Original Paper

Neurofeedback for Children with ADHD: A Comparison of SCP and Theta/Beta Protocols

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Abstract Behavioral and cognitive improvements in children with ADHD have been consistently reported after neurofeedback-treatment. However, neurofeedback has not been commonly accepted as a treatment for ADHD. This study addresses previous methodological shortcomings while comparing a neurofeedback-training of Theta-Beta frequencies and training of slow cortical potentials (SCPs). The study aimed at answering (a) whether patients were able to demonstrate learning of cortical self-regulation, (b) if treatment leads to an improvement in cognition and behavior and (c) if the two experimental groups differ in cognitive and behavioral outcome variables. SCP participants were trained to produce positive and negative SCP-shifts while the Theta/Beta participants were trained to suppress Theta (4–8 Hz) while increasing Beta (12–20 Hz). Participants were blind to group assignment. Assessment included potentially confounding variables. Each group was comprised of 19 children with ADHD (aged 8–13 years). The treatment procedure consisted of three phases of 10 sessions each. Both groups were able to intentionally regulate cortical activity and improved in attention and IQ. Parents and teachers reported significant behavioral and cognitive improvements. Clinical effects for both groups remained stable six months after treatment. Groups did not differ in behavioural or cognitive outcome.

Keywords ADHD - Neurofeedback - Slow cortical potentials - Theta-Beta - Self-regulation

Introduction

ADHD is one of the most common childhood disorders with a cumulative incidence of 7.5% by 19 years of age (Barbaresi et al., 2004). The effects of pharmacological and behavioral approaches to treat ADHD have been criticized as being limited, especially regarding long term effects (Beelmann & Schneider, 2003; Döpfner & Lehmkuhl, 2002).

The percentage of children diagnosed with ADHD who are treated with stimulants is about 86.5% for "definite" ADHD and 40.0% for "probable" ADHD (Barbaresi et al., 2002). Stimulants work quickly and, in about 70% off all children, they improve attention and reduce hyperactivity and impulsivity (Conners, 2002; Wagner, 2002). However, the effects on academic achievement, family relations and the childrens social life are small (Conners, 2002; Spencer et al., 1996). Long term benefits of pharmacotherapy for ADHD have not been established (Goldman, Genel, Bezman, & Slanetz, 1998; Spencer, Biederman, Wilens, & Faraone, 2002). Several concerns regarding side effects, e.g., reduced growth (MTA Cooperative Group, 2004), sleep disorders and several vegetative disturbances (Schachter, Pham, King, Langford, & Moher, 2001) may contribute to decreased compliance in both patients and parents.

Behavioral therapy has been demonstrated to reduce symptoms of ADHD (Döpfner & Lehmkuhl, 2002). However, a significant number of children exhibit even after behavioral interventions ADHD-symptoms and the long term efficacy has been characterized as marginal (Döpfner & Lehmkuhl, 2002). The limitations of pharmacotherapy and behavioral therapy underscore the need for alternative and/or complementary therapies for ADHD with long-lasting effects and minimal side effects. Neurofeedback appears to be such a promising alternative, as reduced behavioral ADHD-symptoms and improved cognitive variables have been consistently reported in the literature after neurofeedback-treatment.

The primary symptoms of ADHD—inattentiveness, impulsiveness, and hyperactivity—are ensured to be the result of pathological neurophysiology and are reflected in specific electrophysiological patterns. The spontaneous EEG activity of children with ADHD is characterized by increased Theta and decreased Alpha and Beta (Monastra et al., 1999; Monastra & Lubar, 2001). Event-related potentials, particularly the P 300, are marked by decreased amplitudes and prolonged latencies (Johnstone, Barry, & Anderson, 2001; Satterfield, Schell, & Nicholas, 1994).

One special type of event-related potentials are slow cortical potentials (SCPs). SCPs are slow DC-shifts of the EEG that reflect the excitation threshold of large cortical cell assemblies: SCP shifts in the electrical negative direction indicate a reduction of the excitation threshold, whereas shifts in the electrical positive direction reflect an increase of the excitation threshold (Rockstroh, Elbert, Canavan, Lutzenberger, & Birbaumer, 1989). Rockstroh, Elbert, Lutzenberger, and Birbaumer (1990) found that children with attentional problems had an impaired ability to regulate their SCPs.

