A Method for Online Correction of Artifacts in EEG signals during Transcranial Electrical Stimulation

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Introduction / Objectives

Simultaneous recording of EEG during transcranial electrical stimulation (tES) is a non-invasive and painless method to evaluate the modulation of cortical oscillatory brain activity and cerebral plasticity. Latest investigations in neuroscience with transcranial direct current (tDCS), alternating current (tACS) or random noise current stimulation (tRNS) provide a wide area of research topics (*Miniussi et al. 2012, Thut et al. 2011*). The distortion of the EEG signals during tES makes it impossible to evaluate the EEG signals. Therefore methods for artifact correction are necessary to reconstruct the underlying EEG signal during tES.

The objective of this paper is to demonstrate a method for online artifact correction of EEG signals during tES. Since any alternating current or random noise current waveform can be of interest, the correction method should be independent of the current waveform.

Materials and Methods

The measured distorted EEG signals (EEG_{meas}) are modeled as a linear superposition of the current reference signals (tACS) and raw EEG signals (EEG_{raw}). A linear regression model can be used for online subtraction of scaled current artifacts from the measured EEG. Therefore, an independent reference signal from the electrical stimulator has to be recorded simultaneously with the EEG signals.

$$EEG_{raw}(k) = EEG_{meas}(k) - B(k) \cdot tACS$$

k: channel index
B: regression factor for channel k
tACS: current reference signal

Two low noise, analogue signals with different polarity were derived from the electrical stimulator (DC-**STIMULATOR** PLUS, neuroConn GmbH, Germany) as reference signals ($tACS_1$, $tACS_2$). The galvanic isolated signals (ampl. ± 40 mV) were fed into the EEG amplifier (DC-EEG amplifier NEURO **PRAX**®, neuroConn GmbH, Germany) together with EEG, EOG and ECG signals. Due to the simultaneous sampling of EEG and reference signals with one amplifier, this setup does not suffer from time jitter between EEG and artifact signals.

A short-time learning period (20 s) was used to calculate the scaling factor B of the regression model for all EEG channel (see figure 1). Due to polarity reversals in EEG recordings during tACS (see figure 2), the correction algorithm chooses one of the signals $tACS_1$, $tACS_2$ or $tACS_1 - tACS_2$ for correction. Additionally, the use of the differential signal $tACS_1$-$tACS_2$ avoids the problem of common mode distortions (e. g. 50/60 Hz).

