Modulating the distribution of thalamocortical synapses on the dendritic tree to facilitate contrast-invariant tuning

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I - Introduction

Simple cells in the cat's visual cortex appear to be orientation-selective, such that they will have a peak response only when receiving stimuli from the dorsal lateral geniculate nucleus (dLGN) for their preferred orientation. The orientation tuning responses of these cells demonstrates contrast-invariance, that is, the stimulus orientations that cause simple cell firing does not change with contrast (Fig. 1). Synaptic depression of dLGN inputs to simple cells, intracortical inhibition, and synaptic noise are proposed mechanisms to explain contrast-invariance [1]. The goal of the research project is to determine whether the location of the thalamocortical synapses could play a significant role in contrast-invariant orientation tuning of simple cells.

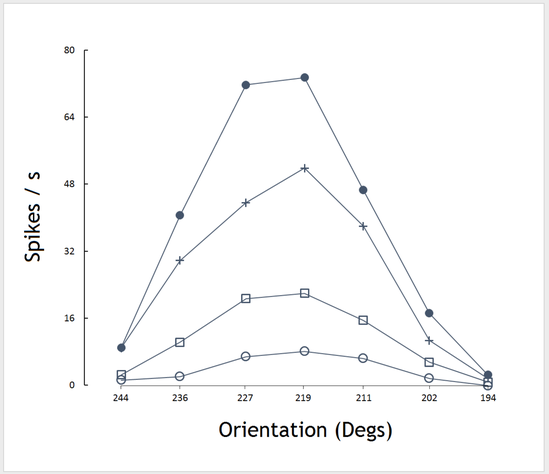

Figure 1. Orientation tuning curve of an *in vivo* simple cell in response to the presentation of sinusoidal gratings at various orientations. Grating contrasts are: 10% (open circles), 20% (squares) 40% (crosses) and 80% (filled circles). [2]

II - Methods

A network model with thalamocortical neurons responding to visual stimuli and projecting to a spiny stellate cell (SSC) was simulated using the computer program NEURON. The model is based on the one used by Bannit et al. (NEURON accession no.39948) but with the effects of synaptic depression and intracortical inhibition ignored. A linear section of the SCC was selected as the experimental branch (EB). Thalamocortical neurons were numbered based on their positioning on a 9x10 receptive field. The field was stimulated using a sinusoidal grating at varying orientations and levels of contrasts, and SSC response was measured as the number of spikes per second (Hz).

Three distribution of dLGN inputs on the EB were tested: all inputs to soma, synapsing based on the relative vertical position on the receptive field (normal), and on its reversed layout (inverse).

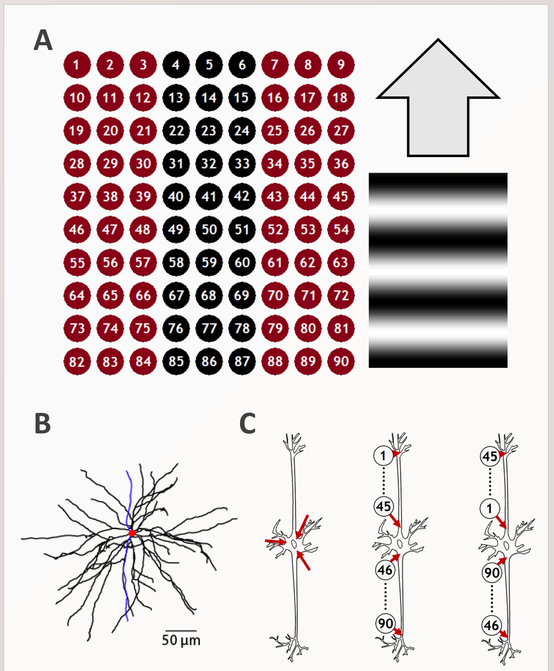

Figure 2. Overview of the experimental methods. ***A***, Modelled receptive field of the dLGN composed of 90 thalamocortical neurons. Black and red circles represent on- and off-center activity respectively. Sinusoidal grating is shown at the 0° orientation. ***B***, Morphology of the modeled cell with emphasis on the EB (blue) and soma (red). ***C***, Distribution of thalamocortical inputs on the EB. Left to right: soma, normal, inverse.

III - Results

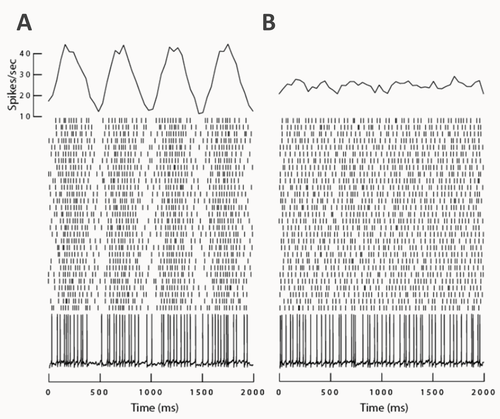

Figure 3. Sample responses of the SSC to a 50% contrast stimulus. ***A***, Stimulus orientation was 90°. ***B***, Stimulus orientation was 0°, as in Fig. 2A. Each panel shows 30 traces (1 intracellular trace and 29 rasters showing spike times) of 2 seconds with the average firing displayed at the top.

