Decoding Movements of the Upper Limb from EEG

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Introduction

A neuroprosthesis can restore movement functions of persons with spinal cord injury. It benefits from a brain-computer interface (BCI) with a high number of control classes. However, classical sensorimotor rhythm-based BCIs can often only provide less than 3 classes, and new types of BCIs need to be developed. We investigated whether low-frequency time-domain signals (i.e., movement-related cortical potentials [1]) can be used to classify hand/arm movements of the same limb. A BCI based on attempted movements may be used to control a neuroprosthesis more naturally and provide a higher number of control classes.

Paradigm

- 15 healthy subjects
- 6 classes: hand open/close, supination/pronation, and elbow extension/flexion (60 trials per class)
- 61 EEG channels + joint angles (for movement onset detection)

Figure 1: Left: Subjects executed movements using an Armeo Spring rehabilitation device (Hocoma, Switzerland). Right: These movements were classified.

Figure 2: Sequence of a trial.

Methods

- Artefact removal
- 0.3 - 3 Hz 4-th order zero-phase Butterworth filter
- Different EEG time windows were used as classifier input (0 to 1s)
- Shrinkage regularized linear discriminant analysis (sLDA) classifier
- 1-vs-1 classification strategy
- 10x10-fold cross-validation
- Calculation of sLDA patterns [2] and transformation to source space with sLORETA, see Figure 3

Figure 3: Patterns were calculated from each 1-vs-1 classifier; subsequently scaled and transformed into the source space; then we calculated the absolute value, and averaged over patterns and from -0.4s to 0.4s relative to movement onset.

Results

- Average classification accuracy: maximum of 55% (9% standard deviation) at 0.25 s for the 1s time window, see Figure 4
- Significance level of the average classification accuracy: 18%
- \( \alpha = 0.05 \), Bonferroni corrected wrt. the length of the presented time window
- All subjects reached significant classification accuracies
- The confusion matrix in Figure 4 indicates that movements involving the same joints (e.g., hand open vs hand close) are less discriminable than movements involving different joints (e.g., hand open vs arm extension)

Figure 4: Left: Grand average classification accuracies (time locked to movement onset) for each time window. The solid line is the chance level; the dashed line is the significance level. Right: Confusion matrix with relative values.

Figure 5: Classifier pattern averaged over all subjects. Only significant voxels are colored (\( \alpha = 0.05 \), nonparametric permutation testing).

Discussion

We have shown that low-frequency time domain signals can be used to discriminate between different movements of the same upper limb. Movement accuracies peak after the movement onset but reach significantly high classification accuracies before the movement onset. This shows that upcoming movements can be classified from the movement planning phase. This is crucial for a BCI applicable for end users with SCI who cannot execute all movements anymore. Furthermore, movements involving different joints are better discriminable than movements involving the same joints.

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References