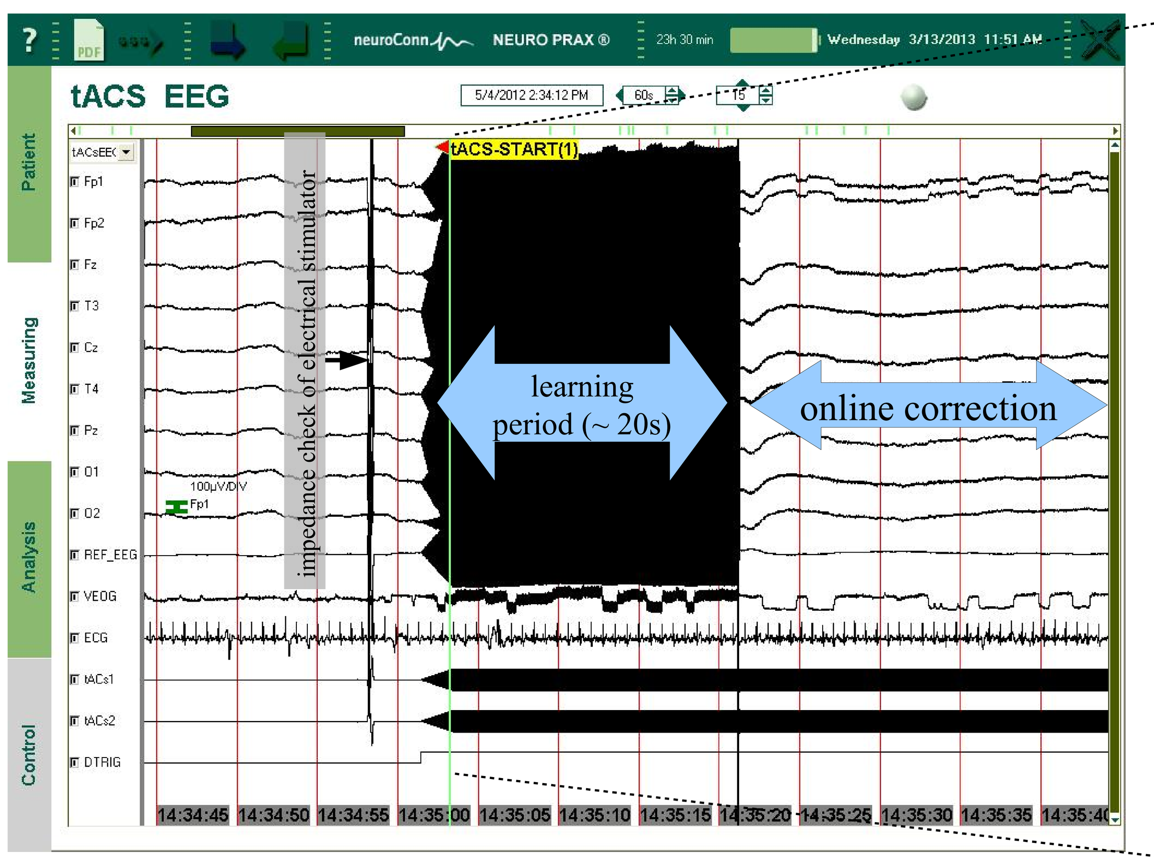

Figure 1: EEG signals before and during the learning and online correction period.

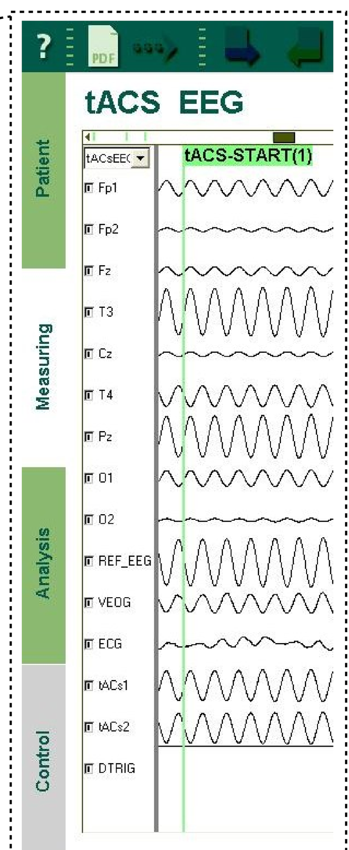

Figure 2: Phase reversals.

EEG was recorded using Ag/AgCl sintered ring electrodes (EasyCap GmbH, Hersching, Germany). For stimulation Ag/AgCl sintered flat electrodes were used (Ø: 12 mm 1,13 cm²). Artifact amplitudes ranges from 5000 - 30000 µV). Sinusoidal and random noise stimulation were tested as follows: sinus 10 Hz/1000 μA_{pp} (P3, P4), sinus 20 Hz/500 μA_{pp} (C3, C4), random noise 300 μA_{pp} (C3, C4).

Online correction was tested by visual inspection (generation of alpha-waves during eyes-closed condition, reconstructed ECG waveform, EOG artifacts).

