Emergence of the spontaneous and stimulation-induced neural activity on the brain connectome

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Motivated by the discovery of a complex spatial structure in resting state BOLD fMRI functional connectivity (FC) and the availability through the use of diffusion MRI of the human connectome –linking local neural networks through white matter fibers, a lot of theoretical work has been devoted in the last decade to the understanding of the underlying mechanisms behind such spatial organization. A plausible dynamical scenario is that the neural dynamics at each local node of the brain but also at the global network level, fluctuates around a fixed point under the effect of local noise [1,2]. More recently, the spontaneous state of the brain has also been found to exhibit scale-free neural avalanches. The preceding theoretical scenario is found to be unable to reproduce such behaviour. Moreover, when trying to reproduce the well established propagation of neural activity on the brain network in response to an external stimulation, this scenario fails to reproduce it, the response decaying strongly while propagating on the network [1], even when trying to correct for such decay [2].

In this work, we address these problems by proposing a new biologically plausible dynamical scenario. At the single node level, we propose that the neural network dynamics also exhibits a fatigue mechanism, like neuronal adaptation. Such a mechanism is found to locally lead to a possible bistability in the dynamics, with a low and a high activity state. While the relative couplings between nodes are given by the connectome, the tuning of their absolute value through a global coupling allows to explore the emerging global dynamics. For an intermediate level of this coupling, and under the effect of noise, scale-free avalanches are found, consisting of series of local low to high activity state switch events. For a sufficiently strong stimulation, a specific propagation of neural activity occurs on the network, as classically observed experimentally, accompanied by a reduction of neuronal firing variability -across trials- as widely observed in electrophysiological experiments [3]. Moreover, for this level of global coupling, BOLD FC is found to fit best the empirical FC, and better than in the case where the model exhibits the preceding fluctuation scenario, that is for model parameters for which local state switches are made impossible. In conclusion, placing the model dynamics in a regime of scale-free avalanches allows to reproduce the diverse signatures of spontaneous and stimulation-induced neural activity on the brain connectome.

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