Nonlinear Cortical Responses can be Generated by Precise Timing of Thalamic Spikes in the Rat Vibrissa System

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Rats and other rodents use their vibrissae to actively explore the external environment, and can discriminate between similar textures using only their vibrissae. As a rat whisks against an object, patterns of vibrissa deflections are produced that reflect the interaction between the vibrissa movement and the textural properties of surfaces. The peripheral representations of the stimulus are transformed by the excitatory-inhibitory interactions of the thalamocortical circuitry, producing representations that eventually give rise to the sensory percept. We previously showed that the response of cortical neurons to temporal patterns of vibrissa deflection was nonlinearly dependent upon the amount of suppression induced by previous deflections. Specifically, many neurons exhibit a “lifting of suppression” phenomenon in which if the excitatory response to a given deflection is suppressed by prior activity, the suppression that would normally be induced is also suppressed and allows for a larger response to a subsequent deflection. This phenomenon results in nonlinear neuronal responses to complex stimulus patterns and is critical in the prediction of responses to arbitrary stimuli. It is not clear, however, if the observed cortical responses are generated through intra-cortical connections or partially inherited from thalamic projections. Lifting of suppression was observed for a significantly smaller percentage of neurons recorded in the ventral posterior medial (VPM) nucleus of the thalamus as compared to cortex, implying that the lifting of suppression phenomenon may be generated through thalamocortical transformations. However, further analysis of the thalamic responses revealed a nonlinear modulation of response timing, which suggested that precise timing of thalamic spikes may contribute to the cortical phenomenon. Here, we explored these thalamocortical transformations through a simple biophysical network model consisting of reciprocally connected excitatory and inhibitory neurons. Responses of single units in the VPM to temporal patterns of vibrissa deflection were used as templates for the input to the cortical excitatory and inhibitory neurons. The model gives rise to many of the cortical phenomena observed experimentally in response to temporal deflection patterns. Therefore, we can use this model to test the hypothesis that precise timing of thalamic inputs can cause excitatory cortical neurons to fire before feed-forward cortical inhibition suppresses further spikes and investigate which aspects of the cortical response are due to changes at the thalamocortical synapse versus intra-cortical connections.

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