Designing hybrid brain-machine interfaces to detect movement attempts in stroke patients

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***Abstract*— Hybrid brain-machine interfaces (BMIs) combining brain and muscle activity are a promising therapeutic alternative for rehabilitation of stroke patients with severe paralysis. In this study, we compare different approaches utilizing electroencephalographic (EEG) and electromyographic (EMG) activity to detect movement attempts of stroke patients with complete hand paralysis. Data of 20 patients with a chronic stroke involving the motor cortex were analyzed, and the performance of EEG-based, EMG-based or hybrid classifiers were simulated offline. We show that the combination of EEG and EMG improves the accuracy of movement detection, but that muscles unrelated to the task can also provide high accuracies, reflecting compensatory mechanisms. This result underscores the importance of appropriate designs of hybrid BMIs to maximize their rehabilitative potential.**

I. INTRODUCTION

Brain-machine interfaces (BMIs) are a promising technology for motor rehabilitation of stroke patients with severe paralysis [1]. These BMIs establish a contingent link between the intentions of movement (usually decoded with electroencephalographic–EEG–activity) and a peripheral feedback assisting such movement, facilitating plasticity and subsequent motor recovery. Given the limited information that the EEG provides to accurately detect movement intention in stroke patients [2], hybrid BMIs combining brain (EEG) and muscle (electromyography–EMG) activity have been recently proposed [3], [4]. Therefore, the sources of activity considered for such BMIs can be of paramount importance to optimize their rehabilitative potential.

Compensatory mechanisms at the brain and muscular levels are common in stroke patients. This has been reflected, for instance, as exaggerated activation of the contralesional (i.e., ipsilateral) hemisphere during movement attempts [5], or as pathologic muscle synergies that cause that muscles that should stay relaxed during a certain task are recruited and activated [6]. If these patterns of activity are considered for the hybrid BMI, their pathologic behavior could be reinforced, leading to maladaptive plasticity.

In this study, we analyze the EEG and EMG activity of chronic stroke patients with complete hand paralysis when they try to move the paretic hand. We compare different configurations for a classifier to decode the movement attempts based on EEG, EMG, or the combination of both.

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II. METHODS

A. Patients and experimental protocol

Data of 20 chronic stroke patients were analyzed (7 female, age 48.5±14.5 years, time since stroke 54.9±61.0 months). All patients had a stroke involving their motor cortex and presented complete hand paralysis. The patients participated in one session in which their EEG and EMG activity were monitored while they attempted to open and close their paralyzed hand. The study was approved by the Ethics Committee of the Faculty of Medicine of the University of Tübingen. Each patient performed between 4 and 6 blocks of 17 trials each. In each trial, audiovisual cues instructed the patients to relax (4-5 s), to try to open and close their paretic hand (4 seconds) and to rest (8-9 seconds).

EEG was recorded from 16 electrodes (Fp1, Fp2, F3, Fz, F4, T7, C3, Cz, C4, T8, CP3, CP4, P3, Pz, P4 and Oz) with an Acticap system (BrainProducts GmbH, Germany). Ocular activity was monitored with vertical and horizontal electrooculographic (EOG) derivations. EMG activity was recorded with bipolar Ag/AgCl electrodes (Myotronics-Noromed, USA) from the *extensor carpi ulnaris*, *extensor digitorum*, *biceps* and *triceps* muscles. All the signals were synchronously recorded at 500 Hz.

B. Detection of movement attempts

The detection of the attempts of movement of the paralyzed hand relied on features extracted from the brain and/or muscular activity. A linear-discriminant analysis (LDA) classifier was used with different configurations of features. A block-based cross-validation procedure was followed, simulating an online scenario (see [2], [4], [7]). An artifact removal procedure was applied to the training dataset, removing EOG contaminations with a linear regression and rejecting trials with motion and muscular artifact with a threshold-based statistical method [7].

The features were extracted from one-second windows. EEG features consisted of power values in the alpha ([7-13] Hz) and beta ([14-30] Hz) ranges, computed with an order-20 auto-regressive model after applying a Laplacian re-referencing (2 features per EEG channel). EMG features were computed as the waveform length of the high-pass filtered signal at 20 Hz (1 feature per EMG channel). For the trials used in the training dataset, 5 one-second windows were extracted to model the *rest* class (i.e., interval [-2, 0] s, with a sliding step of 0.25 s), and 5 windows for the *movement attempt* class (i.e., interval [1, 3] s, with a sliding step of 0.25 s). For the trials in the test dataset, the features were extracted with a sliding window evaluated every 20 ms (from -3 to 4 s), and the classifier generated an output for each of these windows. The performance values analyzed here correspond to the average accuracy of the rest and movement attempt intervals.