Our control for this experiment was the network having the distribution with all thalamocortical synapses on the cell body of the SSC. Fig. 4A shows the response of the cell, displaying strong orientation selectivity that varied with stimulus contrast.

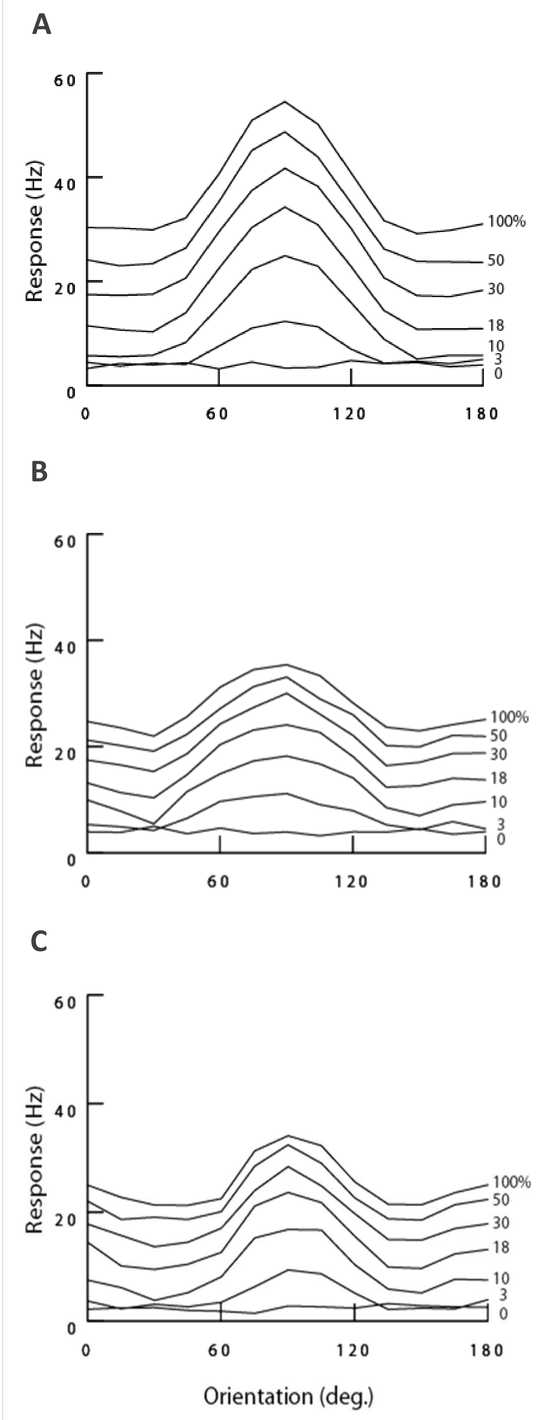

Figure 4. Orientation tuning curves of the SSC with different synapse layouts. ***A***, All thalamocortical inputs synapse at the soma. ***B***, Synapsing in the normal orientation. ***C***, Synapsing in the inverse orientation.

With all inputs on the soma, the background firing rate of the SSC was set to be approximately 2 Hz, consistent with previous experiments [1]. By changing the synaptic distribution from the control layout to the vertically oriented layouts, the strength of the excitatory postsynaptic potential (ESPS) of synapses at the distal dendrites diminished considerably before arriving to the soma. The background firing rate of the SSC fell to 0 Hz. To be able to effectively compare our results to the control layout, a fixed conductance offset was applied so that the background firing rate returned to 2 Hz.

As seen in Fig. 4, the amplitude of the offset for the normal and inverse synaptic layouts were both lower than the control layout, with little difference between the normal and inverse layout. However, the width of the orientation tuning curve appeared smaller in the inverse layout than both the control and normal layouts, indicating sharper orientation selectivity.

IV - Conclusion

From the results of our experiment, we conclude that the location of the thalamocortical inputs on simple cells in the visual cortex has a small effect on the offset produced by increasing stimulus contrast, in comparison to the effects of synaptic depression or cortical inhibition. However, the tuning width of the orientation response varied with respect to synapse distribution. Thus, the next step would be to find out why the inverse distribution of synapsing had greater orientation selectivity than the normal distribution, and whether this type of synaptic distribution is characteristic of vertebrate visual cortex.

V - References

[1] Bannit Y, Martin KA, Segev I (2007) A Biologically Realistic Model of Contrast Invariant Orientation Tuning by Thalamocortical Synaptic Depression. J Neurosci 27(38):10230-10239

[2] Sclar G, Freeman RD (1982) Orientation Selectivity in the Cat's Striate Cortex is Invariant with Stimulus Contrast. Exp Brain Res 46:457-461

VII - Acknowledgements

I would like to thank my supervisor Professor Fortier for his help and guidance during the project, and would also like to thank the University of Ottawa Undergraduate Research Opportunity Program for funding and the chance to participate in a research project