Table 1 Diagnostic instruments and outcome measures

InstrumentAssessmentDiagnostic purpose

Parents

Semi structured questionnaire to assess developmental and health history of the child. t0B

DSM-IV—questionnaires for parents to assess DSM-IV-criteria for ADHD. t0, t1, t2B, O

Eyberg Child Behavior Inventory (Eyberg & Pincus, 1999) measures frequency of problems at home on a 7-point-rating-scale (1 = never, 7 = very often) and their impact on a dichotomous scale (yes vs. no). t0, t1, t2B, O

German Translation of Conners' Rating Scale (Conners, 1997). Parents rate several behavioral aspects of their child (e.g., affect, hyperactivity, aggression) during three days on a 3-point-rating scale from (0 = not at all, 3 = very often, very). t0, t1, t2B, O

Questionnaire to assess parenting style, German version (Miller, 2000). t0, t1, t2B, C

7-point rating scale (0 to 6) to assess the parental satisfaction with therapy. These measures were recorded anonymously. last day of each treatment phaseC

7-point rating scale (0 to 6) to assess the parental expectancies towards the therapy. These measures were recorded anonymously.first day of each treatment phaseC

Teacher

DSM-IV—questionnaires for teachers to asses DSM-IV-criteria for ADHD. t0, t1, t2B, O

Child

Testbatterie zur Aufmerksamkeitsprüfung, Version 1.7 (Zimmermann & Fimm, 1997)—a computerized test battery that measures several aspects of attention. t0, t1, t2B, O

Wechsler Intelligence Scale for Children: Hamburg-Wechsler-Intelligenztest für Kinder HAWIK-III; (Tewes, Rossmann, & Schallberger, 1999). To avoid retest-effects, we conducted the HAWIK-III only at t0 and t2. Retest-interval between t0 and t2 was between 9 and 10 months (interval between t0 and t1: 3 to 4 months, interval between t1 and t2: 6 months). t0, t2B, O

Note. Assessment: t0: baseline, t1: end of the treatment, i.e. after the 30th session, t2: follow-up 6 month after the end of treatment. Diagnostic purpose: B: baseline, O: evaluation of outcome, C: evaluation of confounding variables.

The first neurofeedback studies in ADHD were conducted in the mid 1970s (Lubar & Shouse, 1976; Shouse & Lubar, 1979). Currently, there are about 20 published studies reporting the effects of neurofeedback treatment for children with ADHD. As Vernon, Frick, and Gruzelier (2004) summarize, there are three main neurofeedback parameters utilised for children with ADHD, which include training in decreasing power of Theta (4–8 Hz) and increasing power of Beta (15–20 Hz) and increasing power of the sensorimotor rhythm (SMR, 12–15 Hz). The majority of research groups combine two or more treatment parameters, e.g., inhibiting Theta and enhancing Beta (Lubar, Swartwood, Swartwood, & O'Donnell, 1995) or inhibiting Theta, enhancing Beta and enhancing SMR (Alhambra, Fowler, & Alhambra, 1995). There are only two studies that trained self regulation of SCPs (Heinrich, 2004; Strehl, Leins, Goth, Klinger, & Birbaumer, 2006).

The results of studies that aim at self-regulation of Theta, Beta and/or SMR consistently suggest that neurofeedback treatment reduces ADHD symptoms. Cognitive measures improve, e.g., variables of attention and intelligence (e.g., Alhambra et al., 1995; Fuchs, Birbaumer, Lutzenberger, Gruzelier, & Kaiser, 2003; Monastra, Monastra, & George, 2002). Parents and teacher report behavioral improvements in everyday life, such as decreased impulsivity, hyperactivity and distractibility (Fuchs et al., 2003; Monastra et al., 2002). Alhambra et al. (1995) demonstrated a reduction or discontinuation of stimulant medications. Post-analysis of QEEG reveal changes in treatment parameters (e.g., Monastra et al., 2002). Monastra et al. (2005) summarized that significant clinical improvement was reported in nearly 75% of the patients treated with neurofeedback. No study has reported negative side effects following neurofeedback treatment. Research groups that used SCPs as treatment parameters report a significant reduction of ADHD-symptoms and improved attentional variables (Heinrich, 2004; Strehl et al., 2006). In addition Heinrich (2004) reported a marked CNV (Contingent Negative Variation) increase. Strehl et al. (2006) examined EEG during SCP-treatment. The results indicate that children with ADHD are able to control SCPs and that this ability remains stable six months after treatment.

