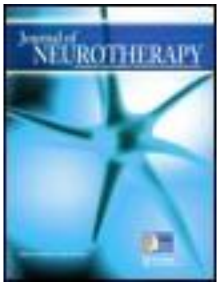

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Slow Cortical Potentials Neurofeedback

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CLINICAL CORNER

Slow Cortical Potentials Neurofeedback

Ute Strehl, PhD, MSc

ABSTRACT. Until recently, slow cortical potentials (SCP) training as a method of brainwave feedback has been widely ignored in the Anglo-American tradition of neurofeedback. One of the reasons was the lack of reliable and valid equipment outside a few research labs in Europe. In the meantime this has changed to the better. With devices now being available there is growing interest in SCP feedback. SCPs are very low shifts of brain activity. As they regulate excitation thresholds they may be used for self-regulation training in pathological conditions where excitation thresholds are impaired. This article explains technical requirements; describes training protocols; and gives a short overview on controlled research in epilepsy, attention deficit hyperactivity disorder, and migraine.

KEYWORDS. Attention deficit hyperactivity disorder, event related potentials, epilepsy, EEG, migraine, neurofeedback, slow cortical potentials

INTRODUCTION

It was only 2006 when Hammond summarized, "What is neurofeedback?" in this journal (Hammond, 2006). He stated that "neurofeedback training is brainwave biofeedback" and gave a short overview of applications. That article and other reviews in the past decade share a kind of "neglect" (e.g., Friel, 2007; Hirshberg, Chiu, & Frazier, 2005) in that none of these articles mentions slow cortical potentials (SCPs) training as a method of neurofeedback. This "unintended lack of attention" is undoubtedly also because of the fact that neurofeedback equipment for many years has not been able to adequately filter SCPs from the raw EEG in a reliable and valid manner. As is shown later in this article, the necessity of controlling artifacts is another issue that may have prevented SCP feedback from receiving more attention. Until the last several years only a few research labs in Europe have been able to record and feed back SCPs. However, progress in the development of amplifiers for EEG recording has now led to devices that are commercially available and affordable. This and published reports on clinical research have led to

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increasing interest in SCP training. Therefore, Dr. Hammond asked the author to write a "practical article on the European model of conducting SCPs training." The primary aim of this article is to present a short manual and "how-to" guide, but "how to do" also requires a knowledge of "why to do." Thus a short introduction into the nature of SCPs is given in the first section of this article. Finally, research results for applications of SCP training are presented.

WHAT ARE SCPs?

SCPs belong to the family of event-related potentials. Unlike the oscillatory activity of the brain waves (delta, theta, alpha, beta, and gamma), event-related potentials do not occur spontaneously, but are time locked. The timing of responses to a stimulus reflects diverse aspects of stimulus processing. SCPs can be observed from 500 msec after the onset of a stimulus. Their duration is from 300 ms to several seconds, and they fluctuate from being electrically negative to electrically positive. Negative surface SCPs result from a sink caused by synchronous slow excitatory postsynaptic potentials in the apical dendrites of layer I in the cortex with a source being located in layers IV and V. Positive fluctuations can be understood as inhibition or abatement of negativities. Electrical negative shifts reflect the activity of large cell assemblies that are responsible for the planning and initiation of goal directed behavior while positive shifts are understood as disfacilitation of excitation thresholds.

FIGURE 1. CNV in an experimental (left panel) and in a feedback setup (right panel).

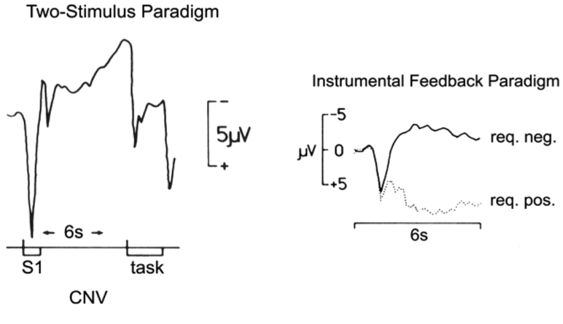


Figure 1 compares the contingent negative variation (CNV) as it is provoked in an experimental design (left panel) and its application in a feedback paradigm (right panel). The CNV is a wide and prolonged negative potential that is contingent on a person's conscious perception of a stimulus that warns him or her of another imminent stimulus to which the person intends to make a response.

