

The contribution of membrane noise to contrast invariance in orientation selectivity

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Introduction

Simple cells in layer 4 of the primary visual cortex of the cat show contrast invariant orientation tuning in which the amplitude of the peak response is proportional to the stimulus but the width of the tuning curve hardly changes with contrast.¹ Contrast invariance is thought to be the result from inhibitory inputs and synaptic depression that function to offset excitation for stimuli away from the preferred orientation. Other studies suggest that noise is another contributor to contrast invariance in orientation tuning.² The extent to which these 3 mechanisms (inhibition, synaptic depression and noise) individually contribute to contrast invariance is not known. In this study, a computer simulation is used to reconstruct the visual network in the cat except for inhibition and synaptic depression so that the role of noise in contrast invariance can be examined. Noise is mostly due to random synaptic inputs³ so this study tested the effects of different levels of synaptic noise. The results show that noise has very little effect on contrast-invariance of orientation selectivity.

Objective

To determine the extent to which synaptic noise contributes to contrast-invariance of orientation selectivity.

Methodology

The NEURON simulation software is used to reconstruct the visual network of the cat as in Yoav Banitt, Kevan A. C. Martin, and Idan Segev.⁴ There are a group of 90 thalamocortical neurons that project to a single spiny stellate cell in V1 Primary visual cortex. The synapses are restricted to the soma of the spiny stellate cell and the amplitude is adjusted so that it corresponds to what it should be in the soma. A sinusoidal grid is slid across receptive field of the thalamocortical cells which subsequently synaptically activate the spiny stellate neuron. The activity of all cells is recorded during the simulation.