Despite of these promising results, neurofeedback treatment is not yet accepted as standard therapy for children with ADHD. This is due to several methodological problems that question the reported positive effects of neurofeedback treatment on children with ADHD: First of all, there is a lack of adequate controls and a failure to control for possible confounds, such as the trainer-patient-interaction. Consequently, there is no evidence to show that the positive effects attributed to neurofeedback are a specific consequence of the manipulation of the electrophysiological variables. Second, follow-ups are missing to examine long-term effects. Third, the follow-up data are incomplete, e.g., EEG-data and information about academic performance are absent (Othmer, Othmer, & Clifford, 1991). Vernon, Frick, and Gruzelier (2004) summarize, that “at this moment evidence for the long-term efficacy of neurofeedback remains equivocal.” Fourth, many neurofeedback studies comprise small sample sizes, e.g., Lubar and Shouse (1976, N = 1), Shouse and Lubar (1979), Tansey and Bruner (1983) and Lubar and Lubar (1984). It is unclear which parameters were used to choose Theta, Beta or SMR or their combination. Information regarding the differential effects on different ADHD-subtypes are missing. It remains unclear if one treatment protocol is more effective than another and if different protocols for different subtypes should be used. Comparison studies of Neurofeedback with behavior therapy do not exist. Only a few studies compared Neurofeedback with drug treatment (Fuchs et al., 2003; Monastra et al., 2002; Rossiter & La Vaque, 1995).

In this study we randomly assigned children diagnosed with ADHD into SCP or Theta/Beta-therapy. This is the first study that compares the effects of SCP-treatment and Theta-Beta-treatment. Confounding variables, such as parental expectancies regarding therapy, parental satisfaction with therapy, and parenting style were assessed. A comprehensive diagnostic assessment that included subjective and objective information from teachers and parents (b) confounding variables (see above), (c) changes in cognition and behavior at the end of the treatment and six months later, and (d) EEG-data during course of treatment and during follow-up were measured.

Strehl et al. (2006) reported on the SCP-therapy of the present neurofeedback-study. In this paper results from both treatments—SCP and Theta/Beta—are reported. Some patients of the SCP-group from Strehl et al. (2006) are identical with patients of the SCP-group of this report.

This study aimed at answering following questions: First, whether patients were able to demonstrate learning of cortical self-regulation. Second, if treatment leads to an improvement in cognition (i.e., attention, intelligence) and behavior (i.e., hyperactivity, impulsivity). Third, if the two experimental groups differ in cognitive and behavioral outcome variables and fourth, if they differ in the stability of cortical self regulation and clinical effects.

Methods

Participants

Participants were children aged 8 to 13 years, who had

(a) Attention Deficit Disorder inattentive type or hyperactive type or combined type according to the DSM IV criteria

(b) no additional neurological or psychiatric disorder and

(c) a full-scale IQ > 80.

Participants were recruited from the outpatient clinic for psychotherapy of the university and from local psychiatric practicing physicians and psychologists.

Participants of both groups were blind to group assignment and assessment. Instruments used for diagnosis and evaluation of outcome are shown in Table 1.

The study was conducted according to the convention of Helsinki and approved by Ethics Committee of the Faculty of Medicine of the University of Tuebingen.

Groups were matched regarding age, sex, IQ, diagnosis and medication (see Table 2). Success of matching was examined with an independent samples t-test (age: t[36], p = 1,000, full scale IQ: t[36], p = .642).

