Estimation of Brain Connectivity: Where Does Variability Come From?

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During the past decades, considerable effort has been devoted to the development of signal processing techniques aimed at quantifying the temporal evolution of the cross-correlation (in a wide sense) between signals recorded from spatially-distributed regions in order to characterize brain functional connectivity during normal or pathological (as in epilepsy) conditions. Besides linear methods introduced in the field of EEG analysis fifty years ago, a number of studies have been dedicated to the development of nonlinear methods, mostly because of the nonlinear nature of mechanisms at the origin of EEG signals. Recent studies showed the potential value of methods commonly used in nonlinear physics. Three families of methods (linear and nonlinear regression, phase synchronization, and generalized synchronization) are reviewed. Their performances are evaluated on the basis of a simulation models in which a coupling parameter can be tuned between subsystems generating bivariate time-series. This evaluation is performed according to quantitative criteria. The main findings of this evaluation are the following. First, some of the methods are insensitive to the coupling parameter. Second, results were found to be dependent on signal properties. In particular, the broadening of the frequency band is a parameter that strongly influences the performances. Third, and generally speaking, there is no 'universal' method for measuring statistical couplings among signals. Indeed, none of the studied methods performs better than the other ones for the studied situations. Finally, linear and nonlinear regression methods were found to be sensitive to the coupling parameter in all situations and showed either average or good performances. This latter point leads the authors to conclude that these "robust" methods should be applied before using more sophisticated methods for assessing the brain connectivity variability.