Complex networks in brain electrical activity

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Abstract – This letter reports a method to extract a functional network of the human brain from electroencephalogram measurements. A network analysis was performed on the resultant network and the statistics of the cluster coefficient, node degree, path length, and physical distance of the links, were studied. Even given the low electrode count of the experimental data the method was able to extract networks with network parameters that clearly depend on the type of stimulus presented to the subject. This type of analysis opens a door to studying the cerebral networks underlying brain electrical activity, and links the fields of complex networks and cognitive neuroscience.

Introduction. – Functional magnetic resonance imaging (fMRI) data for the human brain has been analyzed [1] using a complex networks approach, and evidence was found for a scale-free behavior of the derived functional networks. The spacial resolution of fMRI is outstanding, less than 1 cm³, but the temporal resolution is fundamentally limited, because fMRI measures the metabolic activity of the brain, through the blood oxygen level difference. Because the metabolic activity is a temporal convolution of the computational activity, the temporal resolution is at best on the order of a second. EEG signals on the other hand, with a temporal resolution of less than a milli-seconds, are a measure more directly related to the computational activity of the brain neural ensemble dendritic currents, reflecting excitatory-inhibitory neural communication processes which are believed to reveal the effective network of the brain [2]. Hence, EEG allows recording real-time synchronous neural activity which closely link neural computing and behavior [3]. However, while EEG signals seem to be very rich in information, reliable extraction of information has been elusive [4]. A particular difficulty for using EEG’s to study the functional network of the brain is the fact that EEG signals are only measured at the electrodes on the scalp. So that, until now, only the network derived from the connectivity of the surface electrode signals has been studied [5], which does not reveal the network between the functional regions of the brain. However, with recent advances in EEG tomography [6] it is now possible to locate the source of the signals within the brain, with course accuracy. This development makes possible the construction of functional networks of the brain with a much greater temporal resolution, by a combination of EEG tomography and the methodology employed in [1]. In this paper we describe such a “complex networks” methodology for electrophysiology and apply it to a relatively simple set of data obtained in an event-related potential protocol with 13 subjects and collected with 30 EEG channels. While it is certainly true that 30 electrodes are barely sufficient to obtain good tomographic results, the aim here is to carry out a first test of the approach. The technique can be applied with more extensive data sets, and the envisioned applications are many.

Experimental procedure. – In this work we have applied our analysis to a set of previously obtained and well-studied data. It is a widely observed phenomena in psychophysiology that when a novel (deviant) tone appears in a background of similar (standard) stimuli, the cerebrum elicits an electrical response that peaks 100–200 ms after the deviant stimulus, even if the subject is not attending to the stimuli. This response can be recorded, using EEG, as a negative voltage at the fronto-central electrodes. This negative wave is known as Mismatch Negativity (MMN). The paradigm used in
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thresholds. There is not a clear indication that the networks are scale free.

The application of this approach could range from the basic studies determining the properties of networks associated with event-related potentials or electroencephalography, to the study of pathological brain electrical responses, to biometrics. However, more studies are needed in order to compare the information provided by an electrophysiology complex networks approach with information provided by other functional techniques, such as fMRI, and theoretical information to clearly validate this method. In particular, we plan to analyze elsewhere in more detail the impact of the tomography on the network structure, as well as study other variants for the construction of the networks.

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