Table 2 Demographic and initial assessment information by treatment group

Theta/Beta-groupSCP-group

Age

Mean 9.169.16

Range 8–128–13

SD 1.461.53

Sex

Boys 1616

Girls 33

IQ

Full Scale IQ

Mean 100.31101.78

Range 82–11385–123

SD 7.9811.15

Verbal-IQ

Mean 104.10107.57

Range 92–12787–140

SD 9.6013.492

Performance-IQ

Mean 96.9495.63

Range 71–11781–118

SD 10.9912.42

Diagnosis

ADHS 1515

ADS 44

Comorbidity2 (1 emotional disorder, 1 eunresis)7 (4 learning disorders, 1 enuresis, 1 coordination disorder)

Medication1 (Ritalin, 28 mg per day)1 (Ritalin, 28 mg per day)

Neurofeedback

The training was introduced as a computer game in which one can get points by using one's brain. Participants were advised to be attentive to the feedback and to find the most successful mental strategy to get as much points as possible. No specific instruction was given. Participants were only told that the aim of training is to “speed” up their brain in order to improve certain abilities, such as concentration, that are necessary for doing their homework or exams.

Participants in both groups were placed 50 in. from a notebook in a comfortable chair. As shown in Fig. 1, participants saw one rectangle on the top and one at the bottom of the screen. Dependent upon which of the two rectangles was highlighted, the participant was requested to either “activate” or “deactivate” the brain (see Fig. 1).

Fig. 1 Feedback-screen: (left) smiley face at the end of a successful activation trial; (middle) smiley face at the end of a successful deactivation trial, (left) red cross at the end of an invalid trial

Participants of both groups received feedback about their brain activity by a moving yellow ball (Fig. 1). During each trial, the ball (cursor) moved from the left corner of the screen to the right corner. Successful trials were rewarded by a smiley face that appeared at the end of the trial (Fig. 1). Unsuccessful trials were indicated by a black screen at the end of the trial. If a trial was invalid, e.g., because of eye movements, a red cross appeared after the end of the trial (Fig. 1).

As feedback-program an application of the Thought Translation Device, TTD (Hinterberger et al., 2000) was used. The TTD-software was custom-built at the Institute of Medical Psychology and Behavioral Neurobiology (University of Tuebingen) for research purpose. The feedback-program was controlled by a computer that was connected with an EEG-amplifier (EEG 8, Contact Precision Instruments).

All patients received additional auditory feedback. This was given with a tone that varied in pitch. A harmonious jingle was introduced as positive reinforcement. After each session the total number of smiley faces was exchanged for tokens. Participants collected these tokens and exchanged them for small gifts, e.g., books or toys.

Participants were trained in 3 treatment phases with a break of 4 to 6 weeks between each phase. A phase comprised two weeks and consisted of 10 sessions. One session lasted about 1 hr—preparation time included—and consisted of four runs with 38 trials. According to the participants demands short breaks were made between the trials.

In session 1 to 15, trials with required activation and deactivation were randomly distributed and comprised 50% of all trials. In sessions 16 to 33, the proportion of activation to deactivation trials changed to 75%/25% in favor to activation.

Fig. 2 Trial structure, SCP-group

In order to help the regulatory skills generalizing to everyday life situations transfer trials and transfer exercises were included. During the treatment, 23% of all trials were so called transfer trials. In these trails no cursor was shown and no tone was given during the active phase. At the end of each of these trials, participants were informed by the smiley face and the jingle whether or not the trial was successful. Transfer exercises were done (1) in the weeks between the treatment phases 1 and 2, between the treatment phases 2 and 3 and (2) in the third treatment phase. Participants were instructed to use their strategies for activation in everyday life situations. As a memory aid, a 15×5 in. picture of a computer screen with ball and goal box (see Fig. 1, left and middle graph) was given to each child. Children were instructed to produce the "activation" especially in problem situations, e.g. doing the homework, in which attention and endurance are required. In the third treatment phase children exercised activation while doing their homework after the end of each training session under the supervision of the trainer. The trainer guided the child only in using the activation-strategy and did not assist in solving the particular cognitive tasks.

Treatment and assessment procedures were implemented either by a licensed clinical psychologist or by graduate students under the psychologist's supervision.

SCP-treatment

SCPs were recorded at Cz. To calculate the feedback-signal, the Cz-signal was referenced against the two mastoids and averaged.

For detailed information about signal processing and artifact correction see Strehl et al. (2006), Hinterberger et al. (2004) and Kotchoubey, Blankenhorn, Fröscher, Strehl, and Birbaumer (1997).