Results

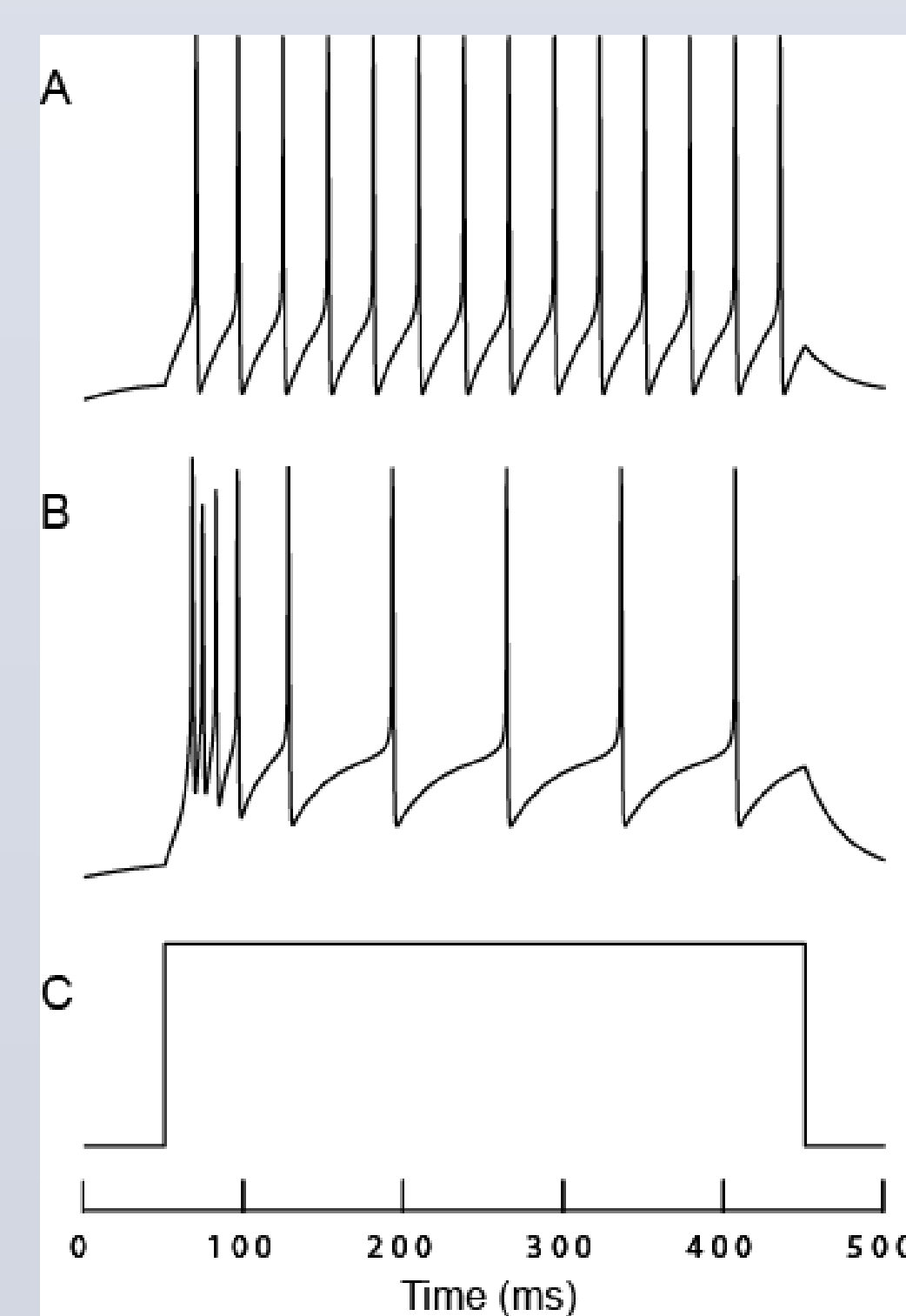


Figure 1: Behaviour (firing response) of a typical thalamocortical neuron given a single, intracellular stimulus. In A) a tonic firing response is observed when the resting membrane potential is set to -62.5 mV. In B) a burst followed by a tonic response is observed when the resting membrane potential is set to -74.5 mV. All other factors are the same.

