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Dimensionality reduction for the analysis of brain oscillations

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Abstract

Neuronal oscillations were shown to be associated with perceptual, motor and cognitive brain operations. While complex spatio-temporal dynamics are a hallmark of neuronal oscillations, they also represent a formidable challenge for a proper extraction and quantifications of oscillatory activity with non-invasive recording techniques such as EEG and MEG. In order to facilitate the study of neuronal oscillations we present a general purpose pre-processing approach, which can be applied for a wide range of analyses including but not restricted to inverse modeling and multivariate single-trial classification. The idea is to use dimensionality reduction with spatio-spectral decomposition (SSD) instead of the commonly and almost exclusively used principal component analysis (PCA). The key advantage of SSD lies in selecting components explaining oscillations-related variance instead of just any variance as in the case of PCA. For the validation of SSD pre-processing we performed extensive simulations with different inverse modeling algorithms and signal-to-noise ratios. In all these simulations SSD invariably outperformed PCA often by a large margin. Moreover, using a database of multichannel EEG recordings from 80 subjects we show that pre-processing with SSD significantly increases the performance of single-trial classification of imagined movements, compared to the classification with PCA pre-processing or without any dimensionality reduction. Our simulations and analysis of real EEG experiments show that, while not being supervised, the SSD algorithm is capable of extracting components primarily relating to the signal of interest often using as little as 20 % of the data variance, instead of > 90 % variance as in case of PCA. Given its ease of use, absence of supervision, and capability to efficiently reduce the dimensionality of multivariate EEG/MEG data, we advocate the application of SSD pre-processing for the analysis of spontaneous and induced neuronal oscillations in normal subjects and patients.

Keywords: dimensionality reduction, brain oscillations, spatio-spectral decomposition, principal component analysis

1. Introduction

The recent development of electrophysiological neuroimaging technology (e. g., EEG and MEG) led to the possibility of recording brain activity using ever-denser sensor arrays. Often, for statistical, numerical and computational reasons, the number of obtained data dimensions is reduced for the following analyses. One of the most common approaches to reduce the dimensionality of data is to decrease the number of EEG/MEG channels by selecting for instance sensors covering a certain parts of the head. Unfortunately, this approach has a big disadvantage as it assumes that cortical activity would produce EEG/MEG signals only in its immediate vicinity. However, due to the volume conduction property of the head, this is not the case and a given cortical current source can produce its maximal scalp electric potential or magnetic field far away from its origin.

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