Multidimensional complex measures for functional connectivity analysis

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There is a growing interest in assessing functional connectivity from fMRI data for human brain mapping. Functional connectivity analysis is based on the concept of synchrony between the signal responses in spatially distinct brain areas [1]. If on one hand, the great spatial resolution offered by magnetic resonance imaging could far improve the identification of functional regions of interest for clinical purposes, on the other hand, its low temporal resolution limits the number of methods that can be used to assess the interactions between the time series associated with such regions. Pairwise fMRI time series associations are usually estimated through zero-lag correlation metrics [2], however the human brain can be modeled as an inherently nonlinear complex system [3], so linear correlation techniques might reveal only partial aspects of the functional interactions between brain areas and could result quite ineffective in modeling complex behaviors. In this work, a set of simulated fMRI data are generated following a block-related experimental design with the aim of comparing different connectivity metrics and providing further insights into the links between the coupling strength of each metric and the parameters of the time series. We propose generalized cross recurrence complex measures to fully capture dynamic coupling behavior between fMRI time series and show their robustness against noise as well as their effectiveness to reveal correlation even in presence of nonlinearity. fMRI data are constructed under the assumption that activations result from underlying neural events as well as noise. Specifically, strong neural events follow a block design, while spontaneous neural fluctuations and spiking events are treated as random deviations from resting baseline. Finally, blood oxygenation level dependent signals are generated with both a linear canonical hemodynamic response function and a nonlinear vascular model. We added different levels of physiological noise and applied progressive phase shifts to signals to investigate whether the correlation metrics reflect various conditions.

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