C. Evaluation of the activity to detect the movement attempts

In a previous study, we proposed a hybrid BMI combining ipsilesional EEG activity and EMG activity from the muscles directly related to the hand opening-closing task [4]. In this study, we investigate how the performance of this decoding strategy changes when we modify the EEG or EMG activity that we use for feature extraction. Firstly, we compare the decoding based on EEG activity from the ipsilesional hemisphere only (3 electrodes: Cx, CPx, Px) or from the whole motor cortex (8 electrodes: C3, Cz, C4, CP3, CP4, P3, Pz, P4). Secondly, we evaluate the influence of the EMG electrodes considered to extract the features: (1) muscles involved in the hand opening-closing task (*extensor carpi ulnaris* and *extensor digitorum*), (2) muscles not involved in the task (*biceps* and *triceps*), and (3) all the muscles. Statistical comparisons between the different configurations were performed using the Wilcoxon signed-rank test, with Bonferroni correction for multiple comparisons (10 in total).

III. Results

Figure 1 displays the performance for each configuration of the decoder of movement attempts, averaged for all the patients. Firstly, we compared the performance of the hybrid decoder combining ipsilesional electrodes and the muscles involved in the task and its two separate components. The hybrid BMI provided significantly higher performance than the EEG decoder ($p = 0.01$). However, the performance of the EMG decoder was not statistically different to the EEG decoder or the hybrid decoder ($p > 0.05$ in both cases).

Secondly, we compared all the variations for each type of decoder (i.e., EEG-based, EMG-based, or hybrid) separately. Regarding the decoding based on EEG, ipsilesional electrodes led to significantly lower performances than when all the motor cortex electrodes were considered ($p = 0.003$). For the decoding relying on EMG, there were no differences between using using the involved muscles, the non-involved muscles, or all of them ($p > 0.05$ for all the comparisons). When EEG and EMG activity were combined in three different approaches for a hybrid BMI (i.e., ipsilesional electrodes + involved muscles; ipsilesional electrodes + all muscles; all motor cortex electrodes + all muscles), there were no significant differences in their performance ($p > 0.05$ for all the comparisons).

IV. Discussion and Conclusion

Accurate designs for hybrid BMIs might determine their rehabilitative potential. However, high decoding accuracies might not relate to the rehabilitative success of the system. We hypothesize that systems that focus on detecting the activation of the highly affected areas (e.g., ipsilesional hemisphere and affected muscles) and reinforce them might have a better outcome in the long term, despite showing worse decoding performance at the beginning.

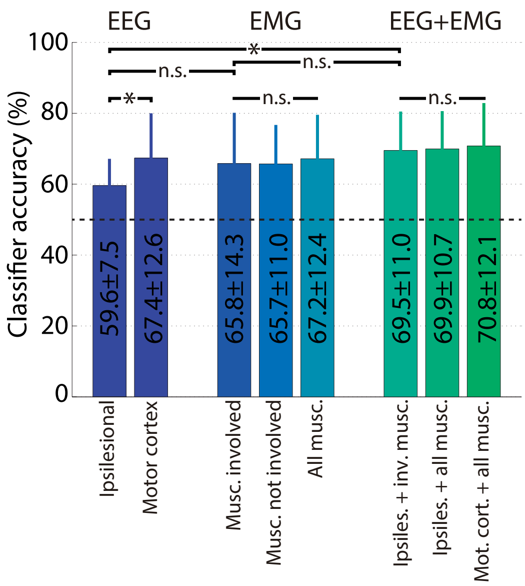

Fig. 1. Decoding accuracy of the proposed schemes. Results of the statistical comparisons are marked on top. The lines above the EMG and EEG+EMG groups summarize the non-significant result of all the possible paired comparisons within the group.

Although EEG activity from the whole motor cortex led to higher decoding accuracy, successful BMI interventions proposed the use of ipsilesional activity only [1], and it has been suggested that contralesional EEG activity might be more prone to contamination by artifacts [7]. Interestingly, muscles unrelated with the task provided equivalent performances to muscles involved in the attempted movement. This reflects compensatory mechanisms of the stroke patients, and underlines the relevance of carefully selecting the muscles that should be trained in each exercise. The undesired co-activation of those muscles might be classified and used to train the patients to reduce it.

Future research should focus on applying these approaches in real rehabilitation interventions in order to assess the actual potential of this technology for motor rehabilitation.

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