The Impact of Structural Heterogeneity on Excitation-Inhibition Balance in Cortical Networks

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The tight, rapid balance of excitation and inhibition is a hallmark of cortical dynamics. However, mathematical models that explain this balance assume a homogeneous connectivity structure. We provide anatomically based estimates of the connectivity of layer 4 (L4) rat barrel cortex that indicate that the local network possesses substantial heterogeneity in input connectivity. We show analytically and numerically that such heterogeneity can prevent the dynamic balance between excitation and inhibition and yield unrealistically sparse and temporally regular firing.

We study cellular and synaptic mechanisms by which a network can maintain balance in spite of structural heterogeneity. We find that homeostatic plasticity in inhibitory synapses can align the functional connectivity to compensate for structural heterogeneity. Alternatively, spike-frequency adaptation can give rise to a novel state in which local firing rates adjust dynamically so that adaptation currents and synaptic inputs are balanced.

The advent of connectomics has triggered great interest in the fine details of connectivity patterns of neuronal circuits. Yet it remains unclear, in general, how and to what extent these details affect the dynamics and function of these circuits. Here we have shown that a specific feature, heterogeneity in incoming connectivity, has a significant qualitative impact on local cortical dynamics, and that the circuits’ proper function depends on the interplay between connectivity structure and single neuron dynamical properties.

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