Results

uncorrected signals ◀ ▶ online corrected signals

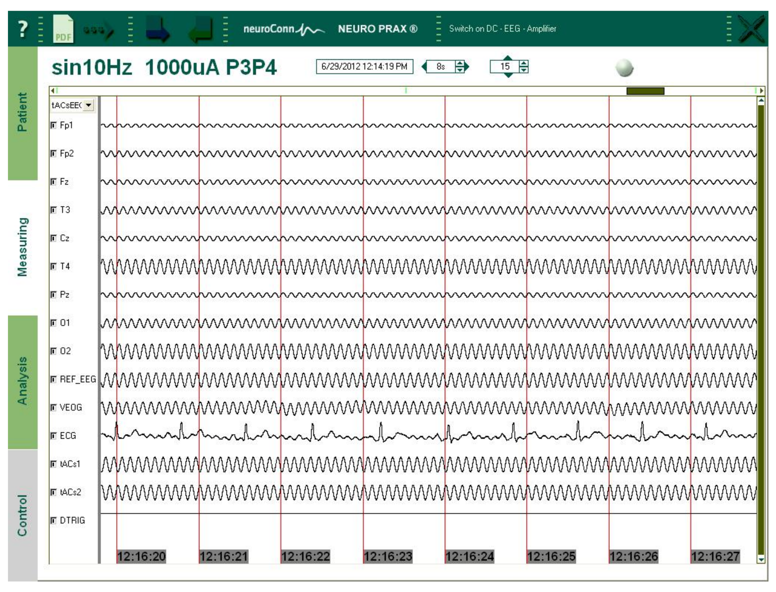

Figure 3a: Sinusoidal stimulation 10 Hz/1000 μA_{pp} at P3, P4.

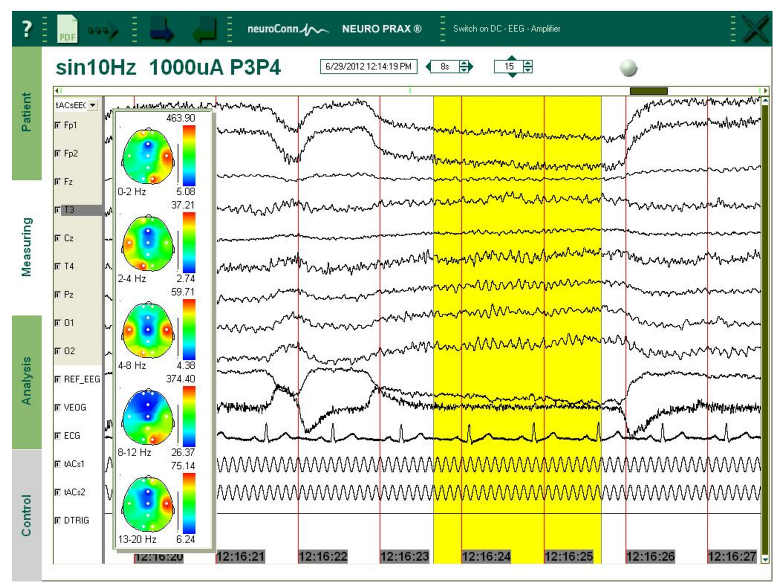

Figure 3b: Online corrected results for signals in figure 3a. Although the stimulation was 10 Hz, α-waves are still visible at the occipital cortex during eyes-closed condition.

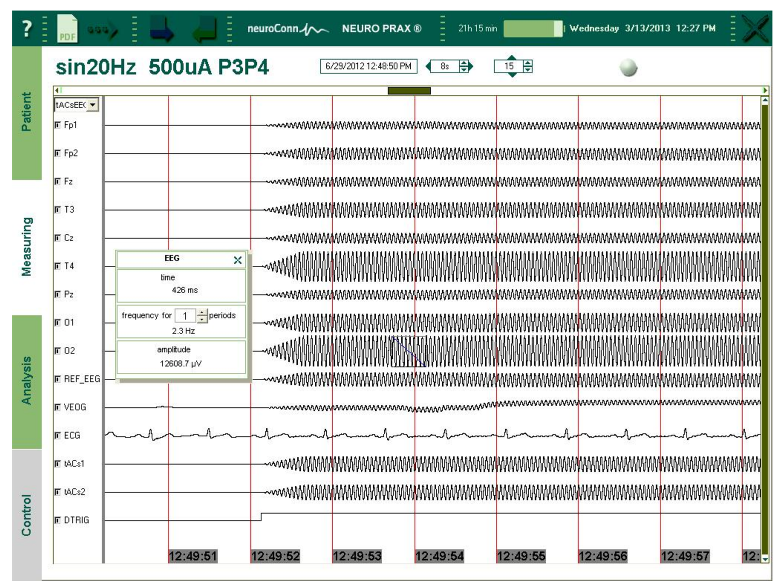

Figure 4a: Sinusoidal stimulation 20 Hz/500 μA_{pp} at C3, C4. Amplitudes increases slowly at the stimulation start.