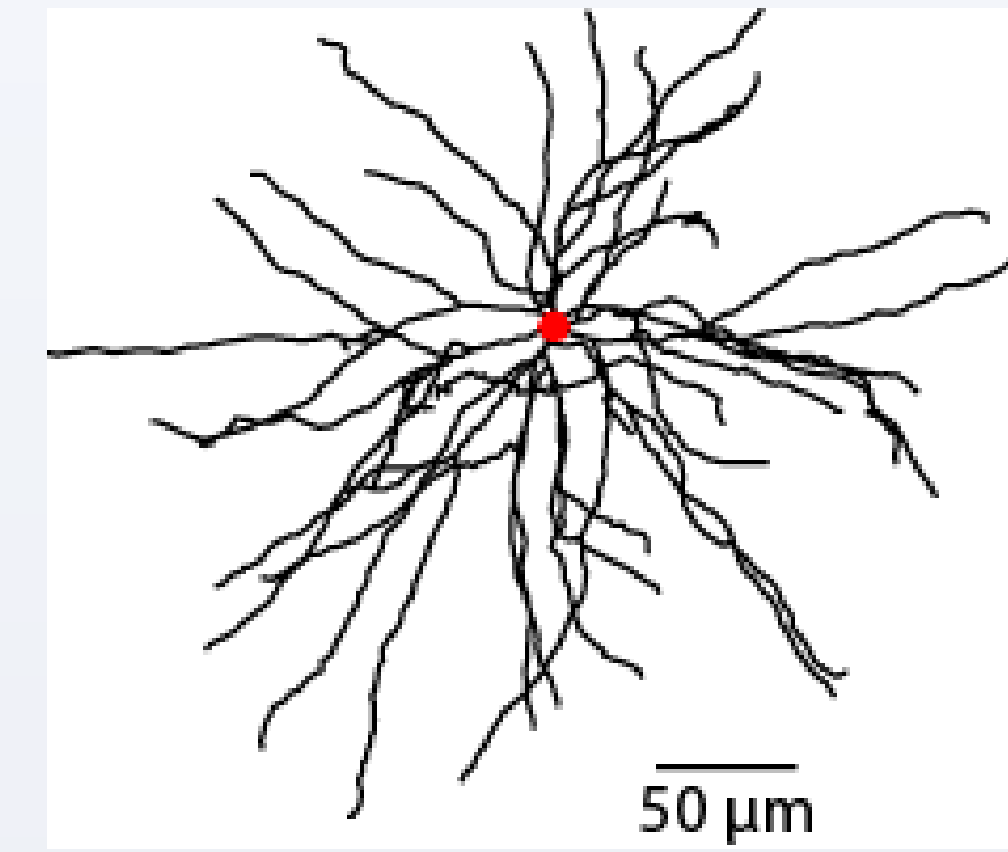


Figure 2. Anatomy of a single spiny stellate neuron. This is the target neuron found in V1 Primary visual cortex. Red dot represents the soma. In the experiments, synapses are restricted to the soma and the amplitude is adjusted to correspond to what it should be in the soma (2 mV).