SCPs can be understood as a phasic tuning mechanism that may serve as a basis for attentional regulation (Rockstroh et al., 1993). In numerous studies a consistent relationship between cortical negativity and reaction time, signal detection, and short-term memory performance has been found (Birbaumer, Elbert, Canavan, & Rockstroh, 1990; Birbaumer, 1999, for an overview). Therefore, diseases that can be characterized by impaired excitation thresholds are candidates for training in the self-regulation of SCPs.

TECHNICAL REQUIREMENTS

As mentioned previously, until recently devices for feedback of SCP were not commercially available, but this has now changed. Next the article presents the common technical standards and procedures necessary for SCP training. Currently available devices may be using deviating solutions.

Amplifier

The recording of SCPs requires a high-pass filter that allows the registration of very low frequencies. This high-pass filter is called the time constant. This time constant should be at least 10 sec. An amplifier that is capable of recording direct current is ideal.

Electrode Montage

SCPs in neurofeedback paradigms are recorded from the vertex (Cz) and depending on the device being used are referenced against one or both mastoids. If both mastoids are used as the reference the signals have to be averaged. To control for artifacts (see next) two or four electrodes are needed to record the vertical and horizontal electrooculogram (EOG; eye movements). As with any other neurofeedback device, an electrode also has to be attached as a ground sensor. Therefore, for proper artifact control having available four to eight channels in the unit is mandatory. To avoid slow potential drifts sintered silver/silver chloride electrodes filled with a conductive paste should be used. Impedance of less than 5 k Ohm should be obtained by careful preparation of the skin with an abrasive cleaning paste.

Signal Processing

Training to self-regulate SCPs always requires the monitoring of two different brain states. The patient is asked either to reduce the excitation threshold (i.e., to produce a negative shift) or to increase it (i.e., to produce a positive shift). Because of the continuous shifting of SCPs from negative to positive as well as for practical reasons each trial takes about 6 to 10 sec, being preceded by a passive phase of about 2 sec. During the passive phase a baseline is calculated over a certain amount of milliseconds. The mean amplitude from the passive phase is then set to zero and serves as baseline for the following active phase. Normally, an acoustic signal marks the beginning of a trial and the task is indicated by a visual symbol. This might be an arrow (up or down), a rectangle (top or bottom of the screen), a colored object (red or green), and so forth. Every 62.5 msec the SCP amplitude is calculated as an average of the preceding 500 msec. The position of the feedback signal (e.g., cursor, ball, changing color) corresponds to the difference of every 500 msec amplitude in comparison with the baseline. For example, the signal may move upward as a negative shift is produced, whereas movements downward indicate that the SCP is less negative than during the baseline, that is, cortical positivity is being produced (negativity is inhibited).

Artifact Control

Although recording the EEG several kinds of artifacts may distort the results, which would generate inaccurate feedback, in SCP training eye movements may especially cause artifacts. Because the neurons in the retina generate electrical potentials, eye movements lead to a change of the polarity. EEG recordings, especially at frontal sites may therefore be influenced by them. Blinks may lead to a positive potential as the eyelid picks up the positive potential of the positively charged cornea. To control these artifacts an EOG is mandatory. The EOG measures potential differences from electrodes placed around the eyes. For the online correction of the EEG, different algorithms are available (Kübler, Winter, & Birbaumer, 2003; Schlegelmilch, Markert, Berkes, & Schellhorn, 2004).

Another source of artifacts is body movement. Muscle activity from such subtle movements as raising one's brow slightly as well as from changes in bodily posture may produce slow shifts in the recording. As amplitudes following from movements tend to be much larger than amplitudes resulting from brain activity, devices with online corrections are preferable. Appropriate software defines trials as invalid as soon as a certain amount of microvolt (μV) change is observed. For example, this can be done by applying a threshold detection algorithm, which eliminates single trials having an amplitude above or below 200 μV before averaging.

