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Selective Enhancement of Motor Imagery Features Using Transcranial Direct Current Stimulation

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Abstract. Transcranial Direct Current Stimulation (tDCS) has been shown to selectively modulate cortical responses in memory, motor and perceptual tasks. Here we show that this type of stimulation results in targeted enhancement of brain patterns elicited during motor-imagery. Offline analysis suggest this may yield higher classification performance. Experiments with healthy subjects (N = 10) and patients with spinal cord injury (N = 9) supports the idea of using tDCS as a facilitator for using brain-computer interfacing (BCI) in the frame of motor rehabilitation.

Keywords: Transcranial Direct Current Stimulation (tDCS), Motor neurorehabilitation, Motor Imagery, Spinal cord injury (SCI)

1. Introduction

Transcranial direct current stimulation (tDCS) selectively modifies neuronal excitability and reportedly enhances cortical responses to sensory stimulation and to improve performance in memory and perceptual tasks [Utz et al., 2010]. Interestingly, stimulation of motor areas results in modulation of the motor evoked potentials as well as changes in event-related desynchronization during Motor Imagery (MI) tasks [Matsumoto et al., 2010]. In turn, MI-based brain-computer interfacing (BCI) has been proposed as a supporting tool for rehabilitation [Millán et al., 2010]. Here we tested the effects of tDCS in both able-bodied subjects and patients with spinal cord injury (SCI). We found targeted enhancement of MI-related features in SCI patients resulting in improved decoding BCI performance.

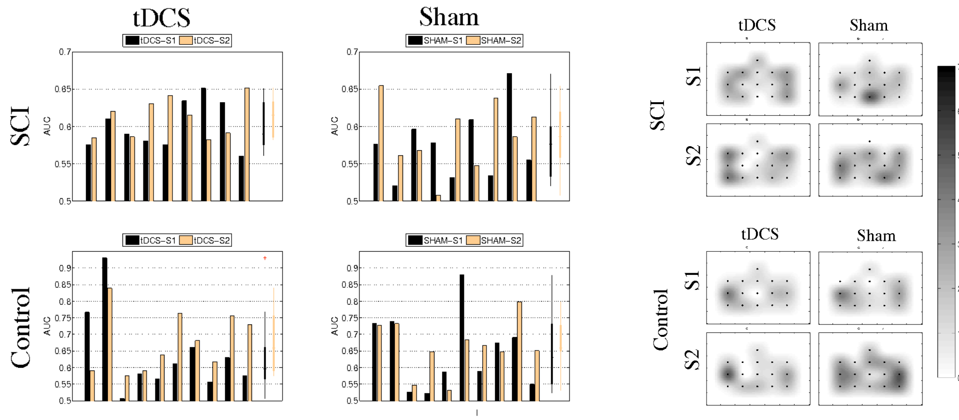
2. Material and Methods

Nine SCI subjects (2 women; age 33.7 ± 8.5; lesions site ranged from C4 to C7) took part in the experiment, as well as ten control subjects (5 women; age 33 ± 7.4). None of them had any prior experience with BCI. Each subject participated in two recording days of BCI training (left vs. right MI) separated by at least one week. On each day, two sessions of about 25 min are performed. Immediately before the first session, tDCS stimulation was applied during 15 min over the left motor area (electrode position C3). The type of stimulation – either anodal or sham – was different on each recording day. The stimulation current was set to 1 mA and the ramp time was 7 s. A pause was introduced between the two BCI sessions so that the second session started one hour after the stimulation.

EEG was recorded at 512 Hz with 16 active surface electrodes (Fz, FC3, FC1, FCz, FC2, FC4, C3, C1, Cz, C2, C4, CP3, CP1, CPz, CP2 and CP4 of the 10/20 system. Reference: right mastoid. Ground: AFz). The signal was filtered in the [0.1 100] Hz range plus 50 Hz notch filter, and spatially filtered with a Laplacian derivation. For each channel we estimate its power spectral density (PSD) in the band 4-48 Hz with 2 Hz resolution over the last second. The PSDs were extracted every 62.5 ms using the Welch method with 5 overlapped (25%) Hanning windows of 500 ms. The discriminant power (DP) of these features (16 channels x 23 frequencies) was computed using canonical variate analysis [Galán et al., 2007]. This reflects the ability of each feature for discriminating between left and right hand MI. The most discriminant features are selected for classification using a Gaussian classifier.

3. Results

Higher performance (area under the ROC curve, AUC) was obtained for control than SCI subjects, as shown in Fig. 1a (Wilcoxon, $p < 0.01$ two tailed). Although a large variability across subjects is observed, a more consistent population performance is observed in the SCI group after tDCS stimulation. Nearly significant differences were found when comparing the performance in the tDCS and sham conditions for the SCI group ($p = 0.065$).



(a) (b)

Figure 1. *(a) Decoding performance (AUC) for all conditions and groups. Each bar corresponds to one subject; rightmost boxplot shows the average performance (b) Topographical localization of discriminant features in the band 6-12 Hz (Top view, Nose up). Gray tones denotes the number of subjects that show discriminant features at each electrode. S1: First BCI session (right after tDCS). S2: Second BCI session (>1hr after stimulation).*

As shown in Fig. 1b both groups (SCI and control subjects) consistently exhibit discriminant activity under the stimulated site (i.e. left motor cortex). Notably, after anodal tDCS SCI subjects show bilateral discriminant activity already at the first BCI session, and features under the stimulated hemisphere remained discriminant during the second session. In contrast, after sham stimulation activity in motor areas was less discriminant at the first session. Similarly, in control subjects, tDCS resulted in strongly localized discriminant information on the stimulated site over the two sessions, while the sham condition presented more bilateral patterns.

4. Discussion

Our results supports the hypothesis that intracranial stimulation enhances cortical activation during motor imagery and lead to discriminant and stable features that can be exploited for BMI. In particular, SCI patients exhibited discriminant activity over the targeted areas immediately after the stimulation, a fact that may facilitate the use of BCI as a supporting technique for motor neurorehabilitation.

Moreover, the present study was performed offline; therefore it still has to be assessed how tDCS influences online control. A related study, where bilateral tDCS was applied to stroke patients during robot-assisted rehabilitation therapy [Ang et al., 2012], reported no significant effects on online performance. The bilateral stimulation they used enhances the ipsilesional hemisphere while inhibiting activation of the unaffected areas. Further work is therefore needed to characterize the type of stimulation (e.g. unilateral vs. bilateral) and the population for which this stimulation effectively influence in the features used by BCI systems.

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