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.

Materials

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). Each subject performed 4 different Sessions.

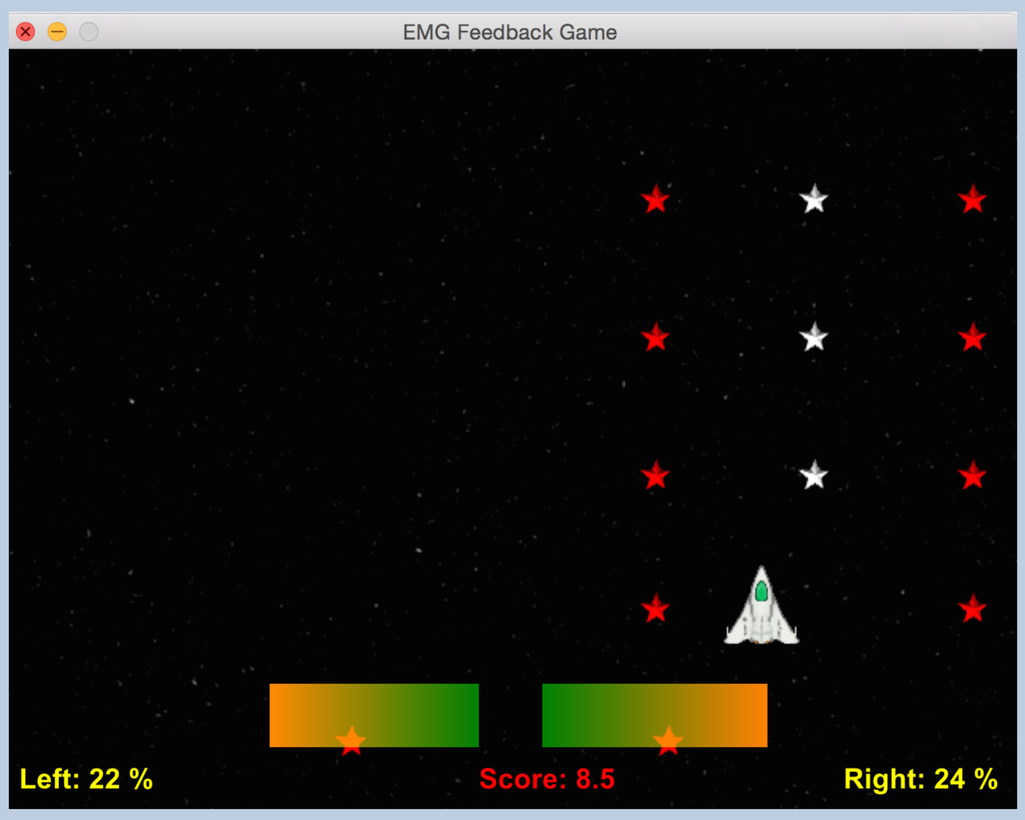

Figure 1: EMG controled video game

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.

Covariance matrix :

$$\mathbf{C}_i = \frac{1}{N}\mathbf{X}_i\mathbf{X}_i^T$$

Logarithmic mapping :

$$\mathbf{S}_i = \mathrm{Log}\left(\mathbf{P}^{-1/2}\mathbf{C}_i\mathbf{P}^{-1/2}\right)$$

Exponential mapping :

$$\mathbf{C}_i = \mathbf{P}^{1/2}\mathrm{Exp}\left(\mathbf{S}_i\right)\mathbf{P}^{1/2}$$

Spatial Filters / patterns :

$$\mathbf{V} = \arg\max \frac{\mathbf{V}\mathbf{R}\mathbf{V}^T}{\mathbf{V}\mathbf{P}\mathbf{V}^T}, \quad \mathbf{A} = \mathbf{V}^{-T}$$