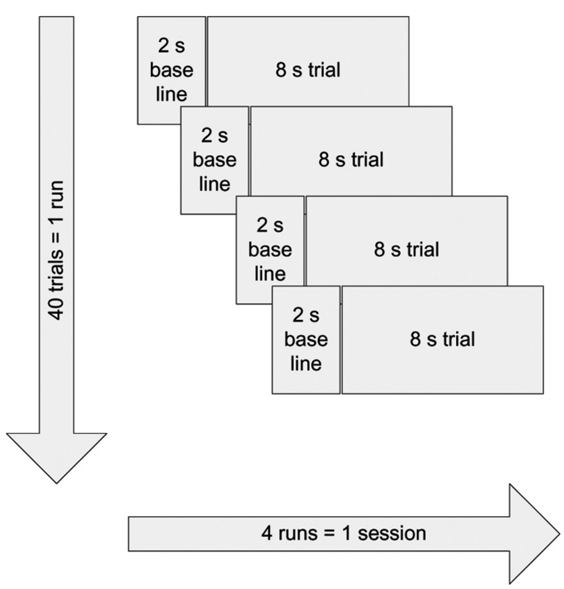
If trials with artifacts are not rejected, the patient will merely learn to move his eyes or other parts of his body to produce an affect. It is of utmost importance that only changes in brain activity are being reinforced. A general prerequisite to avoid artifacts is that patients refrain from moving as much as possible and are carefully monitored by the therapist.

TASKS AND CONDITIONS

As stated previously, SCP training comprises two *tasks*—to produce either negative or positive shifts. The training to produce change in only one direction is limited because the shifts during a trial are relative to the baseline. For instance, if the potential during the baseline is already positive it might be easier to produce a negative shift. With a series of many identical tasks it will be increasingly difficult to shift a potential into the same direction—at least as long as the patient does not shift into the opposite direction during the baseline phase. Therefore, one to three or four identical tasks should be followed by the opposite task in random order. In addition to feedback trials so-called transfer trials are also presented in which no feedback signal is shown. Only after the end of the transfer trial is the patient told whether he or she succeeded. This information is provided by presenting a smiley or other display that stands for positive reinforcement. The aim in presenting transfer trials is for the subject to become accustomed to self-regulation in everyday life situations where no feedback is available.

The duration of a trial is about 6 to 10 sec, and after 25 to 40 trials a break is recommendable. Our "European protocols" normally consist of three to five runs with about 30 to 40 trials each in a session. The total number of sessions in the SCP research studies has been 25 to 35. These sessions are conducted daily or sometimes even twice a day with a break of about 4 weeks after every 10th session. With the exemption of the duration of a trial that has been investigated by Kisil and Birbaumer (1992), all other variables (number of trials during a run, number of runs during a session, amount of sessions and breaks) are based only on convention. An example regarding trials, runs and sessions is given in Figure 2.

FIGURE 2. SCP training: trials, runs and sessions. *Note*. s = seconds.

