Emergence of modular and hierarchical neural networks driven by learning of external stimuli

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ABSTRACT

In the last three decades the field of brain connectivity has explored the function of the white matter. Beyond the specialization of individual cortical regions, it has been found that the cortex is organised into a modular and hierarchical architecture. This type of organization is also been recognised at the microscopic level, in the form of interconnected neural assemblies and it is typically believed that it supports the coexistence of segregation (specialization) and integration (binding) of information. A prominent remaining question is to understand how the brain could possibly evolve into such a network. Here, we give a first step into answering this question and propose that adaptation to various inputs could be the key driving mechanism for the formation of structural assemblies at different scales. To illustrate that we develop a model of (QIF) spiking neurons, subjected to stimuli targetting distributed populations. The model follows several biologically plausible constraints: (i) it contains both excitatory and inhibitory neurons with two classes of plasticity–Hebbian and anti-Hebbian STDP, (ii) dynamics are not frozen after the entrainment is finished but the network is allowed to continue firing spontaneously, and (iii) plasticity remains always active, also after the learning phase. We find that only the combination of Hebbian and anti-Hebbian inhibitory plasticity allows the formation of stable modular organization in the network. Besides, given that the model continues "alive" after the learning, the network settles into an asynchronous irregular firing behaviour displaying spontaneous memory recalls which, as we show, are crucial for the long-term consolidation of the learned memories.