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Specific effects of slow cortical potentials neurofeedback training on attentional performance

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Abstract

The association between successful regulation of slow cortical potentials and latencies in two reaction time tasks was investigated. At the end of a three-day training period successful regulators showed a stronger reduction in latencies than unsuccessful regulators. This was true for a task involving learning, but not if the task only required responding as fast as possible. Our results suggest that healthy participants can learn to regulate SCPs during the course of a short training, and that training success is associated with reduced response latencies. Possible applications of SCP-based biofeedback for rehabilitation after acquired brain injuries are discussed.

1 Introduction

Stroke is one of the leading causes of death and disability in western societies [1]. Cognitive impairments, such as attention deficits play a prominent role [2] and EEG biofeedback (or neurofeedback, NF) has been proposed as an effective treatment [3]. Negative slow cortical potentials (SCP) reflect summation of synchronized excitatory postsynaptic potentials from apical dendrites, whereas positive SCPs derive from reduced inflow to apical dendrites or inhibitory activity. In line with this view, studies show that an increase of negative SCP amplitudes is related to better task performance when attention and motor reactions are required [4, 5]. However, the knowledge about the relation between attention and slow cortical potentials [6] has not yet been exploited for improving attentional functioning in stroke [2].

In this study we sought to relate the progress in SCP control during NF training to latencies (as a measure of attention) in two reaction time (RT) tasks. In the *simple task* subjects had to monitor a series of 31 random letters for 8 occurrences of the letter ”X” and respond to ”X” as fast as possible via a button-click. In the *learning task* subjects had to monitor a series of 31 random letters for 6 occurrences of the two-letter sequence ”A”–”X” and respond to ”X” as fast as possible via a button-click. Optimal performance in this task required subjects to learn the contingency of ”A” being always followed by ”X”. ITI was 690 ms, and both tasks were presented in blocks of nine sequences each.

Across training, we hypothesized a learning effect for SCP regulation, i.e. increasing separation of negativity and positivity trials, and for the learning tasks, i.e. reduced latencies. Our main interests were in the association of regulatory success and response latencies, hypothesizing that successful SCP regulation would correlate with reduced latencies in the learning but not in the simple task.

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2 Methods

Each NF session included 250 trials in which cortical positivity had to be increased and 250 trials in which cortical negativity had to be increased. Trials lasted for 8 s (baseline: 0-2 s, active phase: 2-8 s). Online feedback, from electrode Cz referenced to linked mastoids, consisted of a circle whose size and color indicated whether subjects regulated successfully with regard to baseline activity. Trials were judged successful, and success indicated to the participant, if brain activation was regulated as required by the task (towards positivity or negativity, respectively). Vertical eye movements were corrected for using a regression procedure. After getting acquainted with the RT tasks, eleven healthy student subjects (mean age: 23.20, SD: 5.20, range 20-38) trained for three days during one week. On days one and three, training consisted of two sessions (A & B), and each session comprised one neurofeedback training and the two RT-tasks. On day two, the single training session consisted of the sequence RT-tasks–neurofeedback training–RT-tasks. Here, we evaluate associations between latencies and amplitudes in the EEG at days one and three.

Preprocessing steps for the offline analysis corresponded to the steps used during online training (10 Hz low-pass filtering, detrending to compensate for DC drift, epoching, alignment to pre-trial baseline, correction for ocular artifacts, exclusion of trials with absolute voltages exceeding 100 μV). Then, trials were averaged per regulatory condition, and the mean activity during the 2 s long interval starting from 4 s after the beginning of each trial exported for statistical analysis. One participant was excluded due to low quality of the EEG recording, and another participant did not participate in all training sessions and was therefore excluded. The total sample size available for analyzing the association between amplitude and latencies is, thus, n = 9.

To analyze the relation between latencies in the RT tasks and success during SCP regulation, we followed a two-step approach. First, we established that latencies in the RT tasks decreased, and that SCP regulatory success, i.e. the absolute difference between negativity and positivity trials, increased across training. Then, we analyzed the association between the change in latencies and the change in SCP regulatory success between day three and day one. Reported p-values are two-sided.