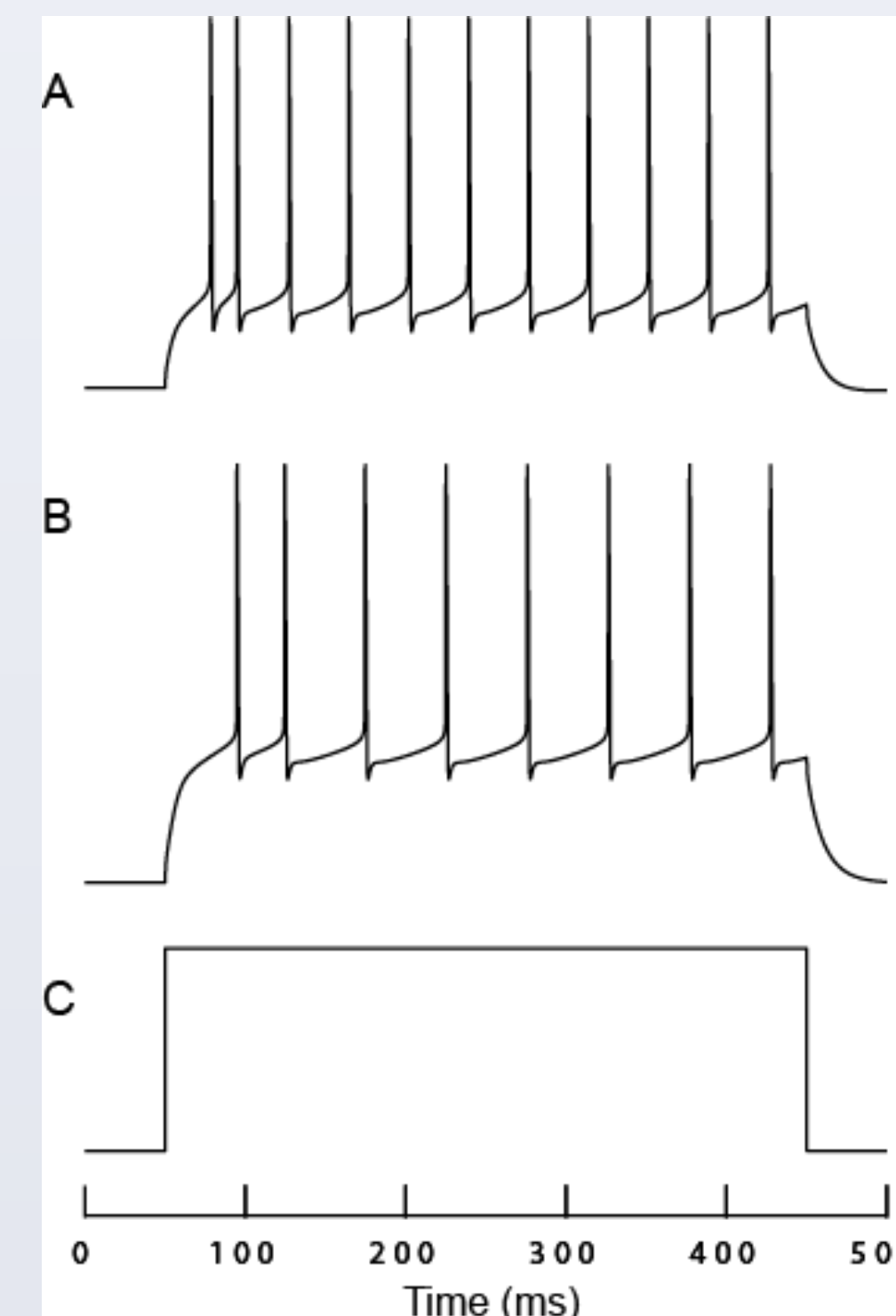


Figure 3: Response of the spiny stellate neuron to a single stimulation. In A) the resting membrane potential set to -62.5 mV and in B) the resting membrane potential is set to -74.5 mV. C) represents the stimulus lasting around 0.4 seconds. There is no burst observed in A) or B). For both, the first two peaks (firing) are close together but they equalize with time.

