On the Modeling and Validation of the Retinal Neural Response to Electrical Stimulation

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Earlier work by Greenberg et al. has shown that the modeling of a retinal neuron in a homogeneous media of uniform resistivity can be, under certain conditions, a predictor of neural excitation. However, the complexities of the neural interconnections of the retina, or connectome, as well as the highly inhomogeneous properties of the retinal layers, highlight the limitations of this simplistic approach. The first observation is that electric fields induced by contact electrodes in an accurate model of the retina, with neural layers characterized by varying resistivity, differs significantly from analytical predictors traditionally used to determine field values to be used as "source" in the neural modeling. The second observation is that neural cells of the retina are highly interconnected, in ways that are yet to be fully understood. While work on the generation of accurate connectomes derived from retinal images are currently underway, these efforts highlighted the significant limitations of using the model of a single neuron as a predictor of neural excitation.

In this work, we extend previously established approaches to the single-neuron and analytical model of the fields as a predictor of neural excitation to computational models with accurate representation of the retinal layers and greater number of connected neurons. We use NEURON as the computational tool to develop and simulate models of neurons and their networks using their biophysical properties and geometries. The extracellular sources for NEURON simulations are extracted from multi-resolution admittance method simulations. While this approach still falls short of representing the actual complex response of the mammalian retina subjected to electrical stimulation, it is a significant step toward the development and integration of computational models that span multiple spatial and temporal scales. It is through these modeling capabilities that we seek to incorporate complex models of retinal structure that will help explain how the retina reacts to various potential stimuli: this would be a significant step toward the optimization of retinal stimulation and the development of high-density biomimetic neural interfaces in general.