Identification of Neuromotor Patterns Associated with Hand Rehabilitation Movements from EMG and EEG signals

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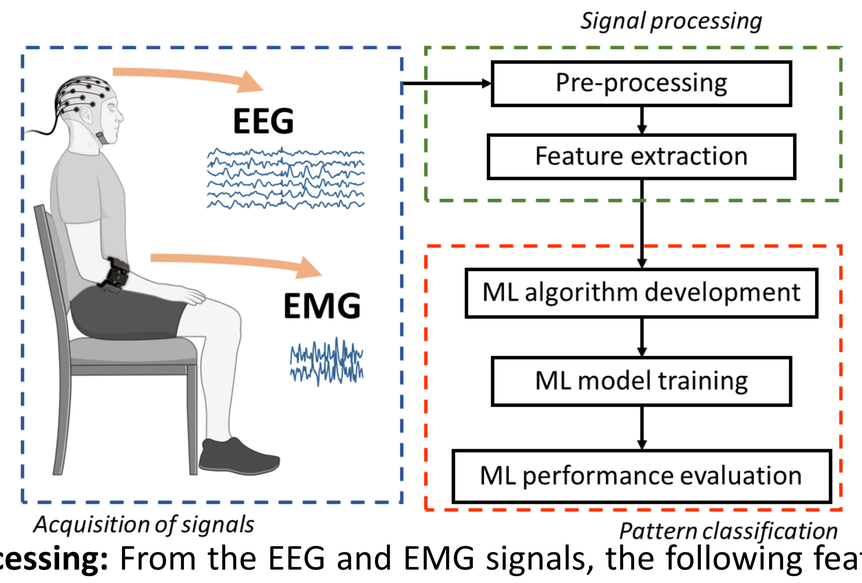
Introduction

Stroke is the leading cause of disability worldwide, with approximately 85% of patients experiencing impairment in the upper limb (from shoulder to finger functionality) [1][2]. Because of the high complexity of its movements, and the importance for the activities of daily life, the rehabilitation of the hand, remains a challenge [3]. We propose a method to identify individual hand movements from electroencephalographic (EEG) and electromyographic (EMG) signals, offering a possibility to monitor brain networks associated to motor control that could be used for neuroprosthetics purposes and post-stroke rehabilitation.

Methods

In this work, we developed a method to identify the intention and execution of hand movements from EEG-EMG signals.

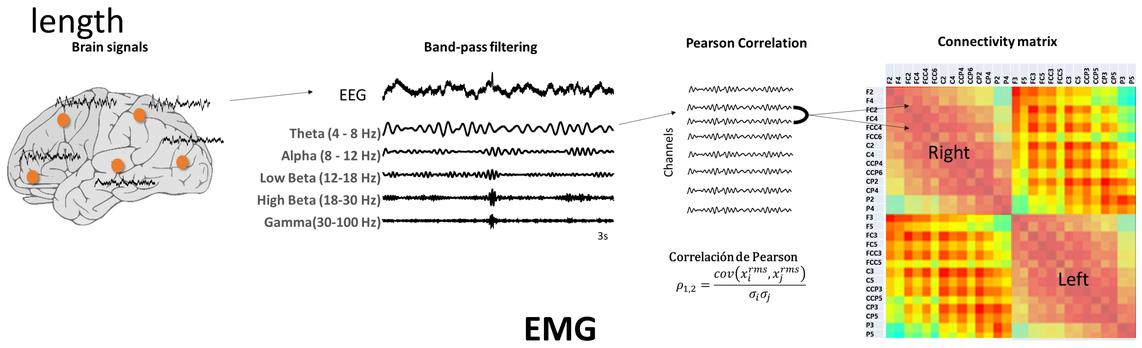
Acquisition of signals: Simultaneous acquisition of EEG (28 channels, 256 Hz) was performed to record cortical activity, and EMG (8 channels, 200 Hz) to record muscle activation of the right forearm during the execution of hand gestures. Synchronization between both systems was achieved using Coordinated Universal Time (UTC).



Signal processing: From the EEG and EMG signals, the following features were calculated:

EEG

- **Power spectral density (PSD)**: theta, alpha, beta_low, beta_high, gamma
- **Functional connectivity (FC)**: node degree, clustering coefficient, path length



EMG

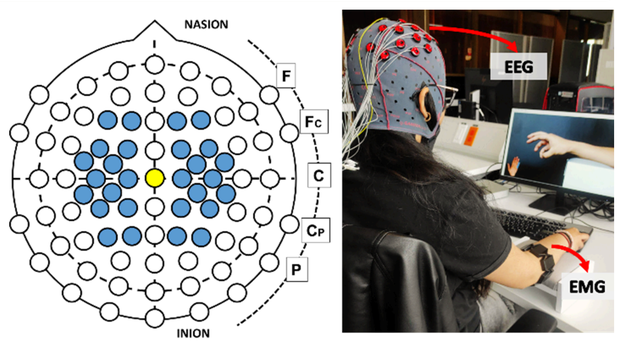
- **Temporal features:** variance, total length, mean absolute value, zero crossing, and Willison amplitude.

Pattern Classification: windows of 3s before and 3s after, were used to identify the intention and execution of hand movements, respectively. Three feature matrices were defined (EEG PSD, EEG FC, and EMG) and used to train and test different machine learning algorithms (k-fold = 5, 70% training set and 30% testing test). The methods used were Ensemble Bagged Trees, ensemble KNN, SVM, wide and medium neural network.