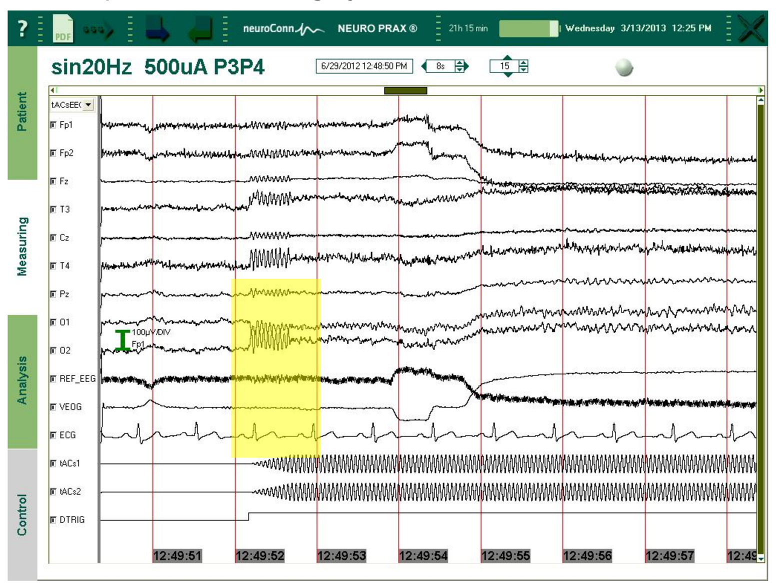

Figure 4b: Online corrected results for signals in figure 4a. Residual artifacts occur at the fading-in period.

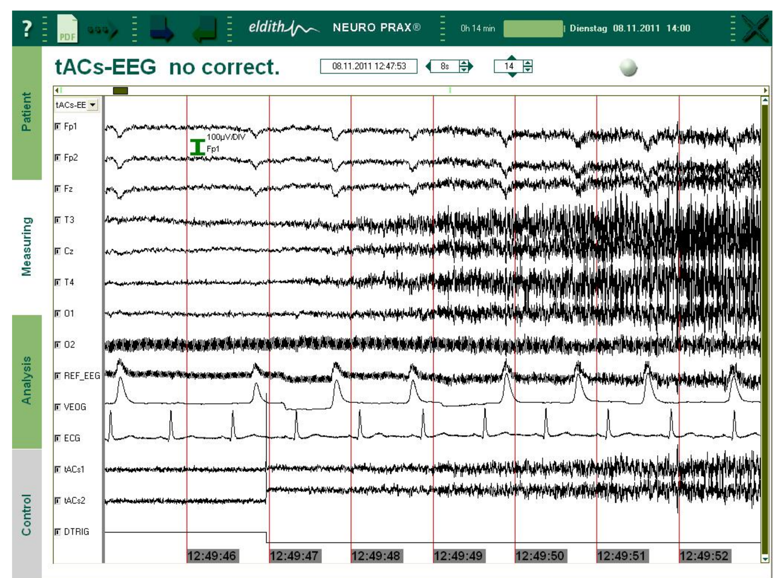

Figure 5a: Random noise stimulation at C3, C4.

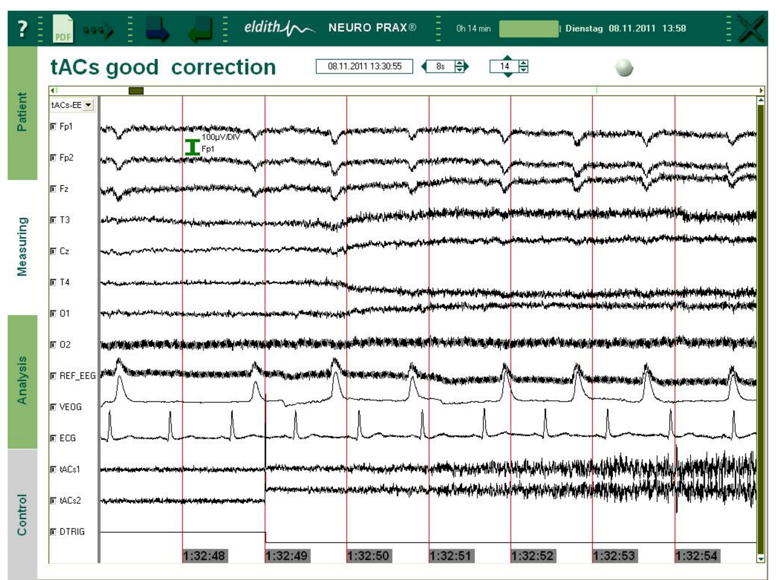

Figure 5b: Online corrected results for random noise stimulation.

