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Control of the temporal interplay between excitation and inhibition by the statistics of visual input

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Introduction

In the primary visual cortex (V1), single cell responses to simple visual stimuli (drifting gratings) are usually strong but with a high trial-by-trial variability. In contrast, when exposed to full field natural scenes with simulated eye movements, the firing patterns of these neurons are sparse but highly reproducible over trials [1]. So far the mechanisms behind these two distinct different response behaviours are not yet fully understood. Different mechanisms are candidates for controlling spike timing precision and models are needed to clarify their respective contribution, which may be of thalamic or intracortical origin. As a first step, we investigated which aspects of the neuronal dynamics can be explained by balanced feedforward excitation and inhibition and its dependency upon the spatio-temporal statistics of the different stimuli. We built a simple model of the early visual system (LGN, V1). The thalamocortical connectivity was similar to the gpush-pullh architecture used in [2], with additional depressing thalamocortical synapses [3]. The model was written in PyNN [4] using NEST [5] as simulator. Indeed, the model can reproduce the main response characteristics of first-order thalamo-cortical neurons in layer 4 of cat V1. During drifting gratings, excitatory and inhibitory conductances of cortical neurons were anti-correlated [6,7], such that excitation can be freely integrated and induce multiple spikes. In contrast, during natural scenes the conductances were correlated, with inhibition lagging by few milliseconds [1,8]. This small lag between excitation and inhibition induces a strong selectivity to synchronous inputs, with a consequence that the responses became sparse and precise. However, some key aspects of the in vivo recordings in cat area V1 cannot be explained, such as selective reduction of stimulus-locked subthreshold noise during natural scene viewing, precise firing during fixational eye-movements and center-surround non-linearities, opening the door for future investigation about the role of intra-cortical recurrent connectivity in further shaping the neuronal responses to natural images. In conclusion, our study points that correlated inhibition can explain, at least in part, sparse and reliable spiking activity as observed in response to natural scenes. This is consistent with its role reported from other sensory modalities and cortical areas [8]. Thus correlated excitation and inhibition could be a general mechanism to induce sparse and precise spiking in the nervous system.

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