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Extraction of motor patterns from joint EEG/EMG recording: A Riemannian Geometry approach.

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Introduction: The combined analyses of brain and muscle signals can be very useful in assessing the cortico-muscular connectivity and reorganization in brain injury. A basic approach would be to assess the sensorimotor (SMR) rhythms with electroencephalography (EEG) during the muscle activation in a pinch-and-hold task. For this paradigm, a cue is presented to the subject to initiate and stop the pinch-and-hold. However, we have found that this simple task can become quite challenging to perform repeatedly and robustly in children with hypertonic or hypotonic muscles, such as in hemiplegic cerebral palsy (HCP). We observed that many children found it difficult to respond immediately to a cue, hold and maintain the pinch on a force gauge, with a specific force, for the length of a trial for multiple trials. In these cases, a self-paced movement execution task appears more appropriate, albeit without an EEG-EMG time-locking event. Inspired by these experimental challenges in assessing the cortico-muscular connectivity in children with HCP, we developed a novel approach to extract SMR spatial patterns from EEG signals using the dynamic information of the corresponding EMG activation. Essentially, in this method the aim is to find EEG sources that can explain the variation of muscle activity. However, due to the different nature of frequency components between EEG and EMG, usual cross decomposition algorithms (CCA, PLS) are not easily applicable towards this goal. Recently, mSPOC was proposed as a novel approach to solve such an issue employing a complex iterative procedure to find components that maximized the envelop of correlation between sources of two sets of multivariate signals. Here, we introduce a simpler alternative methodology, based on Riemannian geometry, that allows to objectively extract EEG spatial patterns that explain variations of EMG power. We show a proof-of-concept in healthy subject's dataset.

Material: 4 healthy subjects participated to this study. 31-channel referential scalp EEG was recorded at 4096 Hz. Differential EMG was recorded at 1200 Hz, using bipolar electrodes at the FDI and ABP muscles of each hand. EEG and EMG streaming data were tagged with a TTL pulse, using hardware triggers, and synchronized offline. EEG and EMG were recorded while the subject engaged in a real-time EMG-controlled video game that presented cues and pinch force feedback, for 20 minutes (executing approx. 40 trials per hand).

Method: EEG signal was filtered between 8-15 Hz and EMG signal was filtered between 30-500 Hz. For both modalities, spatial covariance matrices were estimated using a sliding window of 1.5s with 85% overlap. This procedure produced two sets of covariance matrices that were then projected in their respective Riemannian tangent space using logarithmic mapping. Because of the property of invariance by affine transformation of the Riemannian metric, the tangent space obtained was a rotated representation of the source power. This reduces the problem of extracting sources that match EEG and EMG power, to simply finding rotations in the tangent space that explain the maxima of variance between the two signal sets. This can be achieved by applying a Canonical Partial Least Square (PLS) method. Once the coefficients of the rotations are estimated with PLS, they are back-projected using an exponential map, and diagonalized to produce a set of spatial filters and patterns ranked by their importance. For validating the effectiveness of the spatial pattern extraction, we apply a commonly used method to epoched data -- common spatial patterns (CSP).

Results: A comparison of the patterns extracted with the CSP algorithm and the proposed method is presented in Figure 1. The two methods converge toward the same solution, proving that our method can effectively extract spatial patterns in the same manner as the well-known CSP method.

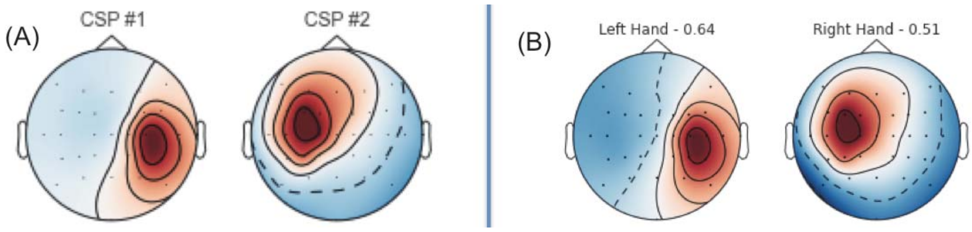

Figure 1. *(A) Spatial pattern extracted by Common spatial patterns. (B) Spatial pattern extracted by the proposed method*

Significance: This document introduces a simple framework to extract spatial patterns corresponding to movement execution, using EMG signal as a reference, without relying on the time-locking of the cue presentation and the subject's response. This can be very useful in assessing cortico-muscular connectivity in challenging subjects with movement disorders. Furthermore, this method can also be generalized to various types of datasets where spatial patterns may be related to power relationship between two sets of multivariate signals, for example: EEG and audio, and the like.