One SCP-trial lasted 8 seconds and consisted of three phases (see Fig. 2): A baseline phase (seconds 0–2), an active phase (seconds 2–7.5) and a reinforcement phase (seconds 7.5–8). At the end of the baseline phase, participants were cued by a highlighted upper rectangle to "activate" their brain and by a highlighted lower rectangle to "deactivate" their brain. "Activation" in the SCP-group meant to produce a SCP-shift in the electrically negative direction, "deactivation" means to produce a SCP-shift in the electrically positive direction. The vertical movement of the ball reflected the degree of the participants' SCP-shifts: The ball moved upwards as the result of a negative SCP-shift and downwards in the case of a positive SCP-shift. At the end of each trial the SCP-power of the whole trial was integrated and subtracted from the baseline. A trial was successful if the integrated electrical activity was—compared to the baseline—negative in activation tasks and positive in deactivation tasks respectively.

Theta/Beta-neurofeedback-treatment

Results from several studies support a frontal electrode position for a theta/beta-neurofeedbacktraining as they found more theta and less beta activity in frontal regions of patients with ADHD (Lubar et al., 1995; Mann, Lubar, Zimmerman, Miller, & Muenchen, 1992; Chabot & Serfontein, 1996). But, if electrodes are fixed frontally, there is a risk of artefacts caused by eye movements. A possibility to minimize this risk is to choose a more central electrode position. Besides, a central position for a theta/beta-neurofeedbacktraining is supported by results from a validation study of Monastra et al. (1999). He observed a significant increased theta/beta-ratio in children with

ADHD aged 6–11 years. For those reasons electrodes in the Theta/Beta-group were placed at C3f (= halfway between C3 and F3) and C4f (= halfway between C4 and F4).

The Theta/Beta-feedback-signal was calculated by referencing the averaged Theta/Beta-ratio, recorded at C3f and C4f, against the averaged ratio, recorded at the mastoids (A1, A2). Hence, training was done with an unipolar EEG-recording.

As Theta- and Beta-frequencies fluctuate more than the SCPs, baseline and feedback phases were extended. At the beginning of each treatment session, a "pre-baseline" was taken, lasting 8 s. One Theta/Beta-trial lasted 10 s (see Fig. 3) with a trial-baseline phase (seconds 0–2), a feedback phase (seconds 2–9.5) and a reinforcement phase (seconds 9.5–10). The Theta/Beta-ratio, measured during the pre-baseline and the ratio, measured during the trial-baseline were integrated, resulting in an "overall-baseline-ratio," which was used as reference for the first trial. With ongoing treatment this reference was updated by each new trial-baseline-ratio.

Fig. 3 Trial structure, Theta/Beta-group

During activation-tasks participants had to decrease the Theta/Beta-ratio, i.e., to decrease the power in the Theta-band and/or to increase the power in the Beta-band. In deactivation-tasks participants had to decrease the Theta/Beta-ratio. The vertical direction of the feedback ball reflected the participants Theta/Beta-ratio: The ball moved upwards in case of a decreasing ratio and downwards in case of an increasing ratio. At the end of each trial the Theta/Beta-ratio of the active phase was averaged and subtracted from the overall-baseline-ratio. A trial was successful if the averaged ratio was—compared to the overall-baseline-ratio—lower in activation tasks and higher in deactivation tasks respectively.

As electrode placement and trial construction differed between groups, therapists could differentiate between them. This means they were not blind and knew which child participated in which group.

Data analysis

EEG-data

EEG-data were analyzed to determine

(a) if participants of both treatment groups were able to differentiate between activation- and deactivation tasks at the beginning of treatment (sessions 2+3), at the end of treatment (sessions 29+30) and at follow-up (sessions 32+33),

(b) if the difference between activation- and deactivation tasks changed during treatment, i.e., between the beginning of treatment (sessions 2+3), the end of treatment (sessions 29+30) and follow-up (sessions 32+33), and

(c) if the power of SCP-amplitudes and Theta/Beta-ratios respectively changed in activation and deactivation tasks during treatment, i.e., between the beginning of treatment (sessions 2+3), the end of treatment (sessions 29+30) and the follow-up (sessions 32+33).

Session 1 and session 31 were discarded as habituation sessions.

