Is Classifying Uni- and Bimanual Motor Imagery Feasible as a Three-Class BCI Problem?

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Introduction: The past decade has seen growing interest in brain-computer interface (BCI) applications for the motor rehabilitation of stroke patients [1]. For the most part, studies have targeted motor function restoration of the paretic limb, reflecting traditional approaches. There is mounting evidence, however, that improvements in unimanual movements do not translate to improved bimanual coordination [2], limiting recovery as the latter tends to be a better predictor of whether motor improvements are maintained outside the clinic [3]. This pilot study investigates the feasibility of using a BCI to discriminate between unimanual and bimanual motor imagery (MI) in able-bodied people.

Materials and Methods: Sixty-four channel EEG was recorded with g.tec g.USBamp amplifiers from 14 able-bodied participants (aged 25±4, 6 females). Participants sat opposite a computer screen and performed left-hand, right-hand, and bimanual (both hands) MI to a pace set by a cue-based visual paradigm. MI was sustained for 4 seconds and repeated 105 times per class. To implement three-class classification, we used the binary Tikhonov regularized common spatial pattern (CSP) algorithm to build three spatial filters, following a one-versus-rest (OVR) approach. Filters were trained on the middle two seconds of each trial. The first and last four rows of the CSP projection matrices were used to spatially filter training data. Their variances formed a feature matrix to train a classifier, following a one-versus-one coding strategy. To find the most discriminative frequency band for each participant, the process was repeated for 26 bands from 1-30 Hz, at 4 Hz wide, with a 5^{th} order Butterworth filter. We investigated three classifiers: a gaussian support vector machine (SVM), a linear discriminant analysis (LDA), and *k*-nearest neighbour (*k*-NN) classifier. Each classifier was evaluated with respect to its prediction accuracy, estimated by 10x10-fold cross-validation (CV). *Results:* The maximum average CV accuracies returned by the SVM, LDA, and *k*-NN classifiers were 71.6±2.5%, 73.2±2.6%, and 71.3±2.5%, respectively. A paired-sample *t*-test showed that LDA classification was significantly better than SVM and *k*-NN ($p<0.05$). Left-hand discrimination tended to produce the highest true positive rate at 75.0%, followed by the right (73.3%), and bimanual class (70.7%). The left- and right-hand conditions were significantly easier to predict than the bimanual class with the LDA and *k*-NN ($p<0.05$), but not with the SVM ($p>0.05$). Nine participants achieved an average accuracy exceeding 70%, and the top performer achieved a maximum classification accuracy of 81%.

Table 1: Confusion matrices: Left: cross-validation scores of SVM; Middle: LDA; Right: KNN. Bold indicates true positives (%).

	Left	Right	Bimanual
Left	**74.1**	11.1	14.8
Right	10.4	**70.8**	18.8
Bimanual	15.1	15.2	**69.7**

	Left	Right	Bimanual
Left	**75.0**	10.1	14.8
Right	10.4	**73.3**	16.5
Bimanual	17.0	12.3	**70.7**

	Left	Right	Bimanual
Left	**75.8**	9.4	14.8
Right	10.4	**74.6**	14.1
Bimanual	21.1	15.3	**63.6**

Discussion: Results indicate the feasibility of using a BCI to classify bimanual MI. The CV accuracies achieved are inline with other OVR-CSP approaches to multi-class classification of MI reported in the literature [4]. Of the three classifiers explored, LDA performed significantly better than the SVM and *k*-NN classifiers, suggesting LDA should be the focus of future studies. Most participants achieved a classification accuracy of above 70%, implying that, given a screening process, the system could be valuable to stroke patients involved in bimanual motor practice.

Significance: We show a BCI can classify unimanual and bimanual motor imagery in able-bodied participants with practical accuracy, demonstrating that a BCI-based training strategy could be designed to encourage neurologically impaired individuals to participant in bimanual motor practice.

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