Effectiveness of cross-frequency phase-amplitude covariance as additional features for Riemannian BCIs

Maria Sayu Yamamoto, Sylvain Chevallier, Fabien Lotte

To cite this version:

Maria Sayu Yamamoto, Sylvain Chevallier, Fabien Lotte. Effectiveness of cross-frequency phase-amplitude covariance as additional features for Riemannian BCIs. BCI 2023 - 10th International BCI Meeting Balancing Innovation and Translation, Jun 2023, Brussels, Belgium. 10.3217/978-3-85125-962-9-179 . hal-04181391

HAL Id: hal-04181391
https://hal.science/hal-04181391
Submitted on 15 Aug 2023

HAL is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L’archive ouverte pluridisciplinaire HAL, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d’enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.
Effectiveness of cross-frequency phase-amplitude covariance as additional features for Riemannian BCIs
Maria Sayyu Yamamoto1, Sylvain Chevallier1, and Fabien Lotte2
1 LISN, University of Paris-Saclay, Gif-sur-Yvette, France; 2 Inria centre at university of Bordeaux, Talence, France;
* 1 Rue Raimond Castaing et Rue René Thom (Bât Digitéo), 91190, Gif-sur-Yvette, France.
E-mail: maria-sayyu.yamamoto@universite-paris-saclay.fr

Introduction: Riemannian geometry has been shown to significantly improve BCI classification performance [1]. However, BCIs are still not reliable enough. To further improve Riemannian BCIs, it is thus worth exploring complementary features to the conventional Riemannian feature, i.e., spatial covariance matrix. In this work, we propose to combine the phase and amplitude covariance (PAC) of cross-frequency bands (FBs) as such an additional feature, inspired by phase-amplitude coupling [2].

Material, Methods and Results: We propose a new symmetric positive definite (SPD) matrix \( P_{PAC+BP} \) that considers multiple features based on phase, amplitude, and band power (BP) of cross-FBs in one covariance matrix (Cov). As summarized in Fig. 1, \( P_{PAC+BP} \) consists of two different block matrices \( P_{PAC} \) and \( P_{BP} \), diagonally arranged with null off-diagonal matrices. \( P_{PAC} \) quantifies the covariance between the phase of low FB (LF) and the amplitude of high FB (HF). The best FB pair LF-HF is selected among 6 pairs \( \{ \delta-\beta, \theta-\beta, \alpha-\beta, \delta-\gamma, \theta-\gamma, \alpha-\gamma, \beta-\gamma \} \) using the classDis FB selection algorithm from [3]. \( P_{BP} \) arranges the conventional spatial Covs in LF and HF diagonally as block matrices. We evaluated the usefulness of \( P_{PAC+BP} \) for mental workload classification using a public passive BCI dataset from [4]. To investigate the contributions of \( P_{PAC} \) and \( P_{BP} \) features, we also compared performances of \( P_{PAC} \) and \( P_{BP} \) individually. As a baseline, we built a Cov with the same structure as \( P_{BP} \) but with \( \beta \) and \( \alpha \) bands, the two most used FBs for EEG-based mental workload classification. Artifacts from that EEG dataset were reduced using ICA.

The dataset consisted of EEG data from 29 subjects who performed zero or two back tasks. The first two blocks were used as the training set, and the final block as the test set. Mean classification accuracies (% using Minimum Distance to Mean classifier [1] were 74.1±15.1, 76.6±20.6, 78.5±21.4 and 84.4±18.4 for the baseline, \( P_{PAC} \), \( P_{BP} \), and \( P_{PAC+BP} \) respectively. Repeated measure ANOVA revealed significant differences between methods (p = 0.01). \( P_{PAC+BP} \) showed statistically significant improvement from baseline (p=0.01). Discussion: All Cov showed better mean accuracy than baseline, with \( P_{PAC+BP} \) showing the greatest improvement. This suggests the effectiveness of PAC as an additional feature to BP.

References