Processing of Directional Information from Neural Output of Rabbit Retina

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The estimation of motion direction from time varying retinal images is a fundamental task of visual systems. Neurons that selectively respond to directional visual motion are found in almost all species. A prominent example of the processing of directional information has been found in the rabbit, where direction selective neurons in lateral geniculate nucleus (LGN) signal movement-direction more precisely than their retinal counterparts [1]. However, the mechanism how this may be achieved remains unclear.
Here we propose a simple model that can explain sharpening of directional selectivity taking into account synaptic input from direction selective retinal ganglion cells (DSRGCs) only. We further suggest a model to account for other than the four cardinal directions encoded by the retina.

1 Methods

We recorded retinal ganglion cell activity from the adult isolated rabbit retina using a 60 channel multi-electrode array (Multichannelsystems, Reutlingen). Moving gratings in eight different directions were used to identify direction selective cells [2]. Directional tuning was determined by means of the index of directional selectivity (*DSi*).

After spike sorting the timestamps were passed to computational models mimicking a cell postsynaptic to the DSRGCs. We applied two models recently proposed to describe retinogeniculate transmission: a voltage-based model [3] that assumes linear summation of excitatory postsynaptic potentials (EPSPs), and an "integrate-and-fire" (I&F) neuron with conductance-based synapses [4]. We investigated the effect of EPSP summation and spike threshold in two different scenarios: (1) synaptic input from a single DSRGC, (2) input from two DS RGCs with different directional tuning.

2 Results and Discussions

2.1 Results

For single retinal input we found that the *DSi* of the LGN neuron increased for all EPSP amplitudes tested (blue traces in Fig 1). While single EPSPs on their own do not reach threshold, rapid spiking activity in the DSRGC can trigger LGN spikes. The maintained firing rate is significantly reduced in our simulations. This effect is more pronounced for lower EPSP amplitudes. These findings were verified by the conductance-based I&F model (red trace in Fig. 1).

The combination of differently tuned ganglion cells often leads to an asymmetric tuning curve. Adjusting the synaptic strength of two inputs leads to symmetrically tuned postsynaptic neurons with intermediate directional tuning (Fig. 2).

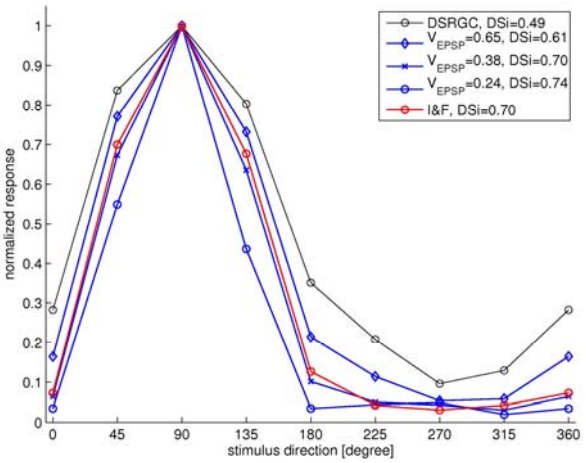

Fig. 1. Sharpening of directional tuning: Normalized response of a direction selective retinal ganglion cell (DSRGC, black trace), and of simulated LGN cells using the voltage based model (blue) or the I&F model (red). LGN cells with smaller EPSP amplitudes (V_{EPSP} given in fractions of the spike threshold) achieve higher index of directional selectivity (*DSi*). The DS index is 1 for cells responsive for a single direction of movement and is 0 for non-tuned cells.

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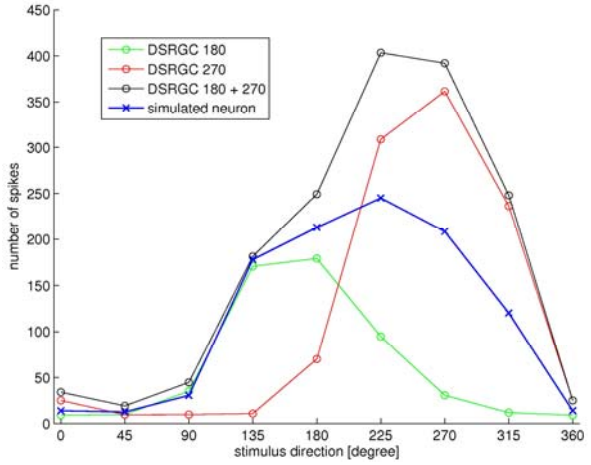

Fig. 2. Simulation of a post-synaptic neuron tuned to an intermediary direction (blue) by combining input of two DSRGCs, tuned to 180° (green) and 270° (red), respectively. Summation of the responses of the two DSRGCs leads to an asymmetric tuning (black).

2.2 Conclusions

Our simulations with realistic synaptic input based on extracellular recordings from retinal ganglion cells can explain the sharpening of directional selectivity found in LGN neurons [1]. The sharpening is a result of the intrinsic spiking pattern of the DSRGCs combined with EPSP summation and spike threshold. As exemplified by the combination of two DSRGCs sharp directional information may provide the basis for fast estimation of local movement across the retina.

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