SCP-group

SCP-amplitudes were calculated for both tasks (activation/deactivation), conditions (feedback/transfer) and the three assessment points (sessions 2+3, sessions 29+30, sessions 32+33). After testing for normal distribution of SCP-amplitudes, the differences between SCP-amplitudes in activation and deactivation tasks were analyzed separately for each assessment point with an independent samples t-test (Kirley et al., 2002). Whether the difference of SCP-amplitudes between activation and deactivation tasks changed over time (Kirley et al., 2002) was analyzed by an ANOVA with repeated measures. The ANOVA was computed for both feedback and transfer conditions. In case of a significant result, post-hoc paired samples t-tests compared the three assessment-times separately. The change of SCP-amplitudes during the treatment (Kirley et al., 2002) was examined by an ANOVA with repeated measures, computed for both tasks (activation/deactivation) and both conditions (feedback/transfer). In case of a significant result, post-hoc paired samples t-tests compared the three assessment-times separately.

Theta/Beta-group

Because of the above mentioned special features of baseline computation, EEG-data-analysis of the Theta/Beta-group differed from the analysis of the SCP-group. The difference between the baseline ratio and the ratio during the feedback phase was computed for each participant, for both tasks (activation/deactivation), both conditions (feedback/transfer) and the three assessment points (sessions 2+3, sessions 29+30, sessions 32+33).

Fig. 4 SCP-group, mean amplitudes in negativity trials and positivity trials; feedback condition

After testing for normal distribution of Theta/Beta-ratios the difference between the Theta/Beta-ratios measured during the activation-tasks and during the deactivation tasks was examined for activation and deactivation tasks separately for each assessment point with an independent samples t-test (Kirley et al., 2002). Whether the difference between ratios in activation tasks and deactivation tasks changed over time (Kirley et al., 2002) was analyzed in two steps: First, an ANOVA with repeated measures examined effects of time (sessions 2+3, sessions 29+30, sessions 32+33) and task (activation/deactivation) for for both conditions (feedback/transfer). Second, in case of a significant result, post-hoc paired samples tests compared measurement-times separately. The change of

Theta/Beta-ratios during the treatment (Kirley et al., 2002) was examined by an ANOVA with repeated measures. ANOVA was computed for both tasks (activation/deactivation) and both conditions (feedback/transfer). In case of a significant result, post-hoc paired samples t-tests compared measurement-times separately.

Psychometric test data

After testing for normal distribution, all data of tests and questionnaires were examined with the same procedure: Effects of time (baseline, end of the treatment, follow-up) and group (SCP-group, Theta/Beta-group) were analyzed by an ANOVA with repeated measures. In case of a significant result, assessment points were compared separately with post-hoc paired samples t-tests.

ANOVA-results were corrected with Greenhouse-Geisser, post-hoc tests with Bonferoni. Effect sizes (ES) were calculated were assessed with Cohen's d (Cohen, 1988) for each significant result after correction with Bonferoni. Cohen's d is computed as the difference between the means, $M_1 - M_2$, divided by the pooled standard deviation .

Results

Self regulation of SCPs

Differences of SCP-amplitudes between activation and deactivation tasks

Differences between SCP-amplitudes in activation and deactivation tasks in the feedback condition were close to significance after Bonferoni-correction (see Fig. 4). Differences between SCP-amplitudes in activation and deactivation tasks were significant in the transfer condition at the end of the treatment (sessions 29+30) ($t[36] = 2.48$, $p = .036$, $ES = .81$) and at follow-up (sessions 32+33) ($t[30] = 2.55$, $p = .048$, $ES = .90$) as can bee seen in Fig. 5.

Fig. 5 Mean amplitudes in negativity trials and positivity trials; transfer condition

Fig. 6 Theta/Beta-group, Theta/Beta-ratio in negativity trials and positivity trials; feedback condition

The difference between SCP-amplitudes in activation and deactivation tasks increased significantly over time (sessions 2+3, sessions 29+30, sessions 32+33) in feedback conditions ($F[2,60] = 5.08$, $p = .020$), but not in transfer conditions. Interaction between time × task was significant in both feedback conditions ($F[2,60] = 5.93$, $p = .012$) and transfer conditions ($F[2,60] = 4.37$, $p = .017$). Between-tasks effects (activation/deactivation) did not reach significance. A post-hoc paired samples test for the feedback condition showed that the difference between SCP-amplitudes of activation and deactivation tasks increased significantly between sessions 2+3 and sessions 29+30 ($t[18] = 3.51$, $p = .006$, ES = 1.09) as well as between sessions 2+3 and sessions 32+33 ($t[14] = 3.07$, $p = .016$, ES = 1.05).