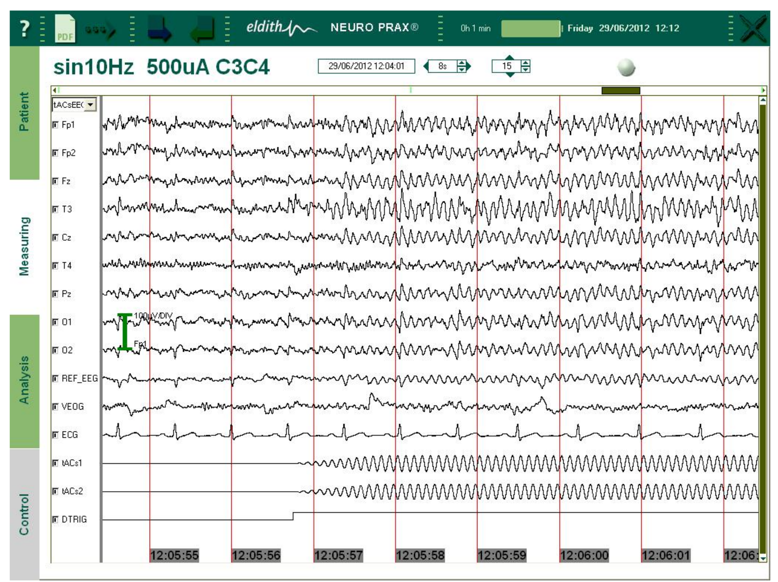

Figure 6a: Residual artifacts in the online corrected signals due to sub-sample phase shifts between reference signal and distorted EEG signal.

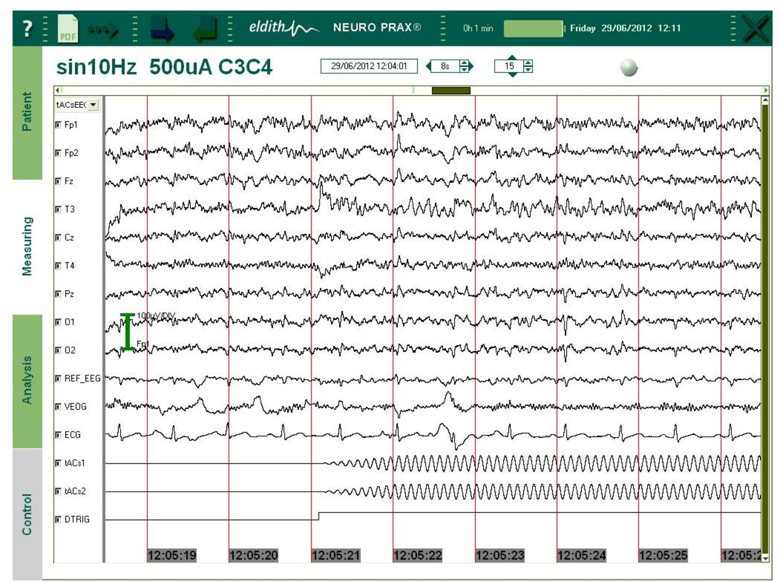

Figure 6b: No residual artifacts in the online corrected signals because of high sampling frequency (4000 Hz) and phase alignment in the sub-sample range.

Conclusions

Artifacts in EEG signals during single-channel tES can be easily corrected using reference signals from the tES device. Appropriate locations for ground and reference electrode as well as phase reversals and shifts has to be considered by the correction algorithm. This new method was implemented into neuroConn's tES-EEG products. Further research is necessary for optimization and correction of multi-channel tES-EEG recordings.

References

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Thut, G., Schyns, P.G., Gross, J. Entrainment of perceptually relevant brain oscillations by non-invasive rhythmic stimulation of the human brain. Frontiers in Psychology 2011; Vol. 2, Article 170.

Poster-ID: P 215 at the 5th International Conference on Non-invasive Brain Stimulation, Leipzig, March 19-21, 2013

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