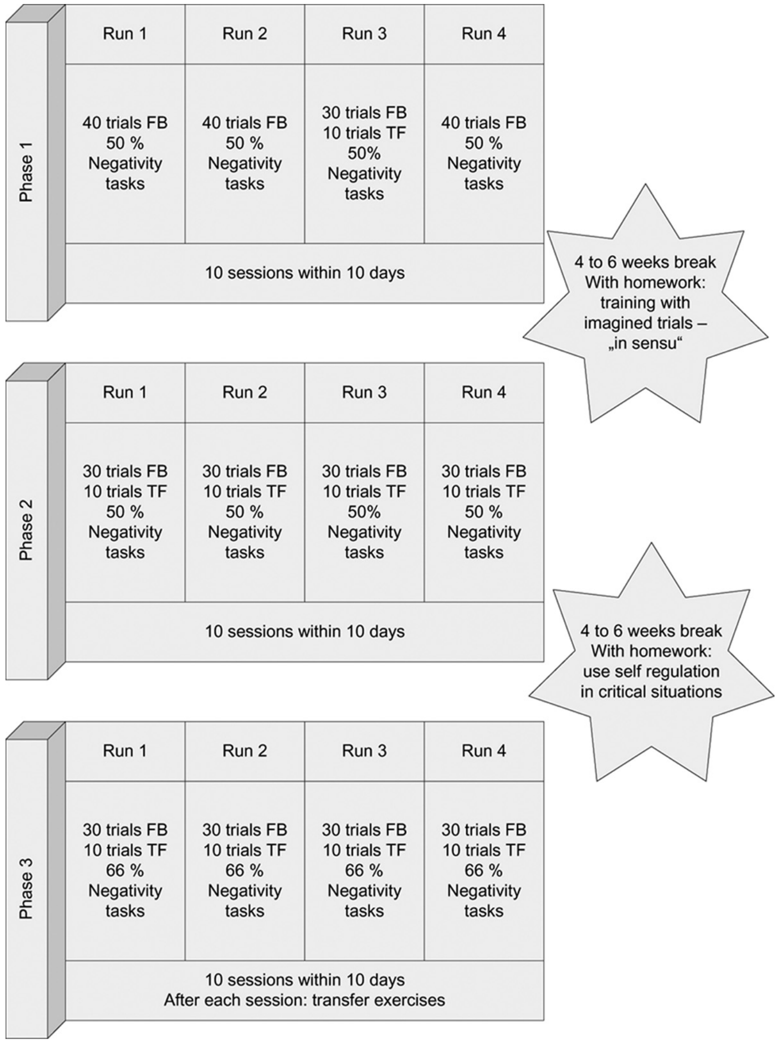


Within a session the amount and sequence of each task (positivation/negativation) and each condition (feedback/transfer) has to be arranged. During the first 5 to 10 sessions the frequency of both tasks might be equal. During the course of training up to two thirds of the tasks will be chosen according to the pathology (see next, indication). Transfer trials can be interspersed from the very beginning, but it might be reasonable in many cases to wait to institute transfer trials until the subject has gained some degree of self-regulation skill in feedback trials. The sequence of tasks and conditions should be random. An example for a possible set up and sequence of training in attention deficit hyperactivity disorder (ADHD) is shown in Figure 3.

The First Training Session

The first session serves as an introduction to the setting and training. The equipment is explained, and especially the young patient should be invited to touch the electrodes, handle pastes, and so on. To prevent artifacts they should be demonstrated before the start of training so that patients may observe the movement of the display as they are encouraged to create artifacts (e.g., move their tongue, clench their jaw, and tense the muscles of the shoulders or frown). After these little "experiments" it is explained that artifacts may be mistaken for success albeit keeping the patient from acquiring self-regulation skills. As the self-regulation of SCPs, especially in the beginning, is more difficult than the self-regulation of EEG frequencies, the therapist should coach and provide reinforcement as much as possible. Compared to frequency neurofeedback training, SCP shifts are not as easily connected to states of mental activation. Therefore, patients search for conscious strategies that might be helpful. In many patients negativities are associated with images of activation; whereas positive shifts are associated with relaxation (and in children sometimes with boredom). But there are patients who use diametrical strategies. It

FIGURE 3. Training protocol ADHD (example).



should be understood that these images are only a means to an end that may not hold in every situation. New images have to be found and eventually no image may be necessary at all. Assistance during this process of trial and error can be realized by a second monitor and an intercom.

To support the process of learning, shaping procedures can be implemented. Corresponding to protocols in frequency neurofeedback training, the thresholds for success should be set low enough to ensure a certain amount of successful trials from the beginning. Sometimes it might be useful to adjust the threshold during a session. Again, a second monitor would be useful.

Transfer of Self-Regulation Skills into Everyday Life

SCP training explicitly emphasizes and arranges for a transfer of the skills learned in the lab into everyday life. Although for technical reasons it cannot be proven whether transfer actually takes place, at least the probability that it may take place has to be provided for. Several strategies might be useful:

Transfer trials during the feedback training. Transfer trials are provided where no immediate feedback is given. Only after the end of such a transfer trial is the patient informed whether he or she produced the shift according to the task. It has been shown that patients are able to develop and improve self-awareness of their ability to self regulate SCPs (Kotchoubey, Kübler, Strehl, Flor, & Birbaumer, 2002).

Transfer of self-regulation training into everyday life. As self-regulation skills develop, the patient is asked to imagine training trials at home as if he or she were sitting in front of the monitor at home. Especially during breaks between training phases this exercise can be assigned and recorded as homework. A downscaled picture of the screen during a task can be given as a memory-aid handout.

Transfer of self-regulation skill to target situations. A further example of facilitating the generalization of self-regulation skills to real life is assigning children with ADHD to do their homework while remembering to use the brain shift to electrical negativity in order to be alert and attentive. Patients with epilepsy can practice self-regulation skills in seizure-prone situations (in imagination, with role playing, or in actual everyday life situations), trying to shift their brain into inhibition of excitation (in an electrical positive direction).