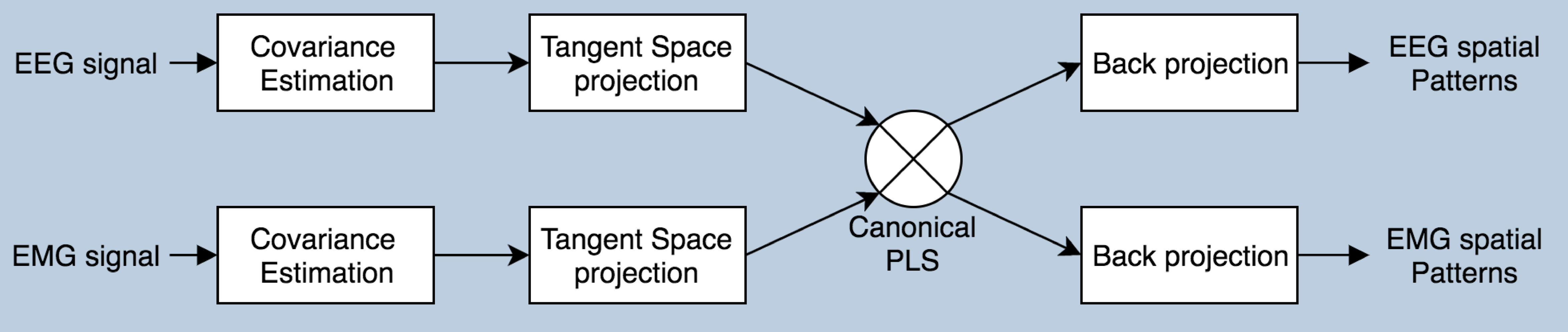

Figure 2: Processing pipeline

Results

The proposed method (**Riemann**) is applied independently on each session and subjects, and is compared to two state-of-the-art methods commonly used to extract motor spatial patterns.

- **Common Spatial Pattern (CSP)** [1] CSP extract patterns using the cue given to the subjects, and therefore no EMG was used.
- **Source Power Correlation analysis (SPoC)** [2] SPoC extract patterns by maximizing correlation to a continuous variable. In our case, the logarithm of the power of the EMG signal (FDI only) was used.

Each method ranks the patterns according to their own criterion, which does not always correspond to the most relevant pattern. The correlation between the power of the spatially filtered EEG signal and the EMG signal (FDI) is estimated and used to find the most relevant pattern (a posteriori).

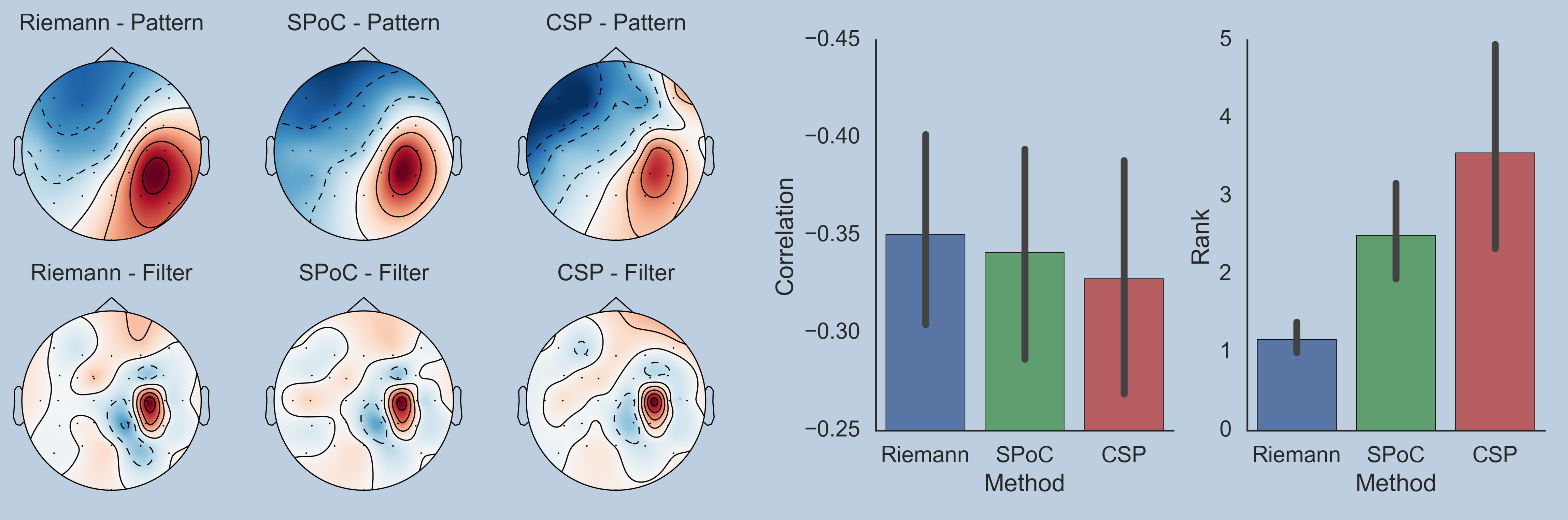

Figure 3: Most correlated pattern and filter (left); Average correlation and rank of the best pattern (right)

Figure 3 (left) illustrates the outcome of the pattern extraction for one subject/session, showing a high similitude between each methods. While the average correlation corresponding to the best pattern is similar for each methods, the proposed method consistently ranks the best pattern if first position, sign of the high robustness of the algorithm.

Conclusion

- We 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.
- The method is simple, effective and robust. It can 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.
- This method is part of a larger framework allowing to extract spatial patterns from any linear projection in the Riemannian tangent space. For example, the PLS can be substituted by a logistic regression or a linear regression to provide a robust alternative to CSP and SPoC, respectively.

References

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