An exploratory fNIRS study towards the implementation of a BCI for lower limbs movements.

Submission No:

3879

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Introduction:

The first experiments to use functional near-infrared spectroscopy (fNIRS) for the purpose of developing Brain Computer Interface was carried out by Coyle and Ward et al. (2004) and Sitaram and Hoshi et al. (2005), who studied the optical response to motor imagery in healthy subjects to demonstrate oxy-Hb concentration increases and deoxy-Hb concentration reductions in the contralateral hemisphere, as compared to the rest state. Moreover Sitaram and Caria et al. (2007) and Sitaram and Zhang et al. (2007) demonstrated that patterns of NIRS signals during motor execution and imagery can be decoded with over 80% accuracy with two different machine learning algorithms. Until now only few fNIRS studies focused on lower limb movements. Suzuki and colleagues (2008) showed that preparation for walking cued by a verbal instruction enhanced frontal activations both during the preparation and execution of walking as well as walking performance.
No studies have so far explored the possibility to adopt fNIRS for developing a BCI in lower limb rehabilitation. Assessing to what extent fNIRS is able to capture specific brain activity related to lower limb movements, and in particular to motor preparation, is the first step towards the development of a BCI system for gait rehabilitation. Here we investigated whether fNIRS can detect brain signal of lower limbs movement preparation (fNIRS).

Methods:

Twelve right-handed subjects participated to the study. A block design paradigm was adopted consisting of sixteen 'left hip' (1-11s) and sixteen 'right hip' blocks of movement preparation periods (1-11s) interspersed with thirty-two rest blocks (15-25s) and presented in a pseudo-randomized order. Preparation periods were followed by movement trials (3s) of the left or right hips respectively (Fig. 1). To avoid habituation and predictability of movement's execution onset, the preparation period varied pseudo-randomly between 1 and 11 s. Only trials with a preparation phase lasting between 9 and 11 s were considered for the analysis (60% of all trials). Participants used a mechanical device (pedals) to perform active lower limb movements simulating walking while sitting on an armchair. Participants were visually cued for left and right hip preparation and execution. The study has been conducted using 48-channels

ETG-4000, Hitachi Medical Systems GmbH, sample rate 10 Hz. The optodes were applied sagittally covering the frontal regions, SMA, and primary and secondary motor and somatosensory areas. Based on the International 10-20 system for EEG electrode placement, Cz was used as a reference point for positioning the optodes. NIRS channel positions in real coordinates obtained from a 3D digitizer (Polhemus 3D) were localized onto the cerebral cortex of an anatomical MR image. T1 weighted MRI images were acquired on a 3 Tesla Siemens scanner. The anatomical MRI images were normalized to Montreal Neurological Institute standard stereotaxic space. The normalization was performed using SPM5. NIRS functional data were pre-processed and statistically analyzed using NIRS-SPM package.

Results:

Our results showed brain preparatory activity related to lower limbs movements in the parietal cortex. Specifically an increase of oxygenated hemoglobin (oxyHb) in the parietal region was observed during the preparation period. A lateralization effect was also observed for left and right hip movements (Fig. 2).

Conclusions:

The present pilot study indicates that functional NIRS can detect motor preparatory activity related to gait and therefore support the idea of developing a specific fNIRS based BCI for rehabilitation of patients with lower limbs impairment. Our future work would exploit whether the observed activity can be detected by a multivariate pattern classifier. Online classification of lower limbs motor preparatory activity would be eventually used for controlling robotic rehabilitation devices.

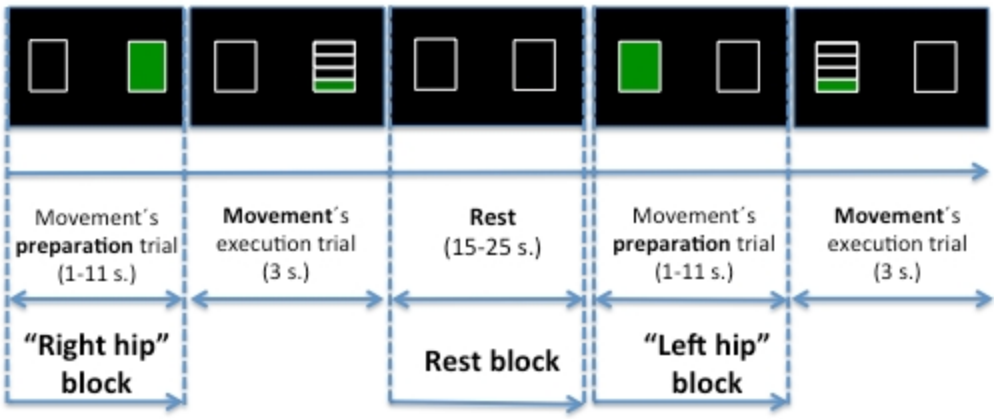

Figure 1. Schematic illustration of the experimental protocol.

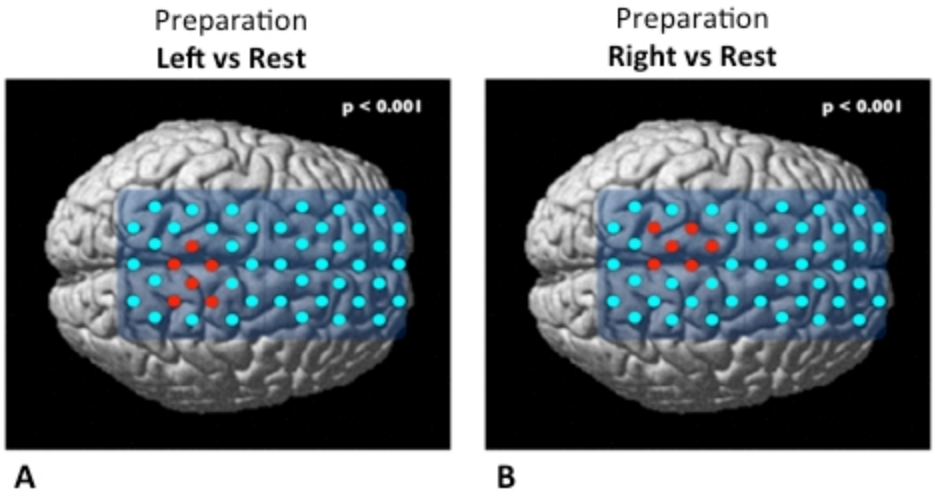

Figure 2. Representative cortical mapping of prepared left (A) and right (B) hip movements based on changes of oxyHb levels. The color indicates the optodes significantly activated (red circles) and non-activated (blue circles) during the contrasts A and B, respectively ($p < 0{,}001$).

Motor Behavior

Brain-Machine Interface

Abstract Information