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Effects of ion channels on the spike timing in the retinal ganglion cells

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The ganglion cells of the vertebrate retina form the pathway by which the retina communicates with the visual cortex. The ganglion cells convert the graded potentials into a pattern of spikes whose characteristics is modulated by the synaptic and membrane currents. The ganglion cells respond with precise and reliable spikes to randomly flickering light [1]. This feature could not be reproduced by the previous models [2,3], described with the deterministic differential equations similar to the Hodgkin-Huxley formulation. We proposed a stochastic model of spike generation in the ganglion cells, based on discrete stochastic ion channels represented by Markov processes [3]. We modeled eight types of ion channels, i.e., Na, Ca(T), Ca(L), Kv, A, K (Ca), h and leakage channels. The proposed model showed precise and reliable spikes to randomly fluctuating current. This result suggested that the stochastic properties of ion channels are critical in determining the reliability of the spike timing in the retinal ganglion cells. However, the underlying mechanisms of the spike timing reliability has not yet been understood [3,4]. In this work, we systematically analyzed the feature of the spike timing reliability and the role of each channel stochasticity through computer simulation.

We measured the reliability of the spike timing for a wide range of fluctuating input patterns by varying the mean and standard deviation. We applied the event synchronization algorithm to simulated spikes [5]. The reliability was obtained from all two combinations in the spikes of 30 trials. The reliability of the spike patterns was strongly correlated with characteristics of the fluctuating input. This indicates the existence of optimal input range for the reliability. In order to clarify the role of ion channel stochasticity, we analyzed the contribution of each channel in the spike reliability, by changing the single channel conductance in simulation without changing the total electrical characteristics of the cell membrane. For a particular channel, the single channel conductance was increased by a factor of 20, the channel density was decreased by a factor of 1/20. The simulated results showed that the spike reproducibility is much influenced by the potassium channels, Kv and A, not by the sodium channel, Na. These results suggest that the stochastic properties of Kv and A channels play a key role in determining the precise spike timing of retinal ganglion cells.

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