Modeling of dendro-dendritic connections between motion-sensitive large field neurons

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By rearranging compartmental models of fly interneurons we investigated the effects of a dendro-dendritic connection via electrical synapses involved in visual motion processing. An experimentally observed spatial blurring can be reproduced by the mere anatomical and biophysical properties of the dendritic trees. A number of other findings need further investigation giving hope to explain previous incompatibilities between model cells and their equivalents in the fly.

The fly's lobula plate tangential cells are part of the visual course control system and constitute a group of individually identifiable neurons. These cells are assumed to spatially integrate the output of retinotopically arranged motion detectors and therefore respond to visual motion in a directionally selective way. In previous studies, their intrinsic active and passive membrane properties have been determined and, together with their anatomical data, were put into precise compartmental models (Borst and Haag, 1996; Haag et al., 1997). Connecting these models with arrays of elementary motion detectors resulted, in general, in a good match between the models' visual response properties and the experimental data (Haag et al., 1999). This, however, was not true for the so-called CH-cells, GABAergic, inhibitory neurons responsible for the response selectivity of FD-cells to small moving objects.

Recent findings about the connectivity between different lobula plate cells revealed that, in contrast to previous assumptions, CH-cells do not seem to receive direct input from visual motion detectors (Haag and Borst, 2002 in press). Rather, they have dendro-dendritic electrical synapse connections to HS-cells and receive their visual

motion signals through this intermediary. The connection between HS- and CH-cells was furthermore demonstrated to have a spatial blurring effect on the representation of motion information on the CH-cells' dendrite. Given that FD-cells are directly connected to a retinotopic array of motion detectors and on top of that receive a dendro-dendritic inhibitory signal from CH-cells, this would lead to an enhancement of motion contrast in FD-cells and, hence, contribute to their response selectivity for relative motion.

In order to account for these new findings and to study their functional consequences in a quantitative way, we decided to use our existing compartmental models of HS and CH-cells and connect them to each other according to the new findings. By rearranging the models in three dimensions a realistic superposition of the dendritic trees was obtained. The dendritic tree of the equatorial HS-cell covered the dorsal half of the dendritic arborization of the ventral CH-cell. The dendritic tree of the southern HS-cell covered the ventral half of the dendritic tree of the same CH-cells. Synaptic connections were made by inserting conductances between dendritic branches in CH- and HS-cells that were closer than a minimum threshold distance. Unit conductances of the electrical synapses were adjusted such as to match experimental data where current was injected into HS-cells and the voltage response was measured in the CH-cell, and vice versa. When a model of the ventral CH-cell was connected to two HS-cells in this way, injections in the equatorial HS-cell produced membrane potential shifts in the CH-cell only in the dorsal half of the dendritic tree. Following current stimulation of the southern HS-cell led to an activity in the CH-cell which was confined to the ventral half of the dendrite. These modeling results are in perfect agreement with calcium imaging experiments where the activity distribution in CH-cells was studied after injecting currents in HS-cells. The current model also produces a spatial blur of the visual motion input on the CH-cell dendrite.

Further investigations will focus on the temporal filter characteristics of the connection (Haag and Borst, 1996) as well as on the resulting effect on the spatial integration properties in CH-cells.

References:

Borst A, Haag J, 1996, The intrinsic electrophysiological characteristics of fly lobula plate tangential cells: I. Passive membrane properties: J.Comput.Neurosci., v. 3, p. 313-336.

Haag J, Borst A, 1996, Amplification of high-frequency synaptic inputs by active dendritic membrane processes: Nature, v. 379, p. 639-641.

Haag J, Theunissen F, Borst A, 1997, The intrinsic electrophysiological characteristics of fly lobula plate tangential cells: II. Active membrane properties: J.Comput.Neurosci., v. 4, p. 349-369.

Haag J, Vermeulen A, Borst A, 1999, The intrinsic electrophysiological characteristics of fly lobula plate tangential cells: III. Visual response properties: J.Comput.Neurosci., v. 7, p. 213-234.

Haag J, Borst A, 2002, Dendro-dendritic interactions between motion-sensitive large-field neurons in the fly: J. Neuroscience (in press)