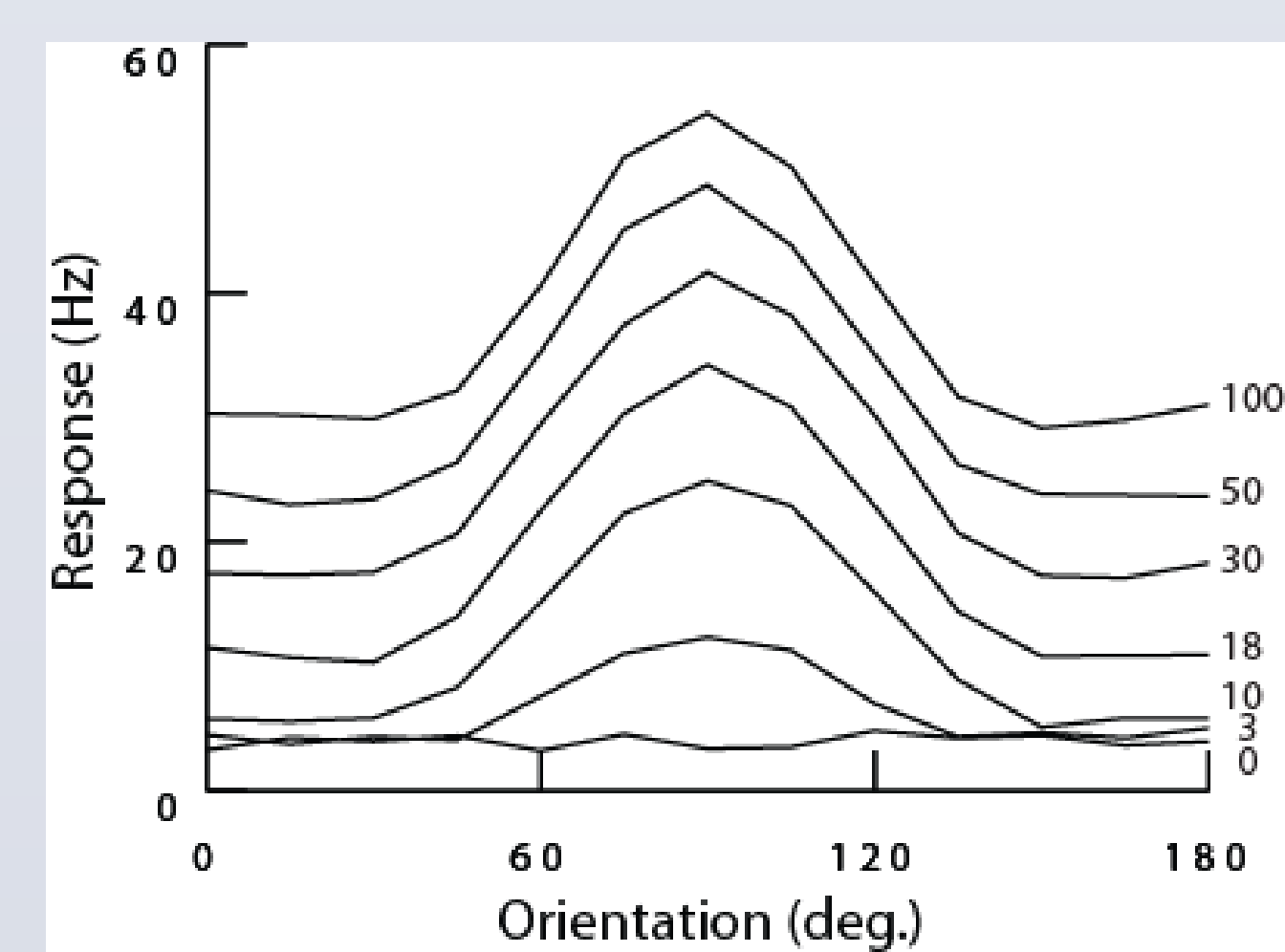


Figure 4. Behaviour of spiny stellate neuron to a sinusoidal grid without noise. X-axis represents orientation in degrees and Y-axis represents the peak response of the cell in Hz. Recordings are from 0° to 180°. A sinusoidal grid is slid across the receptive field and the peak response is monitored. Different contrast levels are tested. The cell is selective for orientations close to 90°. At 0% contrast, the data forms a flat line at 2 Hz (baseline activity of the cell).

