Neurofeedback in ADHD: further pieces of the puzzle – Supplementary Material

Neurofeedback (NF) training

Theta / beta training

Implementation

A theta / beta training can be implemented e.g. as a car race (see Fig. S-1). The child is driving the red car, the blue car is steered by the computer via simulated signals. The red car only moves if theta activity represented by the left bar is below a pre-defined threshold and if beta activity represented by the right bar is above a pre-defined threshold (or if theta/beta ratio is below the threshold). Interpreting NF training as a neuro-behavioural training, the child has to find an appropriate strategy so that the car drives as many laps as possible. A car race typically lasts for five minutes in the beginning of the training and is extended to 10 minutes as the training proceeds so that the children have to sustain an alert and focussed but relaxed state for a longer period.

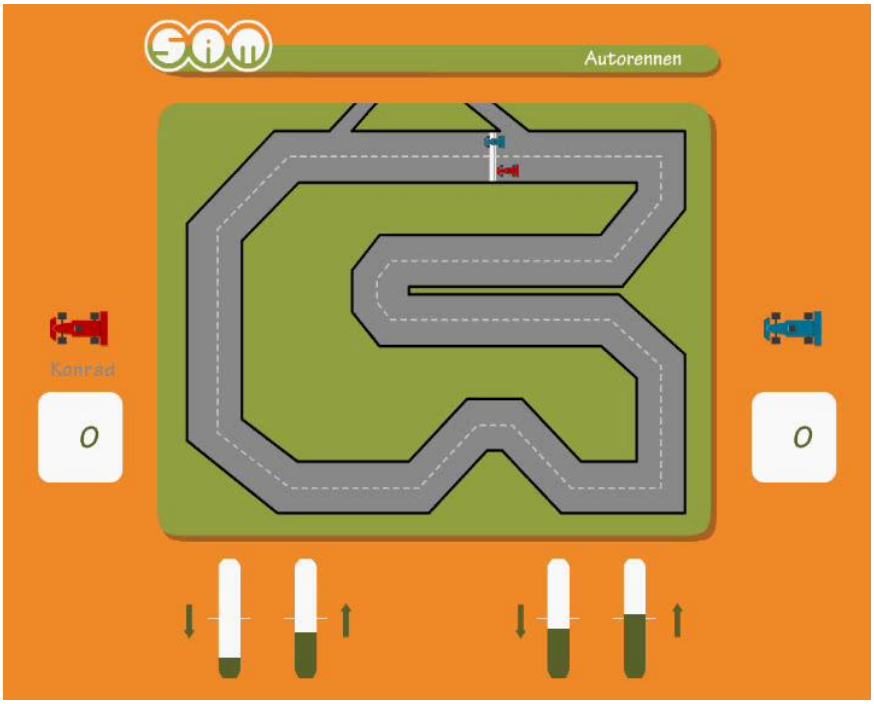

Fig. S-1: Example of a theta / beta training (from the NF program SAM, developed by our group; animations developed by FilmBilder, Stuttgart, Germany)

Technical aspects

Recording bandwidth of 1 - 30Hz is appropriate for theta / beta training. Artefact control (and corresponding feedback) is essential (for all kinds of NF protocols). Vertical electrooculogram (EOG) recording is highly recommend particularly for correcting blink artefacts which have frequency components in the theta frequency range. In our NF program, Butterworth filters (48 dB / octave) are applied to calculate theta and beta activity. Using a moving time window of about 1-2 seconds length, feedback is calculated several times per second. If learning is

assumed to rely on (more or less unconscious) operant conditioning, the delay of feedback should be as small as possible (Sherlin et al. 2011).

Slow cortical potential (SCP) training

Implementation

In Fig. S-2 examples of an SCP training are illustrated. In the green window at the bottom of the screen, a white ball is shown at the left side during the baseline phase (lasting for 2 sec). At the beginning of the feedback phase, a red line appears at the top of this window in a negativity trial. During the feedback phase (6 sec), the ball flies from the left to the right side of the screen. In a negativity trial (related to directing attention), the ball has to be moved upwards by cortical self-regulation. The longer a ball is above the centre line, the more the ball changes its colour to red. In a positivity trial (related to a relaxed state), a blue line appears at the bottom of the window. The ball has to be directed downwards. The longer a ball is below the centre line, the more the ball changes its colour to blue. Successful trials (= correct colour at the end of the trial) are rewarded by a point. Positivity and negativity trials are presented in random order. In a training unit, several series of 30 to 40 trials are typically run.

As in theta / beta training, SCP training can also be implemented as a kind of game. For example, the child is a goalkeeper at a penalty kick in a negativity trial (see Fig. S-2). If the ball is red at the end of the trial, the goalkeeper holds the ball and the child wins a point.

