

# Localization of Event-related (de)Synchronization of Cerebral Cortex during Online Control of Brain-Computer Interface Using Minimum-norm Estimates in the Frequency Domain

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## Abstract

*It is of wide interest to study the brain activity that correlates to the control of Brain-Computer Interface (BCI). In the present study, we propose an approach to image the cortical rhythmic modulation by motor imagery using minimum-norm estimates in the frequency domain. Contralateral decrease (event-related desynchronization, ERD) and ipsilateral increase (event-related synchronization, ERS) are localized in the sensorimotor cortex during online control of BCI.*

## 1. Introduction

A noninvasive Brain-Computer Interface (BCI) that uses scalp-recorded electroencephalogram (EEG) can provide communication and control to people who are totally paralyzed [1]. People can learn to control mu (8-12 Hz) or beta (18-26 Hz) rhythm amplitude using mental strategy of motor imagery to control physical or virtual devices. The EEG power in the mu and beta bands in the central region attenuates during planning and execution of hand and/or finger movement, which is quantitatively defined as ERD. However, our understanding to the cortical sources of ERD is poor due to the limited spatial resolution of EEG which attributed to the volume conduction of the brain.

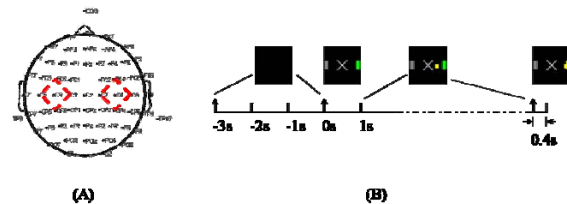
Using recently developed EEG/MEG source imaging method, the origin of rhythmic activity can be detected with improved spatial and temporal resolution. Sources of mu rhythm (ERS) during offline motor imagery were previously investigated using dipole localization method [2, 3] or cortical current density estimates [2, 4]. Jensen and Vanni [5] have developed an efficient approach to estimate the minimum current in the frequency domain. However, as a minimum  $L_1$ -norm approach is employed, an over-

focused solution with a few distinct source points is favored.

In the present study, we propose an approach to image the cortical rhythmic modulation using a weighted minimum  $L_2$ -norm estimate in the frequency domain. Results from on-line BCI experiments revealed spectral changes in the sensorimotor cortex during cursor control.

## 2. Materials and methods

### 2.1. Experimental setup and data acquisition



**Figure 1. Electrode positions and experimental paradigm. A trial ends as the cursor reaches a target. The maximum target time is 6s.**

Healthy subjects (two men, one right-handed and one left-handed, ages 19 - 21 years) participated in the study with written consent according to a protocol approved by the IRB of the University of Minnesota. EEG activity was recorded from 64 standard electrode locations distributed over the entire scalp (Fig. 1A). The signals were acquired with a BrainAmp amplifier (BrainProducts, Germany) at sampling frequency of 1000 Hz. Using the general-purpose system BCI2000 [6], the horizontal cursor movement was controlled by a linear equation of a weighted combination of the amplitude in mu band from EEG channels over the left and right hemisphere. Individual MRI images were acquired on a 3T MRI system (Siemens Trio, Siemens, Erlangen, Germany).

The subject was instructed to move the cursor to hit the left/right target within 6 s by imagining left/right hand movement respectively (Fig. 1B). The accuracy is calculated as the percentage of hits in a run. The experiment consisted of eight 5-min runs separated by 2-min breaks, and each run had 30-40 trials.

## 2.2. Minimum-norm estimate in the frequency domain

Assuming a cortically constrained distributed source model, the relationship between source amplitudes and scalp potentials can be expressed by the following linear model:

$$\Phi(t) = AS(t) + N(t), \quad (1)$$

where  $\Phi$  is a matrix of the measured EEG.  $S$  is the unknown matrix of amplitudes of the dipoles along the time.  $A$  is the transfer matrix. Data are corrupted by an additive noise  $N$ . Although the measured data  $\Phi$  do not give the source strengths  $S$  unambiguously as the number of discretized sources is larger than the number of sensors, a minimum-norm estimate (MNE) in the sense of  $L_2$ -norm can be obtained by applying a linear inverse operator to the measured signals.

Using an N-point fast Fourier transform, both  $S(t)$  and  $\Phi(t)$  are transformed to  $S'(f)$  and  $\Phi'(f)$  respectively in the frequency domain [5]. Then the real  $\Phi'_{\text{Re}}(f)$  and imaginary part  $\Phi'_{\text{Im}}(f)$  of the Fourier

transformed signal were applied to the MNE method resulting in the current distributions  $S'_{\text{Re}}(f)$  and  $S'_{\text{Im}}(f)$ . The source strength estimates are then estimated by summing up the real and imaginary parts and averaged over multiple-trials.

The inverse solution was calculated using BESA (MEGIS Software GmbH, Graefelfing). A realistic geometry head model was applied when calculating the transfer matrix. Depth-weighting and noise regularization procedure were applied.

Individual frequency band and time window of imagination for the minimum-norm estimates was selected with the aid of wavelet time-frequency representation (TFR) [2]. The negative (ERD) or positive (ERS) spectral change is calculated as the percentage change of amplitude in mu band during cursor control in relative to the amplitude during baseline. Statistical thresholding is applied to the cortical ERD and ERS images using an unpaired  $t$  test with the amplitude during imagination compared with baseline ( $p < 0.05$ , Bonferroni corrected).

## 3. Results and discussion

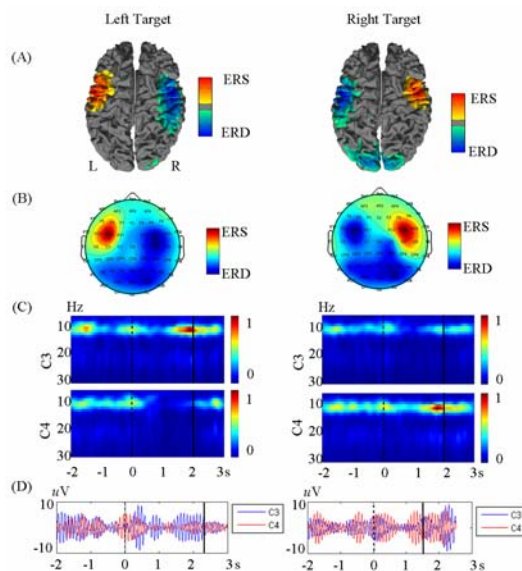
Both subjects AG and LV achieved reliable 1D control over the cursor movement with average accuracy of 88.24% and 92.57% respectively. The representative ERD/ERS pattern is shown in Fig. 2.

The present study for the first time revealed distinct contralateral ERD localized in the sensorimotor cortex during online control of BCI. Functional MRI studies of offline motor imagery co-localized the activation in the contralateral primary motor cortex [7].

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## 5. References

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**Figure 2. Mu ERD and ERS during cursor movement are shown on the cortex (A) and scalp (B) for subject AG. Average TFR (C) and a typical single trial data (D) showed imagery-related modulation. TFRs were realigned at time = 0 s and the target time were normalized to be 2 s.**