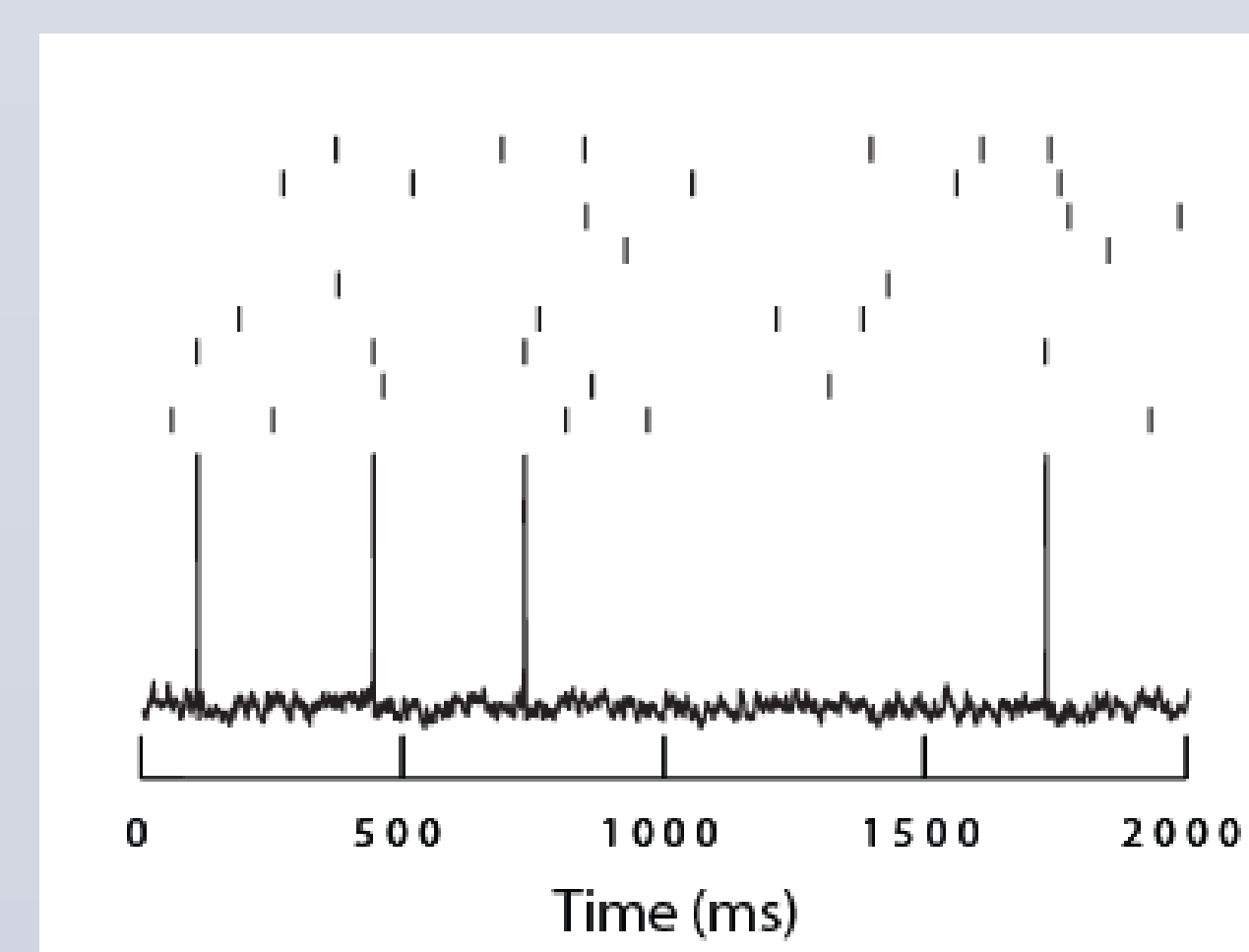


Figure 5. Representation of noise. Thalamocortical cells normally have background noise which cause them to spike at 10 Hz when they are not stimulated. Therefore, when the postsynaptic single spiny stellate neuron is not receiving any visual stimulus, it still receiving quite a bit of inputs. The trace is what is observed without any noise. The times where spikes occur within in a trace are represented by vertical lines. There are a total of 10 traces. The spikes occur randomly at an average of about 2/second.