SCP-amplitudes in activation and deactivation tasks

SCP-amplitudes in activation tasks changed significantly with time in feedback-conditions ($F[2,30]=14.57$, $p<.001$) and transfer conditions ($F[2,30]=6.90$, $p=.005$). Change of SCP-amplitudes in deactivation tasks in both conditions did not reach significance (see figure 4+5).

A post hoc paired samples test showed, that the SCP-amplitude in feedback conditions between sessions 2+3 and sessions 29+30 differed significantly ($t[18]= 3.67$, $p=.004$, ES=1.03) as well as between sessions 2+3 and sessions 32+33 ($t[15]=5.28$, $p<.001$, ES= 1.07). In transfer conditions there were significant shifts between sessions 2+3 and sessions 29+30 ($t[18] = 3.10$, $p=.012$, ES=.98) as well as between sessions 2+3 and sessions 32+33 ($t[15]=24.13$, $p=.006$, ES=1.04).

Self regulation of Theta/Beta

Differences of Theta/Beta-ratios between activation and deactivation tasks

Differences between Theta/Beta-ratios in activation and deactivation tasks were significant at the end of treatment (sessions 29+30) for the feedback ($t[36] = 4.224$, $p < .001$, ES = 1.37) and transfer condition ($t[36] = 3.003$, $p = .010$, ES = 2.25). Differences were also significant at follow-up (sessions 32+33) for the feedback ($t[34] = 3.956$, $p < .001$, ES = 1.32) and transfer condition ($t[34] = 3.131$, $p = .012$, ES = 1.04). Interaction between time × task was significant for feedback condition ($F[2,68] = 7.19$, $p = .002$). Tests of between-tasks effects (activation/deactivation) reached significance for both feedback ($F[1,34] = 18.53$, $p < .001$) and transfer condition ($F[1,34] = 10.19$), $p = .003$) (see Figs. 6 and 7).

Fig. 7 Theta/Beta-group, Theta/Beta-ratio in negativity trials and positivity trials; transfer condition

Fig. 8 DSM Criteria, Parents' ratings; scores below 6 are normal

A post-hoc paired samples test for the feedback condition showed that the difference between Theta/Beta-ratios in activation and deactivation tasks increased significantly between sessions 2+3 and sessions 29+30 ($t[17] = 3.91$, $p = .003$, ES = .96) as well as between sessions 2+3 and sessions 32+33 ($t[15] = 2.94$, $p = .020$, ES = .74).

Theta/Beta-ratios in activation and deactivation tasks

Changes of mean Theta/Beta-ratios were computed separately for activation and deactivation tasks with a General Linear Model for repeated measures. Theta/Beta-ratios in deactivation tasks changed significantly over time for feedback-condition ($F[2,34] = 11.77$, $p < .001$), but not for transfer-condition. There was no change of Theta/Beta-ratios in activation tasks in both conditions. A post hoc paired samples test for deactivation tasks in feedback conditions showed a significant increase of Theta/Beta-ratios between sessions 2+3 and sessions 29+30 ($t[18] = 4.03$, $p = .003$, ES = 1.00) and between sessions 2+3 and sessions 32+33 ($t[17] = 4.17$, $p = .002$, ES = .90) (see figure 6+7).

Behavior

Parental ratings

According to parental ratings, DSM IV criteria were reduced significantly over time for both inattention ($F[2,68] = 9.15$, $p = .001$) and hyperactivity ($F[2,68] = 10.08$, $p < .001$). Interaction of group × time and difference between groups did not reach significance. Post-hoc paired samples tests result in significant changes only for the Theta/Beta-group: Attention improved between baseline and the end of treatment ($t[18] = 3.49$, $p = .009$, ES = .80) and between baseline and follow-up