3 Results

Repeated measures ANOVA of latencies in the learning task revealed significant effects of training day ($F_{1,9} = 3.51, p = .047$), session ($F_{1,9} = 10.37, p = .011$), and their interaction ($F_{1,9} = 7.01, p = .027$). Follow-up analysis indicated that latencies decreased across sessions at day one but remained stable thereafter (see Figure 1 A, Table 1). Latencies in the simple task did not change across training (all $p > .30$). Mean number of errors was low (range $1 - 4\%$) and did not differ between conditions (all $p > .16$).

Results for SCP regulation (see Figure 1 B) showed significant effects of regulation ($F_{1,9} = 16.63, p = .003$), the interaction of regulation and training day ($F_{1,9} = 11.63, p = .008$) and a marginal effect of the interaction of regulation and session within each day ($F_{1,9} = 4.68, p = .059$; see Table 1).

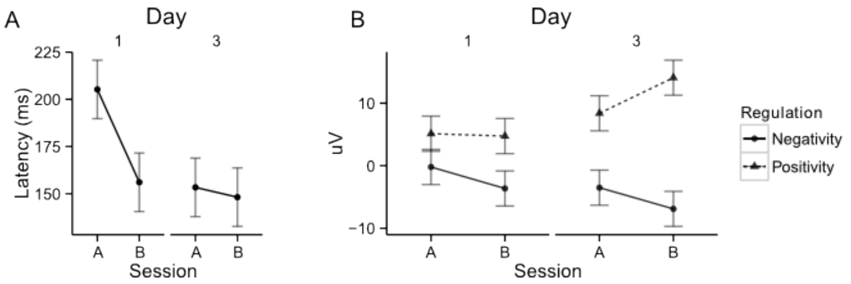

Figure 1: Results of RT-task and SCP training

A: Effects of training on latencies in the learning RT-task at Day 1 and Day 3. B: Results of SCP training at Day 1 and Day 3. Error bars show Fisher's least significant differences.

		SCP (μV)		learning task (ms)		simple task (ms)	
Day	Session	M	SD	M	SD	M	SD
1	a	7.94	8.61	205.23	66.24	435.46	30.23
1	b	8.10	7.95	156.05	55.76	430.46	34.08
3	a	8.85	8.96	153.33	76.56	444.73	38.05
3	b	21.59	13.77	148.14	87.48	434.22	29.11

Table 1: SCP regulatory success and latencies across training

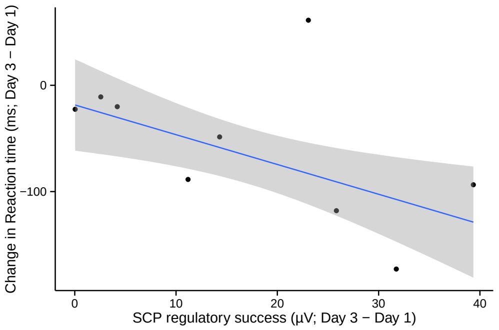

Figure 2: Association between SCP regulatory success and response latencies

Analysis of the association between learning in the learning task and learning of SCP regulation between day three and day one indicated a large –but marginal– negative association (Spearman's $\rho = -.63, p = .076$). Figure 2 shows that subjects who were able to increase the difference in SCP amplitudes between days three and one, tended to show faster response latencies on day three in comparison to day one. In the simple task, changes in latencies between day three and day one were not associated with changes in SCP regulatory success ($\rho = .017$, $p = .982$).

4 Discussion

To summarize, our data show that healthy participants can learn to regulate their SCPs during the course of a short training. Latencies in the learning task decreased across training, but latencies in the simple task remained stable. Further, learning of SCP regulation was marginally associated with reduced latencies in the learning, but not in the simple task. However, because we employed a correlative design it is unknown whether changes in SCP regulatory success play a causal role for latencies in the learning task.

Our results support previous findings that successful SCP regulation is associated with faster reaction times [5]. However, this association was found only for a task which involved learning, but not in a simple RT task. This may suggest that the choice of tasks used in neurofeedback studies may play a crucial role. We thus speculate that associations between SCP regulatory success and behavioral data should be strongest with tasks of medium difficulty involving executive functions [7].

Our results show that successful regulation of SCPs is possible even with limited training and that this change is associated with increased performance in a task requiring attention and motor reaction. Based on these encouraging results, studies are underway aiming to replicate these findings in a large sample of chronic stroke patients.

Acknowledgments

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