Classification of basic imaginary fist movements from EEG registers applying characterization based on spatial filtering in a BCI scenario

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Objective: The purpose of this study is to predict basic fist movements from single-trial EEG registers applying methods based on spatial filtering and supervised classification.

Methods: The EEG registers of 109 subjects, corresponding to the Motor Movement/Imagery Dataset (available at http://www.physionet.org/), were analyzed in a simulated brain-computer interface (BCI) scenario. Every subject completed 87 trials of 4 seconds over a 6-minutes 64-channels EEG record, where each trial corresponded to either an imagined sustained left/right fist movement (opening and closing) or inactivity, resulting in three conditions to predict: inactivity (T0) vs. left fist movement (T1) vs. right fist movement (T2). Initially, two epochs were chosen to segment the time windows of analysis: from -2 to 4 seconds and from 0 to 4 seconds, where 0 represents the onset of the imaginary movement. Afterwards, the EEG time series were preprocessed with FIR filters to select four different bandwidth scenarios: *mu* waves (7.5 – 12.5 Hz), *beta* waves (12.5 – 30 Hz), *mu* & *beta* waves (7.5 – 30 Hz) and a broader bandwidth of 0.5 – 30 Hz.

Subsequently, spatial filtering was performed in two separate ways: common spatial patterns (CSP) and independent component analysis (ICA). Since the former was developed for classification between two groups only, the experimental design of this work included the computation of three sets of CSP in a one-versus-rest approach, i.e., T0 vs. {T1, T2}, T1 vs. {T0, T2} and T2 vs. {T0, T1}. The CSP were computed using all 64 channels and the 8 most discriminant of the resulting surrogate channels were selected for the feature extraction, whereas the spatial filtering using ICA was restricted to 8 channels located over the motor cortex. The extraction of features was performed calculating the logarithm of the variance in the 8 channels and the prediction was carried out employing methods for supervised classification, based on linear discriminant analysis (LDA) and support vector machines (SVM). The parameters for the spatial filters and classifiers were computed exclusively on the training set and used for the independent testing set, so that classification during testing was in real-time. The procedure was repeated five times for every subject and the mean classification performance was calculated for each combination of preprocessing, spatial filtering and classification methods.

Results: The grand mean classification performance applying CSP and SVM was much better than in any other combination, reaching a classification accuracy close to 99.9%. A more detailed presentation of the results is shown in Tables 1 and 2 (largest values of classification accuracy in bold face type). Although prediction in epochs from 0 to 4 seconds increases slightly in comparison to prediction from -2 to 4 seconds, the most noticeable differences were induced by the spatial filters and by the classification methods. In the classification using CSP no remarkable differences are observed among the selected bandwidths, while with ICA filtering the prediction resulted in lower accuracies in the broad bandwidth (7.5 – 30 Hz). In all cases, the classification performance was above the chance level of 33.3%.

Conclusion: The results suggest the feasibility to predict imaginary fist movements from a single-trial EEG record, with accuracies and computational costs enough to be realistic in real-time BCI applications. The analysis carried out in this work takes advantage of the method of CSP extending it for the classification of three conditions, optimizing the features for classification and allowing the prediction to be more successful than using the ICA features. By the other side, the nonlinear structure of the features seems to be better captured by the SVM method, which has the ability to search for the best parameters of classification.

Significance and how this work addresses a BRAIN grand challenge: The real-time prediction of hand movements from information contained in single trial EEG records is an important part of BCI applications. Therefore, a classification accuracy close to 99.9% is a promising result for further studies in BCI research and the methods employed in this study are suitable for neural engineering applications.

Table 1. Grand mean values of classification accuracy for spatial filtering based on CSP

	Epoch of 0 to 4 seconds				Epoch of -2 to 4 seconds			
Classifier	***Mu***	***Beta***	**Broad**	***Mu & Beta***	***Mu***	***Beta***	**Broad**	***Mu &Beta***
LDA	56.40	57.62	42.87	60.17	45.83	45.61	42.11	47.74
SVM	**98.78**	**99.77**	**98.85**	**99.88**	**99.33**	**99.06**	**98.85**	**98.58**

Table 2. Grand mean values of classification accuracy for spatial filtering based on ICA

	Epoch of 0 to 4 seconds				Epoch of -2 to 4 seconds			
Classifier	***Mu***	***Beta***	**Broad**	***Mu & Beta***	***Mu***	***Beta***	**Broad**	***Mu & Beta***
LDA	50.32	55.07	42.81	55.35	44.94	47.51	43.01	47.86
SVM	84.62	84.81	77.18	87.45	73.44	71.53	67.82	72.93