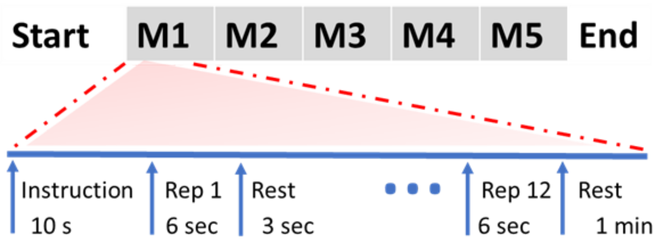
Experimental Task

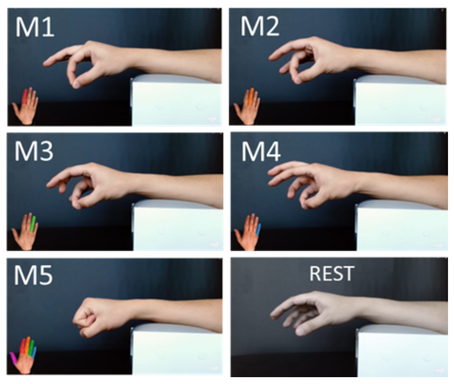
Each volunteer performed 5 distinct hand movements: 4 bi-digital pinches between the thumb and each of the other fingers (index, middle, ring, and little finger), and hand closure.

The experimental task consisted of an instruction, followed by 12 repetitions of each gesture for a total of 1320 observations (22x5x12).



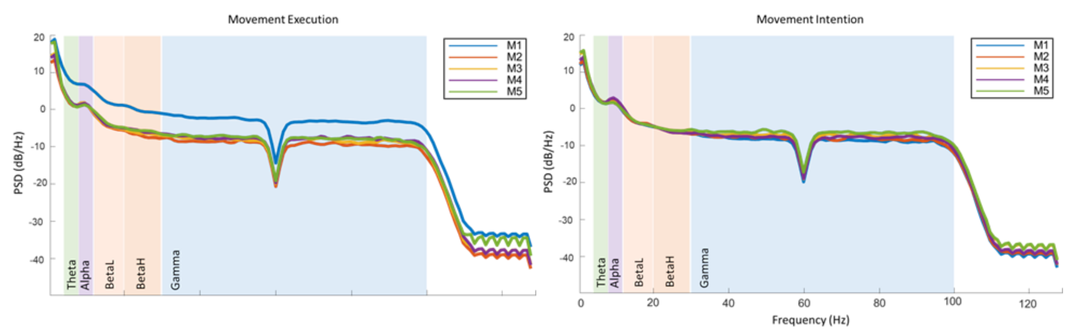
28 Channels F1-F4, FC1-FC4, FCC3-FCC6, C1-C4, CCP3-CCP6, CP1-CP4, P1-P4



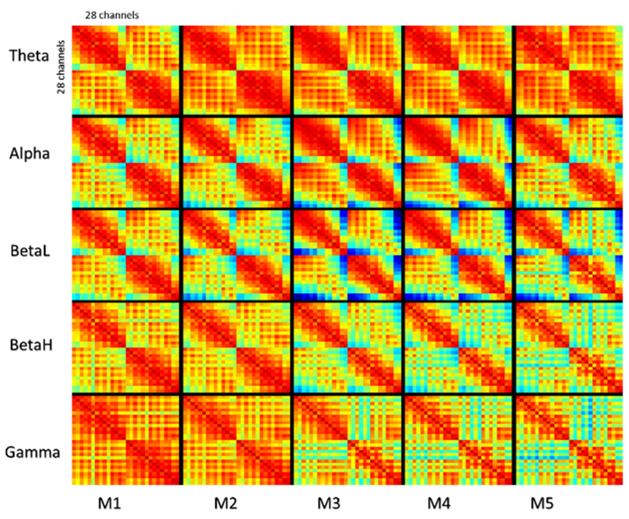


Results

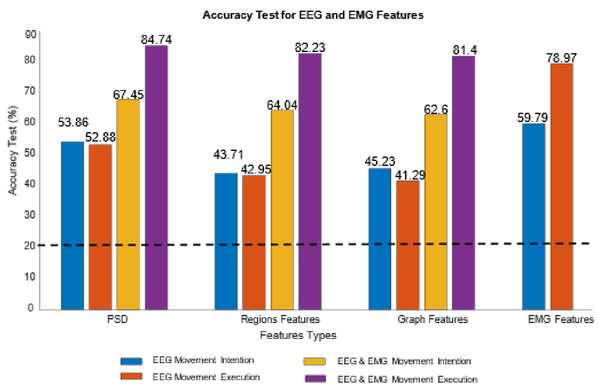
For the EEG, differences between the power spectrum for the analyzed frequencies were observed, during movement intention and execution.



Connectivity Matrices: a change of the connectivity was observed for the 5 movements in different frequency bands. Inter-hemispheric interaction varies is stronger in theta and alpha bands and weaker in low-beta. Higher correlation levels were observed during movements M3 and M4 suggesting greater neural recruitment.



Pattern recognition: The Ensemble Bagged Trees model achieved the highest performance, reaching 84.74% accuracy in gesture identification. This model was trained with 464 learning cycles, using a learning rate of 0.8642 and 3 leaf size. Feature sets based on PSD provide the most effective classification inputs



Conclusion

The combination of EEG and EMG signals enabled high-accuracy classification of hand movement intention and execution, demonstrating that both signals provide complementary information about neuromotor processes.

The Ensemble Bagged Trees model proved to be the most effective, especially when using features related to brain connectivity and muscle activation. These results confirm the potential of multimodal systems to enhance post-stroke rehabilitation through intelligent monitoring and assistance.

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[3] A. Pollock *et al.*, "Interventions for improving upper limb function after stroke", *Cochrane Database of Systematic Reviews*, vol. 2014, núm. 11, nov. 2014, doi: 10.1002/14651858.CD010820.PUB2.

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