A mechanism for neuronal avalanches in the brain. Application to electrical stimulation in epilepsy

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In the last decade, recordings of spontaneous neural activity have revealed the existence of so-called neuronal avalanches, either at the local neural network level in animal preparations (Beggs and Plenz, 2003) or at the whole brain level in humans using magnetoencephalography (MEG) or stereotactic electroencephalography (sEEG) where, for medical purposes, electrodes are implanted in the brain of epileptic patients (Shriki et al., 2013; Zhigalov et al., 2015). In MEG recordings, the presentation of a stimulus has been shown to elicit quantitatively different avalanches (Arviv et al., 2015). In patients implanted with sEEG, repetitive brief electrical stimulations ($\approx$ 1 ms) at an electrode contact elicit a quite specific pattern of strong responses in a subset of contacts, as compared to spontaneous fluctuations. Such responses are potentially very useful to infer the underlying directed structural white matter fibers of the human brain, constituting the brain network linking distant grey matter local networks (David et al., 2013). While the local latency of the stimulation response can be thought to smoothly accumulate with the number of white matter connections, allowing to infer direct connections between distant local networks, previous observations cannot exclude the possibility that such strong stimulations elicit an avalanche, potentially changing the interpretation of these latencies. What are the mechanisms underlying these large-scale neuronal avalanches in spontaneous activity? What is the neural response to an external stimulation?

To answer these questions, we propose a biophysical model of the large-scale activity of the brain where local neural networks, excitatorily connected through a known brain network, have a dynamics described by a neural population rate model with a fatigue mechanism. Compared to previously proposed models, the model is shown to reproduce the main markers of spontaneous neuronal activity. Neuronal avalanches are found to be due to bursts of excitatory activity on the brain network, the fatigue mechanism leading to the termination of such bursts. In response to an external localized stimulation, a quite specific avalanche can be elicited, with a pattern of local latencies characterized by a large number of saturating ones compared to smaller ones. When no avalanche is elicited, the stimulation response hardly propagates on the network. In sEEG recordings, we analyze the stimulation response latencies in different brain regions and across patients. Their distribution is found to be in agreement with the one obtained for the neuronal avalanches predicted by the model. Such pattern of latencies calls for new methods to infer the brain network connectivity, a subject that will be addressed in future work.

References

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