High local synchronization in brain recordings: natural or artifactual?

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The study of how the brain correlates to the mind or how physical process can produce cognition is central to neuroscience research. In this sense, there are two main routes of investigation, the *interactive* and the *non-interactive* one. In the *non-interactive* the focus is to determine what brain areas are activated when specific cognitive task are occurring, here the brain is considered as an entity whose parts can act independently. On the contrary, in the *interactive* model the brain is supposed to work as a whole with many functional links that can be dynamically formed and dissolved. This point of view has gained increasing importance in today's brain research and has been developed by both the theoretical and the experimental researcher.

One of the most sensible tools to study functional connectivity in brain activity is through the study of the phase synchronization of electroencephalographic (EEG) and magnetoencephalographic (MEG) recordings. The usual protocol in most studies consists of correlating some specific mental task with patterns of synchronization between the magnetic or electric field that are produced by the activation of neural generators in different parts of the brain.

The electromagnetic field produced by the brain and recorded extracranially can be modelled (or approximated) as being produced by a finite set of neural generators distributed inside the brain. The field recorded at any moment at any spatial location is the result of the integration of the fields of this set of neural generators each one with a specific strength and orientation.

The analysis of signal synchronization, as a tool of signal processing, is the measure of the stability of a phase difference between two signals. First we must define the instantaneous phase of each signal by some appropriate mathematical transformation, then a time window must be defined and the stability of phase difference inside that window can be estimated using the circular variance (CV). Since high synchronization must correspond to a low CV the synchronization index is usually defined as $R=1-CV$.

The problem:

It can be demonstrated that if two signals are highly correlated their synchronization is also high; while it is not necessarily the case that high synchronization implies high correlation.

Two very close sensors would always measure a very similar field since the electromagnetic field as recorded extracranially is spatially smooth. This fact produces a high value of correlation between the signals recorded by nearby sensors and consequently a high value of synchronization. This high synchronization is purely artifactual since it is not due to the specific activity that is produced right below the sensors but to the smoothness of the electromagnetic field. When we measure synchronization, in our laboratory, in real and simulated data it is always the case that a high synchronization is present between nearby sensors regardless of the specific synchronization, time course, strength, number and position of the generators inside the head.

For our purposes the brain can be considered as a sphere, or hemisphere, filled with magnetic dipoles or electric charges, depending on whether we are consider the magnetic or the electric field (continuous distributions of sources can also be considered if this can simplify the solution).

We would like to know specifically what would be the relation between the smoothness of the electromagnetic field and the consequent temporal correlation that this smoothness induces as a function of the distance between the sensors.

It seems obvious that first we need to find an appropriate mathematical definition of smoothness. We have stated the problem in terms of correlation since this parameter seems easier to handle for analytical purposes and, at the same time, is closely related to synchronization when high.