These transfer exercises have been developed in the European tradition of SCP training. The linkage of SCP shifts to cues to facilitate self-regulation may be more important in SCP training in comparison with neurofeedback targeting changes in frequency bands. It is believed that transfer exercises operate to minimize state dependent learning, and this might be important in frequency training protocols as well.

DIAGNOSIS AND EVALUATION

Apart from assessment procedures that may be necessary to confirm a diagnosis, no specific evaluation of the EEG is necessary prior to SCP training. To evaluate the training process a look at the training data should be done as soon as possible after the end of a session. Variables that can be assessed are amplitudes, and differences between negativities and positivities for both conditions (feedback/transfer). Figure 4 depicts averaged SCP shifts of a training session consisting of 10 trials (one of the

FIGURE 4. Averaged slow cortical potentials in negativity and positivity trials under feedback (upper panel) and transfer (lower panel) conditions. With friendly permission by neuroConn GmbH, Germany.

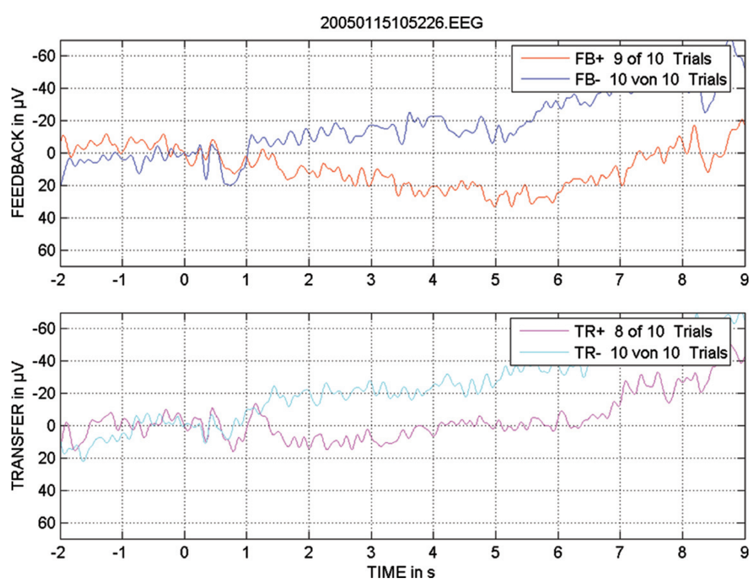
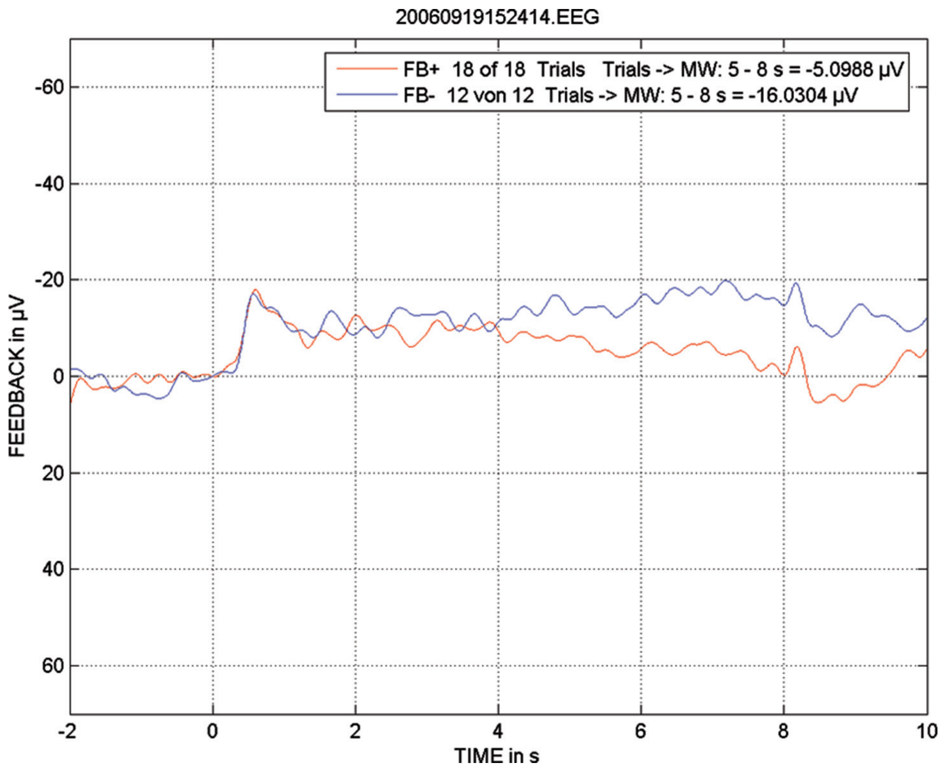