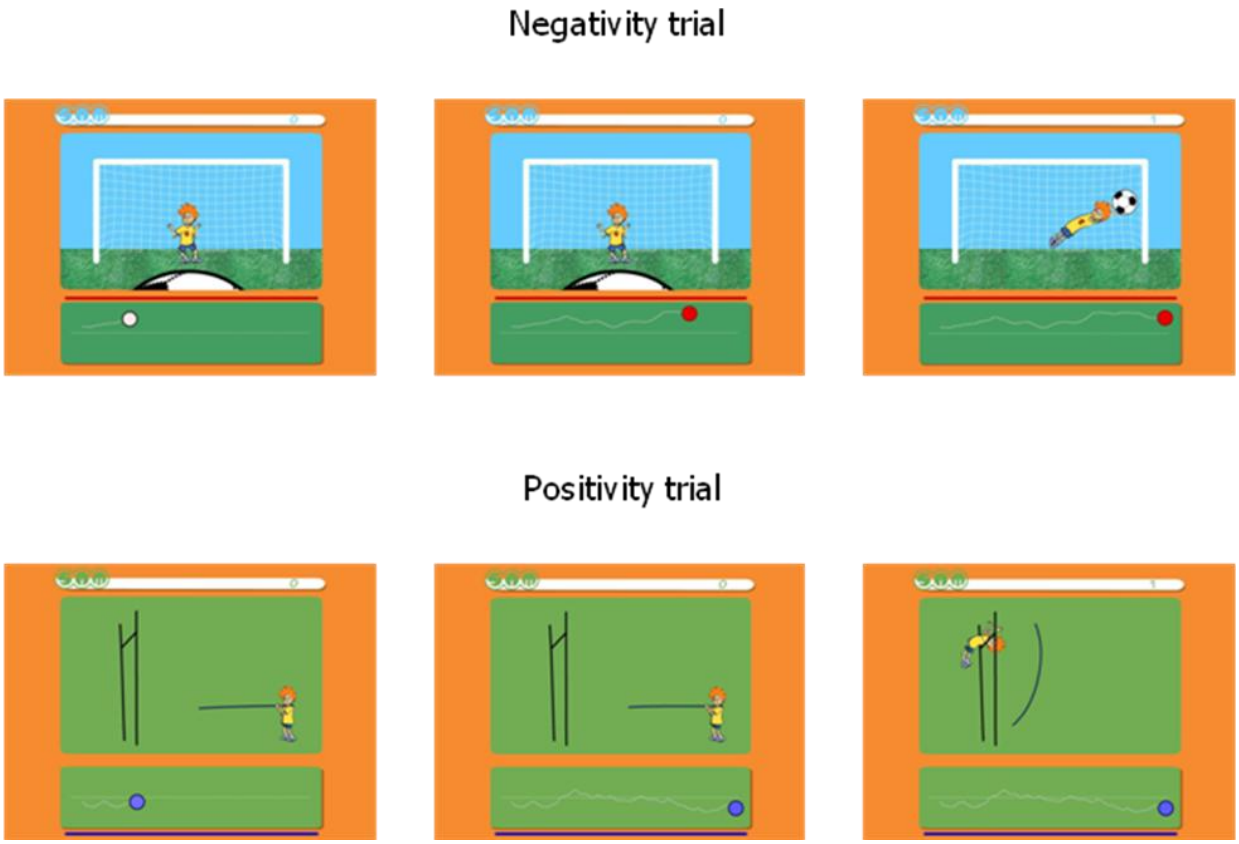

Fig. S-2: Examples for SCP animations (from the NF program SAM, developed by our group; animations developed by FilmBilder, Stuttgart, Germany)

Technical aspects

Since SCPs are changes of cortical electrical activity lasting from several hundred milliseconds to several seconds, frequencies < 1 Hz (near-DC) are of interest. So, for example, a recording bandwith of 0.01 – 30 Hz has to be used. Due to the low high-pass filter, SCP training is more prone to artefacts. Using a moving time window of e.g. 1-second length, feedback is calculated several times per second. If the mean SCP amplitude over the feedback phase (or parts of it) is lower (resp. higher) than the baseline value in negativity (resp. positivity) trials, the trial is scored successful.

Study I - Specific aspects of SCP training in children with ADHD

Data acquisition

The EEG was recorded with sintered silver/silver-chloride (Ag/AgCl) electrodes and Abralyt 2000 electrolyte using a standard BrainAmp amplifier (Brain Products, Gilching, Germany). Every fourth session, activity was recorded from the following sites (10 / 20 system, FPz, Afz, FC1, Fcz, FC2, CPz, POz, Oz, Iz, TP9, TP10 and the right earlobe). EOG electrodes were placed below the left and the right eye. Fz was used as recording reference, the ground electrode was placed at FC6. Impedances were kept below 20 kΩ (and below < 10 kΩ for reference and ground electrode). The sampling rate was 500 Hz, recording bandwidth was set to 0.016 - 120 Hz. During the training, feedback was provided from Cz (with right earlobe as reference).

EEG processing and analysis

For offline data processing, the software program VisionAnalyzer (Brain Products, Gilching, Germany) was used.
The EEG was filtered offline with a 30 Hz (24 dB/oct Butterworth) low-pass filter and a 50-Hz notch filter. Ocular artifacts were corrected using independent component analysis (biased restricted Infomax, 512 steps). Data were segmented into positivity and negativity trials.
For the analysis of neuroregulation data were re-referenced to the averaged mastoid and segments containing amplitude differences of more than 200 µV at Cz were rejected from further analyses.
For sLORETA analysis, segments with amplitude differences of more than 250 µV were excluded and data were re-referenced to the common average reference.
A baseline correction with the 200 ms before the start of the baseline phase serving as baseline was conducted. Averaged event-related potentials for positivity and negativity trials were computed. Only averages with at least 10 trials were included in the grand average.
Neuroregulation data and sLORETA solutions were computed for the interval 4 - 8 sec of the feedback phase.

Study II - NF effects on ADHD-related behaviour in children with tic disorder

Fig. S-3: Flow diagram for randomised, controlled trials (non-pharmacological treatment)