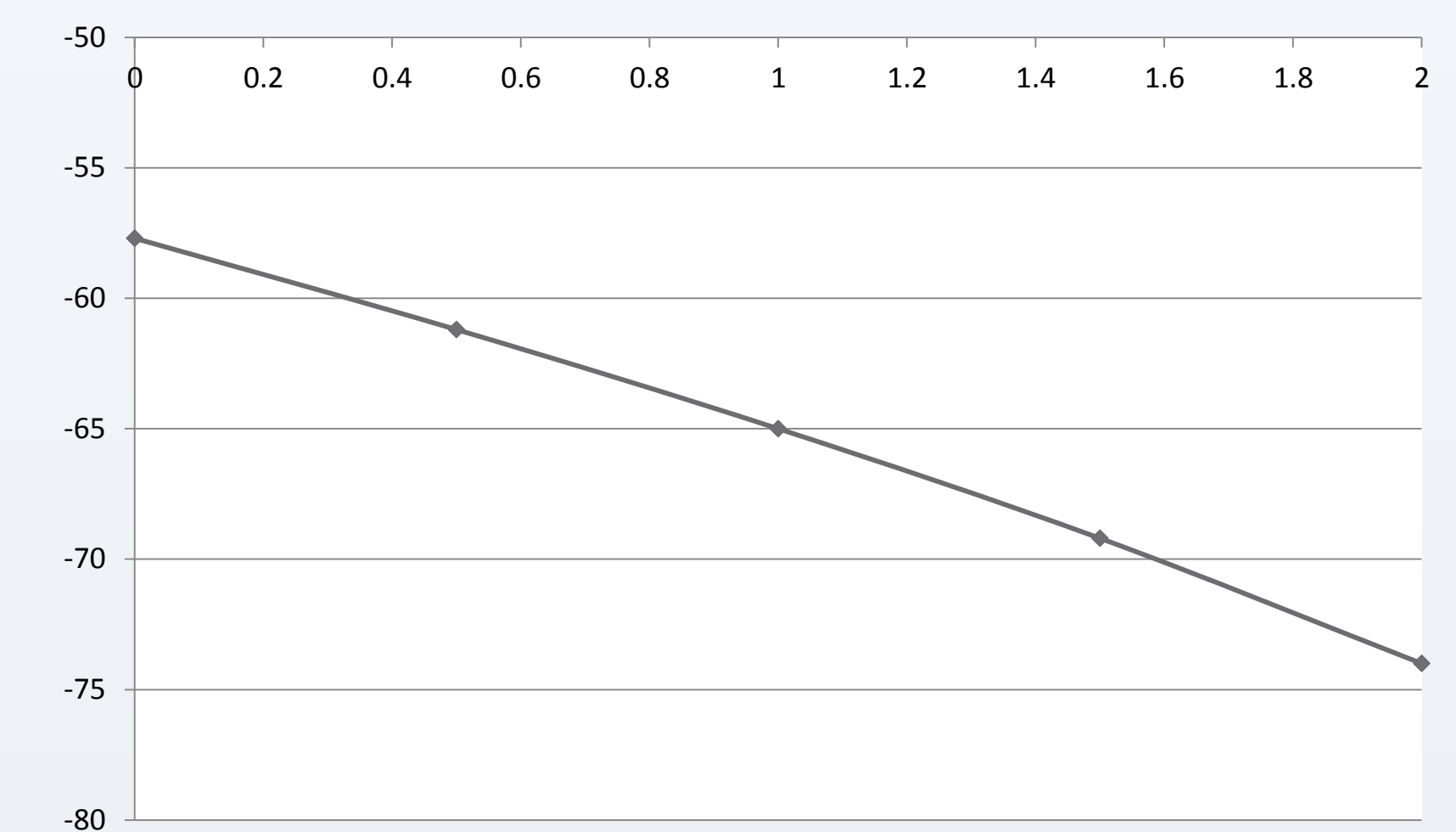


Figure 6. Adjustments to resting potential to maintain 2 Hz spiking. Normally a cell has a resting potential of about -65 mV. To have 2 Hz of background firing in the spiny stellate neuron with this resting potential, synaptic noise must be added. This added noise served as the reference for other noise values. We tested 0 to 2 times this reference value. To maintain a background firing of 2 Hz with changes in synaptic noise, the resting membrane potential of the cell had to be adjusted as indicated on the graph.

