Estimation of effective brain connectivity using a recurrent neural network model on magnetoencephalography data

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Keywords: (Magnetoencephalography ,Brain connectivity , Backpropagation Through Time , Hopfiedl model)

The functional communication mechanism within the brain is given by synchronous neural activity among its different regions. Electroencephalography (EEG) and Magnetoencephalography (MEG) are among the most prominent tools to study noninvasively and with high temporal resolution brain synchronization phenomena. Brain connectivity, in particular, can be subdivided into three types: neuroanatomical (or structural), functional (measured performing cross-correlation) and effective connectivity (referred to a pattern of causal interactions between distinct units within a nervous system).
Structural connectivity concerns the anatomical connections. Since neuronal units can only be functionally connected if there is a structural relation between them, knowing the network structure is fundamental for undestanding mechanisms behind brain functions.
Functional connectivity is measured performing a cross-correlation approach for pairs of EEG or MEG signals and it may be defined as the temporal correlation between neurophysiological events of different brain regions [1]. The idea is that higher correlations are due to stronger functional relationships between the related brain regions. Differently, effective connectivity is defined as the interdependence that one neural system carry out over another. In this case the brain connectivity refers to a pattern of causal interactions between distinct units within a nervous system. It approach is able to describe the dynamic directional interactions among brain regions.
The analysis on these different levels is crucial to elucidate how the units of brain process information though the relationship that links together these three different brain connectivity definitions and it represents a significant challenge in the field of neuroscience. Here, we present a new computational protocol which is able to determine the effective connectivity matrix starting from MEG data. The evolution of each brain state, which is defined for each time t, is assumed to be described by the Hopfield neural network through a non-linear dynamics equation. The evolution of the signal over time has been used to infer the matrix of causal connections through the use of a recurrent neural network model and the Backpropagation Through Time method [2][3], where the neural networks are networks formed by binary McCulloch-Pitts neurons.
The basic idea is that if we are able to learn from the transitions of brain states over time, then we can determine causal relationships among brain units and predict future brain states starting from a specific brain configuration.

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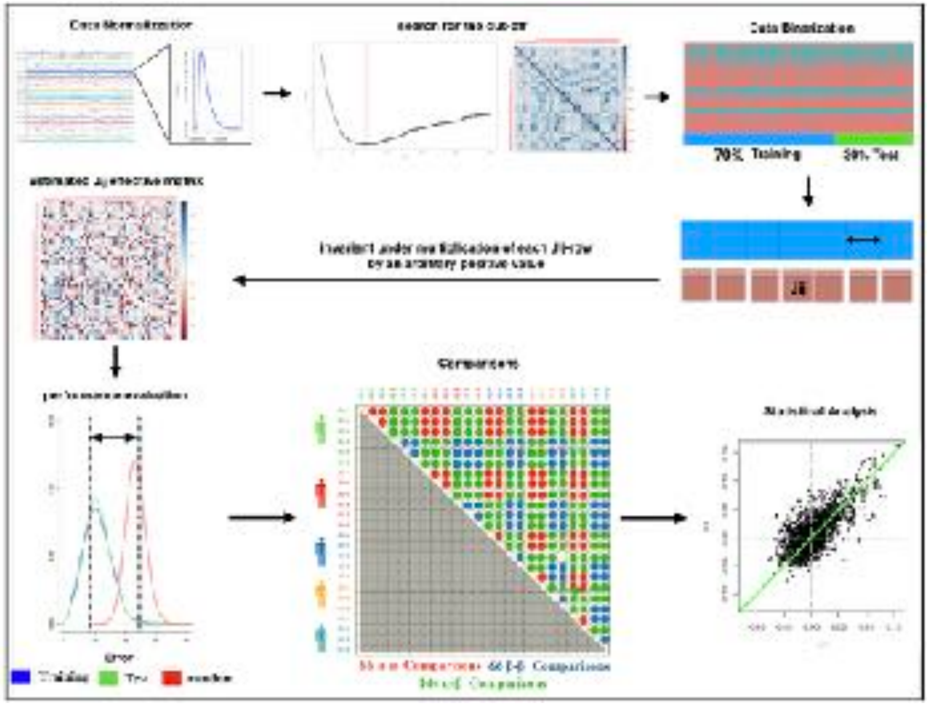

Figure 1. Scheme of the method described in this work.