FIGURE 5. Example for low hit rates albeit good discrimination between the tasks. With friendly permission by neuroConn GmbH, Germany.



positivity task trials was excluded before averaging because of artifacts).

Many devices allow determining hit rates. As can be seen from Figure 5 in certain cases hit rates may not reflect the actual attainment.

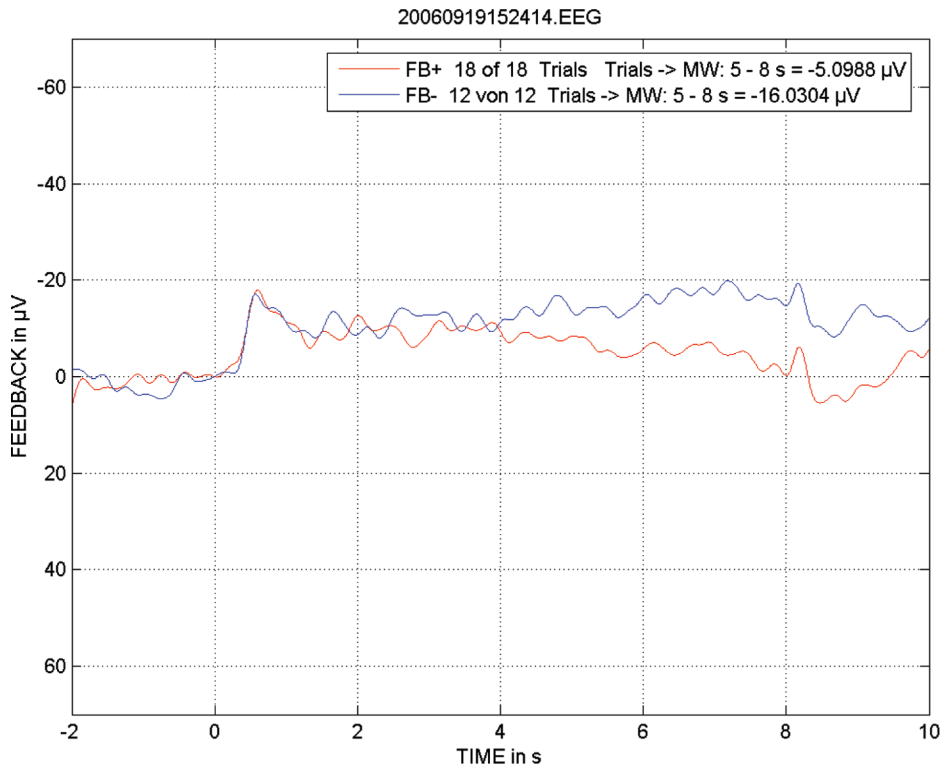
This participant had a hit rate of 84.5% for negativity trials and a hit rate of 5% for positivity trials. As long as there is a differentiation between the shifts of both tasks one would appreciate the performance. Another possible outcome (Figure 6) is a differentiation between tasks in the opposite direction. The hit rate for negativity tasks was 69% and for positivity tasks was 0%. In this case the patient produced negative shifts during positivity tasks and positive shifts in negativity tasks. This shows that he or she was already able to react reliable in two different ways. The next step in training would be to reverse the reactions. Information about hit rates is meaningful regarding the ability to surpass the threshold.

In addition to pre/postevaluation of core symptoms (e.g., behavior, personality variables, mood, attention, quality of life, etc.), changes in cognitive processing should be documented. Assessments of changes in latency and amplitude of event related potentials can be accomplished with tests as the Continuous Performance Test (CPT).

