Multiscale brain functioning analysis: forward and inverse problems in micro and macro-electrodes

Centre de Recherche en Automatique de Nancy UMR CNRS 7039
Université de Lorraine France
CHU Nancy –Neurologie


Contact: Pr Valérie Louis Dorr: valerie.louis@univ-lorraine.fr
Dr Radu Ranta: radu.ranta@univ-lorraine.fr

Context

Brain electrical activities are explored at different spatial scales, from scalp EEG (electrodes placed on the surface of the head for a global or regional vision), SEEG (electrodes implanted in the brain for directly measuring the implanted structure and the adjacent ones) and microelectrodes (which record the activity of individual neurons and their neighbors inside a given structure).

The links between these different scales are far from being fully understood. While it is generally accepted that the macroscopic activity recorded by scalp EEG is the result of activities of the various intracerebral structures, partially measurable by SEEG, the relationships between microelectrodes and the SEEG electrodes are still far from being established. This is partly due to the same causes which prevent the establishment of a strict relationship between surface EEG and SEEG, namely the fact that the spatial sampling becomes increasingly sparse and irregular as the scale decreases: SEEG electrodes SEEG are not implanted in the whole brain volume and microelectrodes explore the activities of some neurons in an even smaller volumes, usually within a single structure. A second difficulty comes from the electrophysiological dynamics intrinsically different among different scales - the frequencies of the recorded signals are very different, for reasons both geometric (spatial structure of groups of neurons), temporal (phase differences and activation) and biological (filtering effect of neuronal cells, especially dendrites) (Buszaki et al., 2012). Finally, feedback effects also appear: if it is obvious that the activity at the microscopic scale is a cause of macroscopic activity (or, in other words, the individual neurons and networks determine the signals recorded by SEEG and beyond by EEG), recent research suggests that low frequency remote activities (therefore registered by the macro-electrodes) influence the activation of neurons in structures explored by microelectrodes (Einevoll et al., 2012).

Objective

The objective of this thesis is to contribute to the modeling and therefore to the understanding of the mechanisms that link the phenomena recorded at the level of micro-electrodes to those recorded at the intermediate SEEG scale. We will focus on the ventral occipito-temporal brain cortex structures explored both by SEEG and microelectrodes. Indeed, according to (Linden et al., 2011), the local electric field and thus the potential measured by SEEG electrodes depend on the size of the volume studied and on the regularity of the underlying cellular organization. It is therefore important to develop models in accordance with a priori location.

Methodology

Microelectrodes record both the activity of close neurons (fast spiking activity) and the averaged local field potentials (LFP) generated by relatively distant structures (slow activity), while the SEEG only measures a superposition of several local fields. A first research direction is to explore
the separation between the two types of activity recorded by the microelectrodes, using information from the SEEG. Simple filtering approaches are unreliable and a possible solution is the Bayesian approach proposed by (Zanos et al, 2011), which uses priors without direct physiological basis (without SEEG validation). A suitable preprocessing will most likely be necessary to estimate the SEEG activity at the site explored by the microelectrodes, and a possible approach implies solving the inverse problem in SEEG after adapting previous work of (Caune et al, 2014).

Once established a methodology to separate local and remote activities, we can evaluate and validate models from several types of activity hence sources during different cognitive tasks. The goal is then to establish relations between the two types of activity (local - remote, similar to micro-macro), adapting techniques such as on coherence, phase-locking value (PLV) or pairwise phase consistency (PPC) between spikes and LFP (Vinck et al, 2010).

References