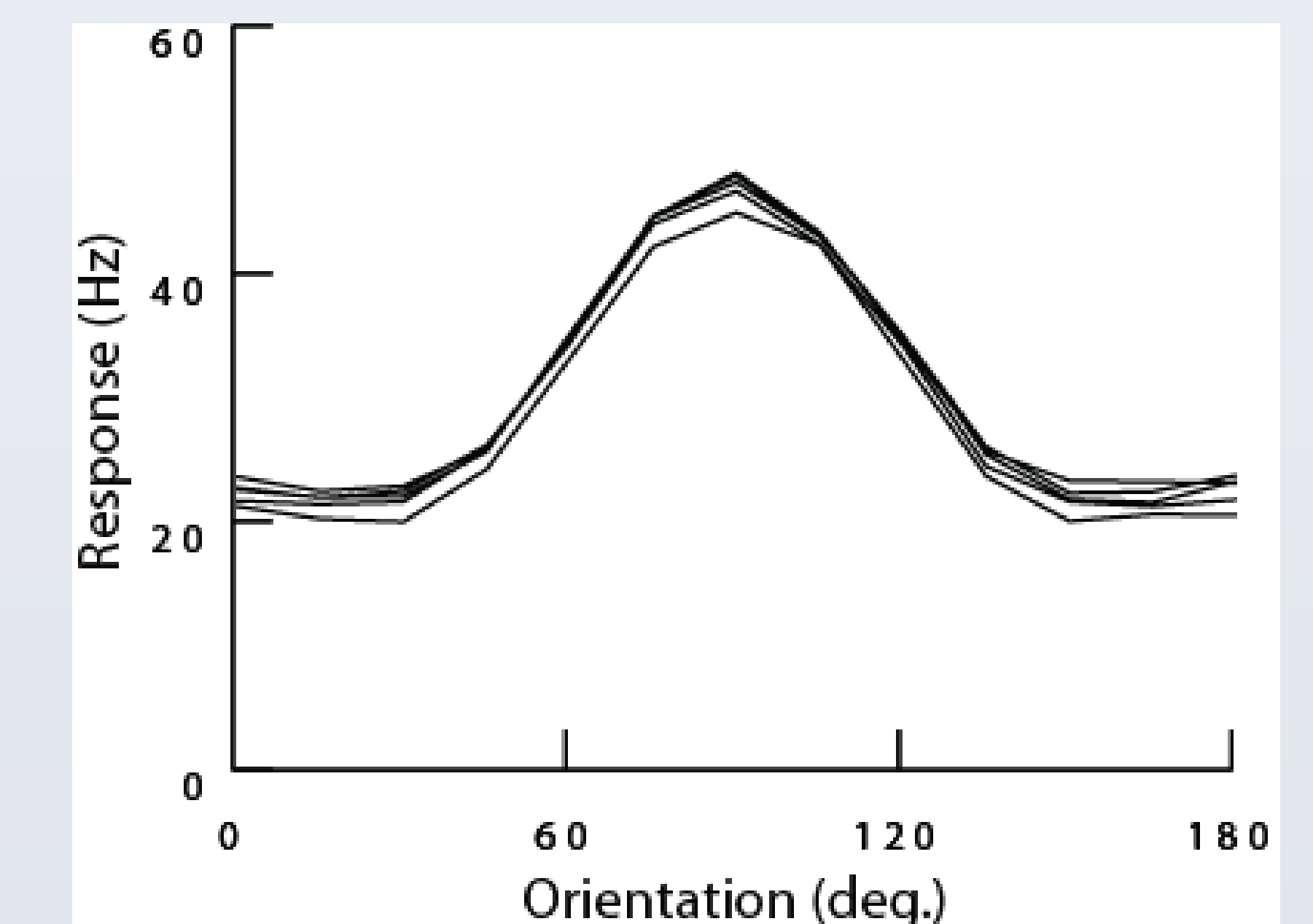


Figure 7. Effects of varying noise levels to contrast invariance. Experiment in Figure 4 is repeated but only for 50% contrast. Different noise levels (0,0.5, 1, 1.5, 2.) and their effects as measured in Figure 6 are shown. The tuning curves become slightly lower with increased noise levels.

Conclusions

Noise has a very small effect which is insufficient to produce contrast invariance that we see in a real cell. Therefore, synaptic depression and inhibitory inputs are the two major contributors to contrast invariance. These results advance the understanding of visual perception and this could lead to the development of software to better interpret images or possibly develop electronic implants to replace missing functionalities.

References

- ^{1,4} Banitt, Y., Martin, K. A. C., and Segev, I. (2007). A biologically realistic model of contrast invariant orientation tuning by thalamocortical synaptic depression. *J. Neurosci.* 27, 10230–10239.
- ² Anderson JS (2000) The Contribution of Noise to Contrast Invariance of Orientation Tuning in Cat Visual Cortex. *Science* 290: 1968–1972.
- ³ Hubbard, J. I., Stenhouse, D., and Eccles, R. M. (1967). Origin of synaptic noise. *Science* 157, 330–331.

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