EVIDENCE BASE, INDICATIONS AND CLINICAL EXPERIENCE

Research in SCPs started with psychophysiological experiments with healthy participants where it was demonstrated that they are able to acquire voluntary control of SCPs. For pathological conditions, Rockstroh et al. (1993) were the first to report a decrease of seizures after SCP training in patients with therapy resistant focal epilepsies. In patients with epilepsies huge cortical negativities have been observed to precede seizures. After the abatement of a

FIGURE 6. Example for good discrimination with low hit rates for both tasks. With friendly permission by neuroConn GmbH, Germany.



seizure these negativities are followed by positive shifts (Ikeda et al., 1996). Therefore, during SCP training, patients were instructed to reduce negativity (i.e., to produce positive shifts) whenever they had the impression that they might have a seizure. Kotchoubey et al. (2001) compared 35 sessions of SCP training with two control conditions: respiratory feedback (RESP) and changes in the medication (MED). There was no change in the RESP group, but both MED and SCP reduced significantly seizure frequency. In an extensive follow-up evaluation it was shown that SCP self-regulation skills continue to improve after the end of training and seizure decrease is stable.

Children with and without attention problems were compared by Rockstroh, Elbert, Lutzenberger, and Birbaumer (1990) in their ability to self-regulate SCPs. Only in feedback trials were children with attention problems able to exert control. In anticipation of a task they showed reduced negativities. It was hypothesized that attention problems are caused by an impairment of the regulation of excitation thresholds. Heinrich, Gevensleben, Freisleder, Moll, and Rothenberger (2004) and Strehl et al. (2006) were the first to assess the effects of SCP training with ADHD children. After 25 sessions with 13 children behavioral symptoms of ADHD improved, impulsivity as measured with the CPT was reduced, whereas the CNV was increased (Heinrich et al., 2004). In the study of Strehl et al. with 23 children significant changes in behavior, attention and IQ were observed after 30 sessions. In addition EEG data proved that children were able to regulate negative shifts in feedback as well as in transfer trials. All changes were stable at 6 months' follow-up evaluation.

Children with migraine were trained by Siniatchkin et al. (2000) in SCP feedback. Compared with healthy controls, children with migraine took longer to control cortical negativity. After 10 sessions this difference could no longer be observed. Number of days with migraine and other headache parameters were significantly reduced.

Although there are no studies of SCP training with other clinical conditions, clinicians may want to use the SCP protocol with other conditions that are characterized by impaired regulation of excitation thresholds. In our outpatient clinic we successfully treated a child with Gilles de la Tourette's tic disease, and other clinicians report improvements in children with autism and with dyslexia.

NEUROFEEDBACK—AND ELSE?

Is neurofeedback a *treatment* for mental disorders or a *training*? This question refers not only to the issue of reimbursement by social and health insurance agencies. It points to whether the feedback sessions are sufficient in and of themselves or need to be accompanied by additional therapeutic interventions such as medications, cognitive behavior therapy, or parental training. Similar to studies with frequency protocols there is no systematic research on this topic. Studies with SCP training have been performed with (e.g., Kotchoubey et al., 2001) or without (Heinrich et al., 2004; Rockstroh et al., 1993; Strehl et al., 2006) additional therapeutic elements. Unfortunately, a comparison between these two approaches cannot be performed as the effect of additional interventions cannot be isolated. The same conclusion holds for neurofeedback studies that used EEG frequency protocols (e.g., Monastra, Monastra, & George, 2002; Thompson & Thompson, 1998; Tinius & Tinius, 2000). Monastra et al. reported that parenting style exerts a significant moderating effect on behavioral outcome measures as rated by parents. This result could be used as a rationale for interventions in addition to neurofeedback. As a conclusion the clinician has to decide after the diagnostic evaluation about additional problems/behaviors to treat that are not under the influence of a patients' cortical self-regulation.

SUMMARY

SCPs are very slow shifts of brain activity with a duration of up to several seconds. They are either electrical negative or electrical positive. Negative shifts reflect the activity of large cell assemblies that are responsible for planning and initiation of goal directed behavior, whereas positive shifts are understood as inhibition or abatement of negativities. Because SCPs regulate the excitation threshold, they may be used in self-regulation training in conditions with impaired excitation thresholds. Studies have shown that after SCP training, patients with conditions such as epilepsies, ADHD, and migraine improve in core symptoms as well as in cognitive variables.

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