improved self-esteem) and the status of medication have to be controlled for to establish the clinical efficacy of SCP training in ADHD.

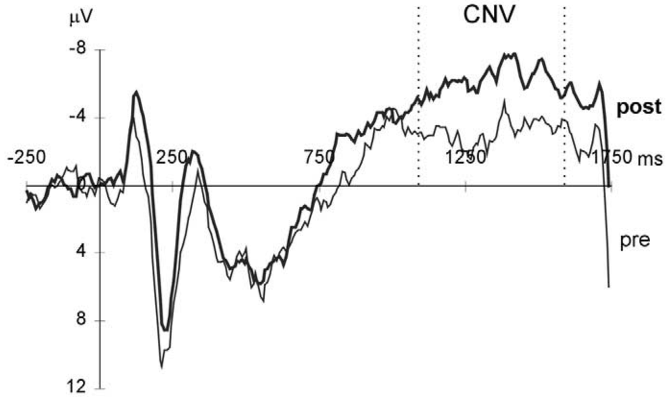

Figure 1. Grand mean event-related potentials (ERPs) of the attention-deficit/hyperactivity disorder training group (n = 13) recorded at Cz in the cue condition of a continuous performance test. The thin line curve represents the ERP before starting the training (pre); the thick line curve represents the ERP recorded at the end of the training course (post). A pronounced increase of the contingent negative variation (CNV) in the 1100–1600-msec interval (between vertical dotted lines) can be observed.

This study was supported in part by Hogrefe Verlag, Göttingen and several International Service Clubs from the Göttingen area.

We thank Susanne Mock, Svenja Schulz, Wolf-Dieter Bloemer, and Paul Aner for their support. In GöFI, Mouse and Elephant from the German television program "Die Sendung mit der Maus" were used with the kind permission of WWF, Köln.

American Psychiatric Association (1994): *Diagnostic and Statistical Manual of Mental Disorders*. 4th ed. Washington, DC: American Psychiatric Press.

Banaschewski T, Brandeis D, Heinrich H, Albrecht B, Brunner E, Rothenberger A (2003): Association of ADHD and conduct disorder— brain electrical evidence for the existence of a distinct subtype. *J Child Psychol Psychiatry* 44:356–376.

Barkley RA (1997): Behavioral inhibition, sustained attention, and executive functions: Constructing a unifying theory of ADHD. *Psychol Bull* 121:65–94.

Birbaumer N, Elbert T, Canavan AGM, Rockstroh B (1990): Slow cortical potentials of the cerebral cortex and behavior. *Physiol Rev* 70:1–41.

Döpfner M, Berner W, Flechtner H, Lehmkuhl G, Steinhausen HC (1999): *Psychopathologisches Befund-System für Kinder und Jugendliche (CASCAP-D)*. Göttingen: Hogrefe.

Döpfner M, Lehmkuhl G (2000): *DISYPS-KJ—Diagnostik-System für psychische Störungen im Kindes- und Jugendalter*. Bern: Hans Huber.

Elbert T, Rockstroh B, Lutzenberger W, Birbaumer N (1984): *Self-Regulation of the Brain and Behavior*. Berlin: Springer.

Kotchoubey B, Schleichert H, Lutzenberger W, Birbaumer N (1997): A new method for self-regulation of slow cortical potentials in a timed paradigm. *Appl Psychophysiol Biofeedback* 22:77–93.

Kotchoubey B, Schneider D, Schleichert H, Strehl U, Uhlmann C, Blankenhorn V, et al (1996): Self-regulation of slow cortical potentials in epilepsy: A retrial with analysis of influencing factors. *Epilepsy Res* 25:269–276.

Moll GH, Heinrich H, Trott GE, Wirth S, Bock N, Rothenberger A (2001): Children with comorbid attention-deficit-hyperactivity disorder and tic disorder: Evidence for additive inhibitory deficits within the motor system. *Ann Neurol* 49:393–396.

Polich J (1998): P300 clinical utility and control of variability. *J Clin Neurophysiol* 15:14–33.

Rockstroh B, Elbert T, Birbaumer N, Wolf P, Duchting-Roth A, Reker M, et al (1993): Cortical self-regulation in patients with epilepsies. *Epilepsy Res* 14:63–72.

Rockstroh B, Elbert T, Lutzenberger W, Birbaumer N (1990): Biofeedback: Evaluation and therapy in children with attentional dysfunctions. In: Rothenberger A, editor. *Brain and Behavior in Child Psychiatry*. Berlin: Springer, 345–357.

Sartory G, Heine A, Müller BW, Elvermann-Hallner A (2002): Event- and motor-related potentials during the continuous performance task in attention-deficit/hyperactivity disorder. *J Psychophysiol* 16:97–106.

Sergeant JA, Oosterlaan J, Van der Meere JJ (1999): Information processing and energetic factors in attention-deficit/hyperactivity disorder. In: Quay HC, Hogan A, editors. *Handbook of Disruptive Behavior Disorders*. New York: Plenum Press, 75–104.

Tewes U, Rossmann P, Schallberger U (2000): *Hamburg-Wechsler-Intelligenztest für Kinder III (HAWIK-III)*. Göttingen: Hogrefe.

van Leeuwen TH, Steinhausen HC, Overtoom CC, Pascual-Marqui RD, van't Klooster B, Rothenberger A, et al (1998): The continuous performance test revisited with neuroelectric mapping: Impaired orienting in children with attention deficits. *Behav Brain Res* 94:97–110.